UNIVERSITAT DE BARCELONA

MASTER FINAL PROJECT

MASTER OF ENVIRONMENTAL ENGINEERING

Development of 3 new Solid Recovered Fuels (SRF) with high calorific value from solid waste

Author

Bàrbara Bedmar Alonso

June 2017

Director/s

Dr. Joan Dosta Parras

Department of Chemical Engineering and Analytical Chemistry. University of Barcelona

Dr. Sergio Martínez Lozano

Leitat Techonological Centre

LEITAT managing technologies

INDEX

TABLE INDEX

FIGURE INDEX

ABSTRACT

Circular Economy is a concept where Waste Management is a key point. There is a considerable generation of industrial and solid waste and at the same time an exploitation of non-renewable resources for energy generation. The aim of the project is to connect this amount of generated waste with the energy demand of the society, applying effectively the concept of Circular Economy. The result product is the Solid Recovered Fuel (SRF). SRF is a fuel produced from non-hazardous waste from municipal, industrial and the construction sector in compliance with the European Standard EN 15359. This paper presents the design of 3 new SRF by mixing solid waste from a rejection from an industry of tires, sludge from a paper industry, the rejection of a biologic-mechanical treatment plant of solid urban waste and high-density polyethylene (HDPE). The formulation of the new SRF is mainly determined by the industry requirements, considering the main parameters such as the high heating value (HHV), % moisture and % ash content.

A new SRF formulated for an industry of the renewable and environmental sector (SRF 1), focused on the gasification technology, could be formed by 30% of the rejection tire industry and 80% of HDPE. The SRF 1 will have a HHV of 40.88 MJ/kg, only 0.607% of moisture and 5.06% of ash content. It can be included in the classification from the UNE-EN 15359 as a SRF of class 3, being the limiting parameter the % of chlorine.

Another new SRF based on the demands of a concrete producer industry, SRF 2, could be design by 20% of tire rejection, 10% of sludge from a paper industry, 30% of rejection of a biologic-mechanical treatment plant of solid urban waste and 40% of HDPE. The SRF 2 will have a HHV of 27.97 MJ/kg, 15.37% of moisture and 13.43% of ash content. It can be included in the classification from the UNE-EN 15359 as a SRF of class 5, being the limiting parameter the Hg content.

Finally, the SRF 3, designed by concerning the demands from a ceramic production plant, it can be formed by 30% of tire rejection, 10% of rejection of a biologic-mechanical treatment plant of solid urban waste and 60% of HDPE. The SRF 3 will have a HHV of 36.58 MJ/kg, only 4.013% of moisture and 6.36% of ash content. It can be included in the classification from the UNE-EN 15359 as a SRF of class 3, being the limiting parameter the chlorine content.

Keywords: *Circular Economy, Solid Recovered Fuel (SFR), industrial waste, municipal waste, calorific value.*

1. INTRODUCTION

Solid recovered fuel (SRF) is a fuel produced from non-hazardous waste from municipal, industrial and construction waste in compliance with the European Standard EN 15359. The use of SRF as an alternative fuel is being carried out in concrete plants, power plants, industrial plants, incineration plants with energy recovery, gasification, pyrolysis and plasma plants (IDAE, 2011).

The European Union is emphasizing a new concept: Circular Economy. Within the circular economy, the role of waste management is to collect, treat and use it as a secondary resource or for recovering energy back into the cycle of production and consumption (SITA, July 2013). Producing SRF from industrial and municipal solid waste demonstrates the circular economy in action and makes possible the achievement of several goals targeted by the European Commission in the waste policy and legislation (European Commission, Environment, Waste, 2017):

- A common EU target for recycling 65% of municipal waste by 2030;
- A common EU target for recycling 75% of packaging waste by 2030;
- A binding landfill target to reduce landfill to maximum of 10% of municipal waste by 2030;
- A ban on landfilling for separately collected waste;
- Specific measures to promote the re-use and stimulate industrial symbiosis –turning one industry's by-product into another industry's raw material

In addition to that, SRF has other environmental benefits. The use of them could reduce the emission of greenhouse gases, increase the use of renewable energy, save natural resources like coal or natural gas and reduce the dependence on non-renewable energies.

This project is carried out with the goal of applying all these legislation by designing new SRF adapted to the industry demands. To make this possible, is important to apply the current legislation and certificate the final products. The next chapters are going to indicate in detail the current legal situation. Firstly, it will be shown the standardization situation and then, the legal framework.

1.1. European standardization of Solid Recovered Fuels

European Standards for SRF will support the free trade of these fuels on the international market. It is a way to regulate the trade and the quality of the SRF and helps building acceptance and trust among the end users (Frankenhaeuser, 2011).

In 2002 the European Commission gave a mandate (Mandate 325) to CEN (European Committee for Standardization) to develop a set of Technical Specifications concerning the use of SRF for energy recovery in waste incineration or co-incineration plants, the CEN/TC 343 (EcoStandards, 2017). The mandate 325 of Solid Recovered Fuels specifies that the standards shall include all standards listed in the Work Programme developed by CEN TF 118 Solid Recovered Fuels and CEN/TC 335 Solid Biofuels.

In addition to that it must include standards on the determination of the biodegradable fraction and/or biogenic fraction of SRF and the HHV and LHV of these fractions (Frankenhaeuser, 2011).

CEN/TC 343 is established on 13 March in 2002 and develops the relevant European Standards for the market for SRF. It has been published 6 Technical Reports, 16 European Standards and 6 Technical Specifications (for more detailed information, see Annex I).

The scope is*: "Elaboration of Standards, Technical Specifications and Technical Reports on SRF, prepared from non-hazardous waste to be utilized for energy recovery in waste incineration or co-incineration plants, excluding fuels that are included in the scope of CEN/TC 335"* (European Committe for Standarization, 2013).

Concluding, Figure 1 shows in which part of the process of developing a SRF does the CEN/TC 343 takes part. The production and trade of SFR depends on the characteristics of the solid waste and the specific customer requirements in terms of physical composition and energetic characteristics. CENT/TC 343 works on the line from the point of reception of non-hazardous waste until the delivery point of the SRF.

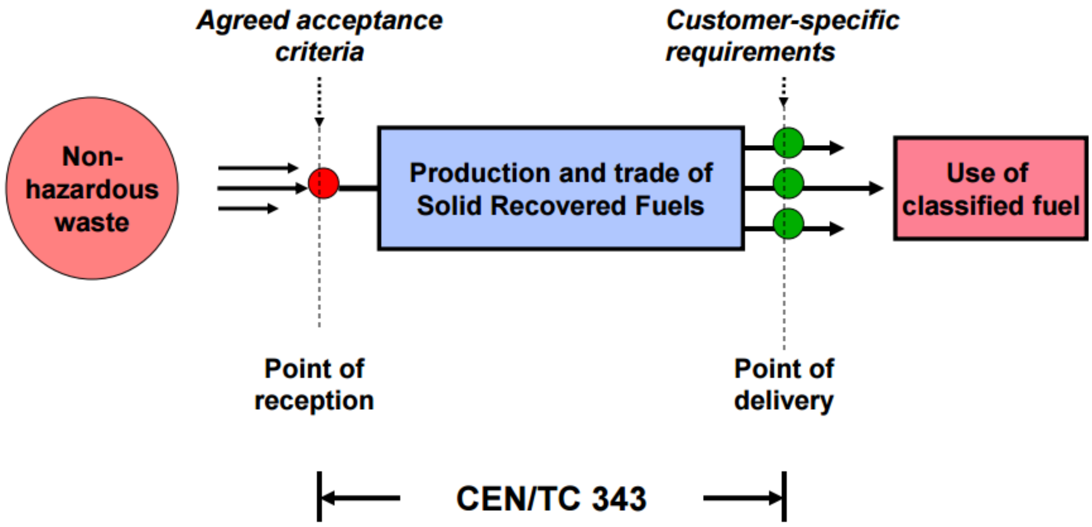

Figure 1.Scope of European Standardization of SRF. (Frankenhaeuser, 2011)

1.2. Legal Framework for solid Recovered Fuels

The production of SRF are generated from non-hazardous combustible waste for the substitution of primary fuels with the aim of producing heat and/or power and for the production of material products, such as clinker for cement, is part of a complicated business environment, which is affected by a wide legal framework (European Committe for Standarization, 2013):

- The Waste Directive (Directive 2008/98/EC). In which the definition on 'recovery' covers the production of SRF.
- The Landfill Directive (Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste). The directive sets some targets for the diversion of solid waste from landfill.
- The Waste Incineration Directive, WID (Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste).
- The Directive on Large Combustion Plants, LCP (Directive 2001/80/EC of the European Parliament and of the Council of 23 October 2001 on the limitation of emissions of certain pollutants into the air from large combustion plants).
- The Industrial Emissions Directive, IED (Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control).
- The Renewable energy directive, RES Directive (Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources).
- The Kyoto Protocol (which considers the reduction of Greenhouse Gases (GHG)).

2. OBJECTIVES AND JUSTIFICATION

The project is motivated because of highlighted reasons. It is based in an application of the concept of Circular Economy, because there is an unquestionable generation of industrial and urban waste and, at the same time, an exploitation of energy resources like fossil fuels. For that reason, the project is relating the energetic valuable waste with the energetic demand of some industries such as ceramics industry, concrete industry or power plants.

The general targeted objective is to develop and evaluate certification requirements of 3 new SRF. To achieve this main objective, the following goals were proposed:

- To study and determine the methods for the complete characterization of solid waste.
- Physic-chemical and energetic analysis of different wastes (tires rejections, sludge from a paper industry, high density polyethylene (HDPE) and the rejection of a biologic-mechanical treatment plant of solid urban waste).
- To study and determine those energy properties demanded by potential end users.
- To create a Decision Matrix as a tool to select the ingredients for the SRF according to the availability, physic-chemical and energy characterization, requirement of pretreatment technologies and other criteria.
- To develop 3 formulations of SRF adjusted to the energy requirements of the industries.
- To analyze policy and legislation requirements to certificate the FSR produced.

3. MATERIALS AND METHODS

This chapter presents the applied methodology to achieve the objectives targeted previously. It is divided in three 3 parts. Firstly, it is shown the methods for characterizing solid waste from a perspective of an ingredient for a future SRF. After that, the methodology to build a Decision Matrix in order to choose the best mixing ingredients option and, finally, it is presented the necessary requirements for the certification of a SRF.

3.1. Methods for characterizing solid waste

In order to characterize the solid waste that might be part as a ingredient of the new SRF, it is necessary to apply Standard Methods. This is a priority for the project because the certification of a SRF requires the application of these Methods. Table 1 shows which norms are applied for each analyzed parameter.

Table 1. Indicator and method use to characterize solid waste

Indicator	Method
Moisture	UNE-CEN/TS 14774:2007
Density	UNE-CEN/TS 15103:2007
Grain size analysis and particle size distribution	UNE-CEN/TS 15149:2007
Ash content (including mercury (Hg))	UNE-CEN/TS 14775:2007
Volatile content	CEN/TS 15148:2005
Elemental analysis	CHNSO
Chlorine (Cl) and Sulfur (S)	CEN/TS 15289:2006

The most important parameters to consider for developing a SRF adjusted to the industry demands are the HHV, the ash content and the moisture. On the other hand, for the certification of the new SRF the relevant parameters are low heating value (LHV), Cl and Hg content.

The analytical method applied to determine moisture is based on the relation between the initial weight of the waste and the weight of the waste after being in an oven at 105°C for 24 hours. The ash content is analyzed by warming the sample at 250°C for 50 minutes and to determine the new weight of the sample. The volatile content is calculated by the results of warming the sample until 900°C for 7 minutes. The elemental analysis is based on the determination of the carbon, hydrogen and nitrogen content of the sample.

The apparent density is estimated following the indications of the TS UNE-CEN 15103, with a 20L cube and with a balance of 0.1 mg of resolution. The analysis of the particle distribution is executed with a vibrational sieve with sieves of 200 mm of diameter with the following mesh openings: 1.8mm, 2.8mm, 2cm and 4cm.

In Annex II there are developed in detail the procedures used to analyze in the laboratory the moisture, ash content, volatile content, elemental analysis, Cl and S. The HHV is obtained by bibliographic review and Hg is evaluated by the analysis content of the ash applying UNE-CEN/TS 14775:2007.

3.2. Decision Matrix

The Decision Matrix is a tool used to identify with which solid waste and in which proportion might the SRF be formulated. Connecting the physical, chemical and energetic characteristics analyzed from different solid waste with the specific physical, chemical and energetic demands from industries it can be obtained the proportion of each solid waste for the formulation of the SRF.

The structure of the Decision Matrix is constructed in two tables. Firstly, it must be defined the waste characteristics. This characterization might be done in the laboratory and then, compare it with the existing literature. Secondly, industry demands will be collected in another table.

Finally, there will be a third table, the Decision Matrix, where the proportions of the wastes for creating the SRF will relate to the industry demands table.

The formulation of the SRF will be based on the most restricting parameter for the industry, which means that the other parameters will have an equal or higher quality than it was demanded.

3.3. Requirements for the certification of SRF

The Spanish Association of Standardization and Certification (AENOR) in collaboration with companies involved in the trade and consumption of SRF participating in the Technical Committee TC 343 are working on the standardization and regulation of the SRF in the Spanish legislation.

AENOR certificates products, services and processes and constitutes a distinguish element in the market, generating trust between customers and consumers. AENOR developed the regulation NORMA UNE-EN 15359. From this norm, it will be studied the requirements to certificate the SRF formulated from the Decision Matrix. Basically, NORMA UNE-EN 15359 classifies the SRF according to the LHV, Cl and Hg content. The classification (see Table 2) goes from 1 (higher quality) to 5 (lower quality).

Table 2. Classification of the SRF from NORMA UNE-EN 15359

Parameter		1	2	3	4	5
LHV	MJ/kg d.w. (average)	≤ 25	≥ 20	≥ 15	≥ 10	≥ 3
valor Cl	% d.w. (average)	≤ 0.2	≤ 10.6	≤ 1.0	≤ 1.5	≤ 3
Valor Hg	mg/MJ (median)	≤ 0.02	≤ 0.03	≤ 0.08	≤ 0.15	≤ 0.50
Valor Hg	mg/MJ (percentil 80)	≤ 0.04	≤ 0.06	≤ 0.06	≤ 0.30	≤ 1.00

Dry weight; d.w.

4. RESULTS AND DISCUSSION

This chapter presents the results obtained by applying the methodology shown before focused on achieving the objectives targeted.

The results are divided in four parts. Firstly, it is shown the solid waste characterization. Afterwards, it is presented industry demands. Then, it is related the waste characterization and the industry demands, trying to mix the ingredients in the optimum proportion to accomplish the industry requirements and finally, they are presented the accomplished requirements to certificate the formulated SRF and the class they belong to.

4.1. Solid waste characterization

Table 18 summarizes the energetic, physical and chemical characteristics of the different solid waste, such as the rejection from an industry of tires, sludge from a paper industry, the rejection of a biologic-mechanical treatment plant of solid urban waste and HDPE. The HHV data comes from bibliographic review. Additionally, the LHV is extracted from the equation (1) in MJ/kg (IPPCguidelines, 2006):

$$LHV = HHV - 0.212 \cdot H - 0.0245 \cdot M - 0.008 \cdot Y \qquad (1)$$

H = % hydrogen in elemental analysis
M = % moisture
Y = % oxygen in elemental analysis

All the laboratory analysis performed to obtain the parameters such as the density, particle size distribution, moisture and elemental analysis have been done in triplicates or at least duplicate to ensure and guarantee a precise data. Finally, in Annex III there are some pictures presenting the work done at the laboratory to obtain the solid waste characteristics.

The following chapters present the data and the treatment of it to obtain the main parameters required to characterize each solid waste. First, it is shown the treated data of the analysis of tire rejection. Then, the treated data of the sludge from a paper industry, the rejection of a biologic-mechanical treatment plant of solid urban waste and it ends with the treated data of the HDPE.

4.1.1. Tire rejection

This chapter presents the parameters obtained from the characterization of tire rejection by processing the data. Table 3 presents the calculation of the density, Table 4 the particle size distribution, Table 5 the calculation of the moisture and Table 6 the elemental analysis of tire rejection.

Density

Table 3. Calculation of the density of tire rejections

Tare (kg)	0.666
Volume (l)	12
Weight (kg)	4.285
Density (kg/m^3)	**301.55**

Particle size distribution

Table 4. Particle size distribution of tire rejection

	Test 1 (kg)	Test 2 (kg)	Test 3 (kg)	Standard Deviation	Average (kg)	Particle distribution	**% accumulated**
Sieve 1 (4cm)	0.053	0.024	0.045	0.014	0.041	7.08%	**100%**
Sieve 2 (2cm)	0.071	0.157	0.162	0.051	0.130	22.71%	**92.92%**
Sieve 3 (2,8 mm)	0.152	0.155	0.086	0.069	0.131	22.86%	**70.21%**
Sieve 4 (1,8 mm)	0.008	0.007	0.004	0.002	0.006	1.10%	**47.35%**
(<1,8 mm)	0.104	0.103	0.588	0.279	0.265	46.25%	**46.25%**
					0.572	100.00%	

Moisture

Table 5. Calculation of the moisture of tire rejection

	Sample (g)	Dry sample (g)	% Moisture	**% Moisture average**	Standard Deviation
Sample 1	8.650	8.548	1.17%	**1.23%**	0.065
Sample 2	12.647	12.493	1.22%		
Sample 3	6.936	6.846	1.30%		

Elemental analysis

Table 6. Elemental analysis of tire rejection

% (w/w)	N	C	H	S
Sample 1	0.79	84.93	7.31	<1
Sample 2	0.64	86.61	8.62	<1
Sample 3	0.96	85.13	7.65	<1

Average % (w/w)							
N		**C**		**H**		**S**	
%	Standard Deviation	%	Standard Deviation	%	Standard Deviation	%	Standard Deviation
0.80	0.160	**85.56**	0.917	**7.86**	0.679	**<1**	-

4.1.2. Sludge from a paper industry

This chapter presents the parameters obtained from the characterization of sludge from a paper industry by processing the data. Table 7 presents the calculation of the density, Table 8 the particle size distribution, Table 9 the calculation of the moisture and Table 10 the elemental analysis of the sludge from a paper industry.

Density

Table 7. Calculation of the density of sludge from a paper industry

Tare (kg)	0.282	0.282	0.282
Volume (l)	0.900	0.900	0.850
Weight (kg)	0.718	0.710	0.693
Density (kg/m^3)	0.484	0.475	0.483
Standard Deviation	0.004		
Average Density (kg/m^3)	**480.610**		

Particle size distribution

Table 8. Particle size distribution of the sludge from a paper industry

	Tare (kg)	Test 1 (kg)	Test 2 (kg)	Test 3 (kg)	Standard Deviation	Average (kg)	particle distribution	**% accumulated**
Sieve 1 (4cm)	0.594	0.000	0.000	0.000	0	0.000	0%	**100%**
Sieve 2 (2cm)	0.554	0.143	0.121	0.037	0.055	0.100	23.39%	**100%**
Sieve 3 (2,8 mm)	0.518	0.282	0.299	0.355	0.038	0.312	72.66%	**76.61%**
Sieve 4 (1,8 mm)	0.487	0.013	0.008	0.014	0.003	0.011	2.66%	**3.95%**
(<1,8 mm)	0.007	0.004	0.005	0.008	0.002	0.006	1.29%	**1.29%**
						0.429	100%	

Moisture

Table 9. Calculation of the moisture of the sludge from a paper industry

	Sample (g)	Dry Sample (g)	% Moisture	**% Moisture average**	Standard Deviation
Sample 1	26.01	13.82	46.83%	**46.73%**	0.899
Sample 2	27.18	14.25	47.57%		
Sample 3	24.13	13.08	45.78%		

Elemental Analysis

Table 10. Elemental analysis of the sludge from a paper industry

% (w/w)	N	C	H	S
Sample 1	0.40	32.93	4.51	<1
Sample 2	0.39	28.76	3.95	<1
Sample 3	0.34	30.99	4.01	<1

Average % (w/w)							
N		**C**		**H**		**S**	
%	Standard Deviation	%	Standard Deviation	%	Standard Deviation	%	Standard Deviation
0.37	0.032	**30.90**	2.086	**4.15**	0.307	**<1**	-

4.1.3. Rejection from a biological-mechanical treatment plant of urban solid waste

This chapter presents the data obtained from the characterization of the rejection from a biological-mechanical treatment plant of urban solid waste. The data has been processed to obtain the main parameters. Table 11 presents the preparation of the representative sample and the moisture, Table 12 the calculation of the density, Table 13 the elemental analysis of the sludge from the rejection from a biological-mechanical treatment plant of urban solid waste .

Preparation of the representative sample and moisture

Table 11. Preparation of the representative sample

	% sample	Sample (g)	dry sample (g)	% moisture	**% moisture Average**	% dry sample	Representative sample (g)
Plastic	29.73%	8.14	7.15	12.16%	**34.40%**	4.72%	6.72
Paper - aluminum	5.41%	13.53	8.00	40.87%		5.28%	0.83
Paper	8.83%	30.62	13.01	57.51%		8.58%	0.98
Foam	0.12%	6.00	4.19	30.17%		2.76%	0.03
Textile	24.74%	80.61	46.20	42.69%		30.47%	3.65
Metal	2.77%	39.19	25.81	34.14%		17.02%	-
Organic matter	8.64%	17.51	8.02	54.20%		5.29%	1.03
Non-combustible	4.15%	36.44	33.09	9.19%		21.82%	0.96
Sanitary textile	6.81%	5.61	3.63	35.29%		2.39%	1.14
Fine particles	8.80%	3.49	2.52	27.79%		1.66%	1.67

Density

Table 12 Calculation of the density of the rejection from a biological-mechanical treatment plant of urban solid waste

Tare (kg)	0.66
Volume (l)	20
Weight (kg)	3.18
Density (kg/m^3)	**126.04**

Elemental Analysis

Table 13. Elemental analysis of the rejection from a biological-mechanical treatment plant of urban solid waste

% (w/w)	N	C	H	S			
Sample 1	0.87	55.15	18.3	<1			
Sample 2	0.57	60.07	11.47	<1			
Average % (w/w)							
N		**C**		**H**		**S**	
%	Standard Deviation	%	Standard Deviation	%	Standard Deviation	%	Standard Deviation
0.72	0.212	**57.61**	3.478	**14.89**	4.829	**<1**	-

4.1.4. HDPE

This chapter presents the data obtained from the characterization of HDPE. The data has been processed to obtain the main parameters. Table 14 presents the calculation of the density, Table 15 the particle size distribution, Table 16 the calculation of the moisture and Table 17 the elemental analysis of the HDPE.

Density

Table 14. Calculation of the density of HDPE

Volume (ml)	900	900
Weight (g)	49.92	47.9
Density (kg/m^3)	55.47	53.22
Standard Deviation	1.590	
Average density (kg/m^3)	**54.34**	

Particle size distribution

Table 15. Particle size distribution of the HDPE

	Test 1 (g)	Test 2 (g)	Average (g)	Standard Deviation	Particle distribution	**% accumulated**
Sieve 1 (4cm)	0	0	0.00	0	0%	**100%**
Sieve 2 (2cm)	0	0.01	0.00	0.005	0%	**100%**
Sieve 3 (2,8 mm)	46.32	49.83	48.07	1755	93%	**100%**
Sieve 4 (1,8 mm)	3.28	3.49	3.38	0.105	7%	**6.83%**
(<1,8 mm)	0.2	0.08	0.14	0.060	0%	**0.27%**
			51.60		100%	

Moisture

Table 16. Calculation of the moisture of HDPE

	Tare (g)	Weight (g)	Dry weight (g)	Moisture (%)	**Average moisture (%)**	Standard Deviation
2h	311.21	27.60	27.48	**0.43%**	**0.34**	0.228
2h	5.92	7.82	7.78	**0.51%**		
24h	91.66	2.07	2.06	**0.08%**		

Elemental Analysis

Table 17. Elemental analysis of HDPE

% (w/w)	N	C	H	S
Sample 1	<0.01	77.2	3.22	<1
Sample 2	<0.01	80.38	9.42	<1

Average % (w/w)							
N		**C**		**H**		**S**	
%	Standard Deviation	%	Standard Deviation	%	Standard Deviation	%	Standard Deviation
<0.01	**-**	**78.79**	2.248	**6.32**	4.384	**<1**	-

As presented in Table 18, PEHD has the best quality, with a HHV of 43.03 MJ/kg, only 0.34% of moisture and only 4.4% of ash content. On the other hand, the solid waste with the worst quality is the paper mill sludge, with only 4.92 MJ/kg, 51.3% of ash content and 46.73% of moisture. The rejection of the tire industry and the rejection from a biological-mechanical treatment plant of solid urban waste have an intermediate quality; they are useful to equilibrate the mix with the other two wastes for the formulation.

It must be considered that all wastes are generated in continuous along the year and in the order of tons, meaning the availability is not a limitation.

Data highlighted in bold in Table 18 is the one that will be compared and related with the industry demands later. Table 19 presents the bibliographic data of the parameters of characterization of the solid waste. Comparing the analytical parameters and the bibliographic data from the tire rejection, the HDPE and the sludge from the paper industry are really adjusted. These kinds of solid waste maintain their characteristics. On the other hand, when comparing the analytical data with the literature review, the rejection from a biological-mechanical treatment plant of solid urban waste oscillate, its characteristics could easily vary.

Table 18. Solid waste characterization by analytical methods in the laboratory.

Solid waste characterization			Tire rejection	Sludge from a paper industry	Rejection from a biological-mechanical treatment plant of solid urban waste	HDPE
			W1	W2	W3	W4
Energetic characteristics	Calorific value	**HHV (MJ/kg d.w.)**	**35.86**	**4.92**	**24.28**	**43.03**
		LHV (MJ/kg d.w.)	34.17	2.37	20.06	41.56
Physical characteristics	Particle size distribution		100% passing 4cm, 93% passing 2cm, 70% passing 2.8mm and 47% passing 1.8mm	100% passing 4cm, 100% passing 2cm, 77% passing 2.8mm and 4% passing 1.8mm	-	100% passing 4cm, 100% passing 2cm, 6.83% passing 2.8mm and 0.27% passing 1.8mm
	Density(kg/m^3)		301.55	408.61	126.03	54.34
	Physical analysis	**Moisture (%)**	**1.23**	**46.73**	**34.40**	**0.34**
		Volatile content (% d.w.)	93.5	67.9	87.5	97.3
		ash content (% d.w.) 550ºC	**6.6**	**51.3**	**17.4**	**4.4**
Chemical characteristics	Elemental analysis (% d.w.)	C	85.56	30.9	57.61	78.79
		H	7.86	4.15	14.89	6.32
		O	5.78	64.58	26.78	14.89
		N	0.8	0.37	0.72	<0.01
		S	<0.1	<0.1	<0.1	<0.1
		Cl	**<0.025**	**<0.025**	**<0.5**	**<1**
		Hg	**<0.1**	**<0.1**	**<0.1**	**<0.1**
Availability			continuous availability	continuous availability	continuous availability	continuous availability
Annual generation			2,500 tn/year	-	33,000 tn/year	1,000 kg/year
Current destination			concrete plants	-	compost and ceramic industry	-

Table 19. Solid waste characterization by literature review

Solid waste characterization			Tire rejection R1	bibliography*	sludge from a paper industry R2	bibliography*	Rejection from a Biological-mechanical treatment plant of Urban Solid Waste R3	bibliography*	PEHD R4	bibliography*
Energetic characteristics	Calorific value	**HHV (MJ/kg d.w.)**	**35.86**	**B**	**4.92**	**H**	**24.28**	**K**	**43**	**G**
		LHV (MJ/kg d.w.)	34-39	B	14.69	H	11.07	K	40	G
Physical characteristics	Particle size distribution		-	-	100% passing 1.0 mm 94% passing 0.5 mm; 66% passing 0.25 mm; 40% passing 0.125 mm; 24.5% passing 0.063 mm.	F	-	-	-	-
	Density(kg/m^3)		390-535	B	500-750		500-750	I	950	G
	Physical analysis	**Moisture (%)**	**1.72**	**C**	**58.99**	**H**	**22.71**	**K**	**0.16**	**G**
		Volatile content (% d.w.)	62.0-66.0	A	62.1		65.2	K	99.74	G
		Ash content (% d.w.) 550°C	**4.8-8.2**	**A**	**28.3**	**H**	**12.08**	**K**	**0.05**	**G**
Chemical ccharacteristics	Elemental analysis (% d.w.)	C	80.2-89.1	A	37.17	H	-	-	0.05	G
		H	7.2-7.6	A	4.46	H	14	K	85.46	G
		O	2.3-3.1	A	28.97	H	-	-	14.18	G
		N	0.2-0.4	A	1.29	H	-	-	0.3	G
		S	1.4-2.4	A	0.35	H	-	-	-	-
		Hg (mg/MJ)	-	-	0.0143	H	0.1	K	-	-
		Hg (ppm)	**-**	**-**	**0.1**	**E**	**0.0143**	**K**	**-**	**-**
		Cl	**0.2**	**D**	**0.02**	**E**	**0.5**	**K**	**<1**	**J**

* [A] (López, 2012) , [B] (IDAE, 2011) ,[C] (Juma, Markoš, Annus, & Jelemenský, 2006), [D] (Lorea & VanLoo, 2005), [E] (Dunster A. M., 2007), [F] (Chinnathan, Peitao, Dachao, Yafei, & Kunio, 2014), [G] (ECN. Phyllis2. HDPE., 2012), [H] (Colomer, Alberola, Herrera, Gallardo, & Bovea, 2009), [I] (Marín, 2016) [J] (Residuos Gencat, 2017) [K] (Izquierdo, Alcón, Cuquerella, & Vinuesa, 2013)

4.2. Industry requirements for SRF

The second part needed to formulate a SRF using the Decision Matrix is to identify the industry demands in terms of energetic, physical and chemical characteristics. Data of Table 20 was obtained by means of a questionnaire sent to different industries representative of several sectors where SRF could be of interest.

The 1st industry is a company dedicated to design, manufacture, installation and start-up of gasification plants of biomass and waste for the generation of renewable energy (electricity and heat). The most exigent parameter demanded is the ash content (with only 5%).

The 2nd industry is a concrete producer. For the concrete industry, the most important parameters are the HHV (18MJ/kg) and moisture (15%).

Finally, the 3rd industry is a ceramic producer. Their energetic demand is similar as the other industries. It is not exigent in terms of moisture but it is in terms of ash content (6.5%).

Table 20. Industry demands for SRF

Solid Recovered Fuel (demand)			Industry 1: Renewable and Environment Sector	Industry 2: Concrete production	Industry 3: ceramics production
Energetic charac.	Calorific value	**HHV (MJ/kg d.w.)**	**20**	**18**	**18.24**
		LHV (MJ/kg d.w.)	21	-	19.43
Physical characteristics	Waste configuration	configuration	crushed	Crushed	-
		Particle size (mm)	4	-	-
	Density(kg/m^3)		350	-	-
	Physical analysis	**Moisture (%)**	**8**	**15**	**14.71**
		Volatile content (% d.w.)	80	-	78.82
		Ash content (% d.w.) 550ºC	**5**	-	**6.5**
		Biomass fraction (%)	50	-	-
		Plastic fraction (%)	25	-	-
		Others (%)	25	-	-
	Flashpoint (ºC)		-	>100	-
Chemical characteristics	Elemental analysis (% d.w.)	C	-	-	50.02
		H	-	-	5.88
		O	-	-	39.3
		N	-	-	-
		S	0,5	<1	0.14
		Hg (mg/kg)	**0.2**	**10**	**-**
		F (mg/kg)	0.1	-	-
		Cl	**0.05**	**0.6**	**0.26**

4.3. Decision Matrix

Relating the data of solid waste characterization and the requirements provided by the industries, it is developed a Decision Matrix.

Table 21 shows the normalization values from 1 (worst quality) to 15 (high quality) for the solid waste and the new SRF evaluated parameters. This table has been prepared in order to normalize the parameters by comparing different current SRF and making an approximation of which are the highest and lowest values a parameter might have. With it, all the parameters can be treated and related by using the same criteria.

To understand the procedure used to give values to the different parameters, it is presented an example. If there is a solid waste with a HHV of 25 MJ/kg, its value will be 9. If the moisture is 6% and the ash content is 15%, their value will be 11 and 5, respectively. In conclusion, the most relevant parameter would be the moisture with a value of 11 out of 15 and the less relevant parameter will be the ash content, with a value of 5 out of 15.

Table 21. Reference for the normalization of the solid waste characteristics

Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
HHV (MJ/kg d.w.)	≤0	≤5	≤8	≤10	≤13	≤15	≤18	≤20	≤25	≤30	≤35	≤40	≤45	≤47	≤50
Moisture (%)	≥50	≥45	≥40	≥35	≥30	≥25	≥20	≥15	≥10	≥8	≥6	≥4	≥2	≥1	≥0
Ash content (% d.w.)	≥25	≥23	≥20	≥18	≥15	≥13	≥10	≥9	≥8	≥7	≥6	≥5	≥3	≥1	≥0

Table 22 summarizes the most important parameters of the solid waste from a perspective of an ingredient for a future SRF. To study a SRF it is important to consider the HHV, moisture and ash content. As it shows, the most valuable waste is HDPE because it has in 2 out of 3 parameters (ash content and moisture) the highest value, 15. Tire rejection is as well a useful ingredient for a future SRF, it has high values in all of the parameters. On the other hand, the sludge from a paper industry and the rejection from a biological-mechanical treatment plant of solid urban waste have relatively low values in all parameters.

Table 22. Normalization of the solid waste characteristics

Parameter	Solid Waste							
	Tire rejection		Sludge from a paper industry		Rejection from a Biological-mechanical treatment plant of solid urban waste		PEHD	
	W1	Value	W2	Value	W3	Value	W4	Value
HHV (MJ/kg d.w.)	35.86	**12**	4.92	**2**	24.28	**9**	43.03	**13**
Moisture (%)	1.23	**14**	46.7	**2**	34.4	**5**	0.34	**15**
Ash content (% d.w.)	6.6	**11**	51.3	**1**	17.4	**5**	4.4	**13**

4.3.1. SOLID RECOVERED FUEL 1

Using the same criteria for the industry demand as it was used for the characterization of solid waste; the main characteristics studied are the HHV, moisture and ash content.

The quality of the SRF that the 1st industry is demanding goes from 8 to 12 (Table 23). It means that the most exigent parameter is the ash content because it has the highest value, 12. Working on that, it is possible to find the proportion of different solid waste to make the best formulation.

If the formulation comes from the most exigent parameter means that the other parameters will have equal or higher quality than the Industry 1 demanded.

Table 23. Normalization and proportion of the new SRF 1

Parameter	**Formulation Industry 1**							
	SRF 1	Value	W1	W2	W3	W4	Final parameter	Final value
HHV (MJ/kg d.w.)	20	**8**	0.3	0	0	0.7	40.88	**13**
Moisture (%)	8	**10**					0.607	**15**
Ash content (% d.w.) 550ºC	5	**12**					5.06	**12**

As Table 23 shows, the proportion of the different solid wastes is the following:

- 30% of tire rejection (W1)
- 70% of HDPE (W4)

In this case, W2 and W3 can not be considered in the formulation because its low quality doesn't adapt to the industry demands.

From this formulation, the HHV will have a value of 13 instead of 8, a moisture value of 15 instead of 10 and an ash content value of 12, as it was the most demanding parameter. It is necessary to perform a laboratory analysis to set the real parameters of the SRF, but in general terms, the new SRF will have a HHV of 40.88 MJ/kg, 0.607% of moisture and 5.06% of ash content comparing to the 20 MJ/kg, 8% of moisture and 5% of ash content demanded by the industry 1.

4.3.2. SOLID RECOVERED FUEL 2

The quality of the SRF that the 2nd industry is demanding goes from 7 to 8 (Table 24). It means that the most restrictive parameter is the moisture, with a value of 8 out of 15. Working on that, it is possible to find the proportion of different solid waste to make the best formulation.

If the formulation comes from the most exigent parameter, the moisture, means that the HHV will have equal or higher quality than the Industry 2 demanded. In this case, the industry did not give the ash content parameter, but by applying the formulation, the ash content will be as low as possible.

Table 24. Normalization and proportion of the new SRF 2

Parameter	Formulation Industry 2							
	SRF 2	Value	W1	W2	W3	W4	Final parameter	Final value
HHV (MJ/kg d.w.)	18	**7**	0.2	0.1	0.3	0.4	27.97	**10**
Moisture (%)	15	**8**					15.37	**8**
Ash content (% d.w.) 550ºC	-	**-**					13.43	**6**

As Table 24 shows, the proportion of the different solid wastes is the following:

- 20% of tire rejection (W1)
- 10% of sludge from a paper industry (W2)
- 30% of Rejection from a Biological-mechanical treatment plant of solid urban waste (W3)
- 40% of HDPE (W4)

From this formulation, the HHV will have a value of 10 instead of 7 and a moisture value of 8 as it was the most demanding parameter. It is necessary to do a laboratory analysis to set the real parameters of the SRF, but in general terms, the new SRF will have a HHV of 27.97 MJ/kg, 15.37% of moisture comparing to the 18 MJ/kg, 15% of moisture demanded by industry 2. The industry did not claim a precise quality in terms of ash content, but the SRF will offer an ash content of 13.43%.

4.3.3. SOLID RECOVERED FUEL 3

The quality of the SRF that the 3rd industry is demanding goes from 8 to 11 (Table 25). It means that the most exigent parameter is the ash content, with a value of 11 out of 15. Working on that, it is possible to find the proportion of different solid waste to make the best formulation.

If the formulation comes from the most exigent parameter, the ash content, means that the other parameters, HHV and moisture, will have equal or higher quality than the Industry 3 demanded.

Table 25. Normalization and proportion of the new SRF 3

<table>
<tr><th rowspan="2">Parameter</th><th colspan="8">Formulation Industry 3</th></tr>
<tr><th>SRF 3</th><th>Value</th><th>W1</th><th>W2</th><th>W3</th><th>W4</th><th>Final parameter</th><th>Final Value</th></tr>
<tr><td>HHV (MJ/kg d.w.)</td><td>18.24</td><td>8</td><td rowspan="3">0.3</td><td rowspan="3">0</td><td rowspan="3">0.1</td><td rowspan="3">0.6</td><td>36.58</td><td>12</td></tr>
<tr><td>Moisture (%)</td><td>14.71</td><td>9</td><td>4.013</td><td>12</td></tr>
<tr><td>Ash content (% d.w.) 550ºC</td><td>6.5</td><td>11</td><td>6.36</td><td>11</td></tr>
</table>

As Table 25 shows, the proportion of the solid waste is the following:

- 30% of tire rejection (W1)
- 10% of rejection from a Biological-mechanical treatment plant of solid urban waste (W3)
- 60% of HDPE (W4)

In this case, W2 can not be considered in the formulation because its low quality doesn't adapt to the industry demands.

From this formulation, the HHV will have a value of 12 instead of 8, a moisture value of 12 instead of 9 and an ash content value of 11, the same quality as it was demanded. It is necessary to do a laboratory analysis to set the real parameters of the SRF, but in general terms, the new SRF will have a HHV of 36.58 MJ/kg, 4.013% of moisture and 6.36% of ash content comparing to the 18.24 MJ/kg, 14.71% of moisture and 6.5% of ash content demanded by the industry 3.

4.3.4. Comparison of the results obtained for the SRF analyzed

As it can be observed in previous chapters, not all solid wastes could be used to design the 3 SRF. Only the SRF 2, the less restrictive, can be formulated with the 4 solid wastes. It is the only SRF that includes the sludge from a paper industry in the proportion of 10%. This is because of the huge ash content of the solid waste.

On the other hand, the most used solid waste is the HDPE as 70% in SRF 1, 40% in SRF 2 and 60% in SRF 3. It has the best energetic, chemical and physical characteristics. Its substantial proportion in the formulation of the SRF allows to achieve a great quality.

4.4. Analysis of the certification requirements for SRF

The last objective targeted is to analyze the certification requirements in order to classify the SRF formulated in the different classes by the regulated norm UNE-EN 15359 (AENOR).

The final characteristics of the SRF haven't been analyzed in the laboratory. The data is obtained by mixing in the different proportion the basic parameters of the individual solid waste. Considering that the individual parameters are maintained even when mixed. The class of each parameter concerns to Table 2. Table 26 presents a compilation of the main parameters of each solid waste in relation to the classification of the UNE-EN 15359. Table 27 presents the final classification of the new SRF formulated. SRF 1, applying the demands from Industry 1, could be considered as a SRF of class 3. The second SRF could be considered in class 5 and the last SRF is from class 3. All of them have a high LHV. The limiting parameter for SRF 2 is the Hg content, for SRF 1 is the chlorine as well as for SRF 3.

Table 26. Compilation of the main parameters for the different solid wastes

	W1	**W2**	**W3**	**W4**
HHV (MJ/kg d.w.)	35.86	4.92	24.28	43
LHV (MJ/kg d.w.)	**34.11**	**2.37**	**20.06**	**41.53**
Hg (mg/kg ash)	<0.1	<0.1	<0.1	<0.1
% ash content (d.w.)	6.6	51.3	17.4	4.4
Hg (mg/MJ) median	**0.019**	**2.156**	**0.06**	**0.0001**
% Cl	**0.025**	**0.025**	**0.05**	**1**

Table 27. Classification of the final SRF

	SRF 1	Class	**SRF 2**	Class	**SRF 3**	Class
LHV (MJ/kg d.w.)	39.30	1	29.69	1	37.16	1
Hg (mg/MJ) median	0.0059	1	0.2376	5	0.0119	1
Cl %	0.70	3	0.42	2	0.61	3
Final Class	**3**		**5**		**3**	

5. CONCLUSIONS AND RECOMMENDATIONS

The targeted objective of the project is to develop and evaluate the certification requirements of 3 new SRF. By carrying out laboratory analysis and bibliographic review, 4 solid wastes have been characterized; tire rejection, sludge from a paper industry, the rejection of a biologic-mechanical treatment plant of solid urban waste and HDPE.

In addition to that, by means of a questionnaire, 3 different industries have reported their optimum characteristics for the use of a SRF. The industries that have participated are from the renewable and environmental sector, a concrete producer and a ceramics producer. By creating a matrix decision relating all the data of the different parameters, it was given a formulation mixing the different solid waste to obtain the following designs and classification according to the NORM UNE-EN 15359.

A new SRF formulated for an industry of the renewable and environmental sector (SRF 1), focused on the gasification technology, could be formed by 30% of the rejection tire industry and 80% of HDPE. The SRF 1 will have a HHV of 40.88 MJ/kg, only 0.607% of moisture and 5.06% of ash content. It can be included in the classification from the UNE-EN 15359 as a SRF of class 3, being the limiting parameter the % of chlorine.

Another new SRF based on the demands of a concrete producer industry, SRF 2, could be design by 20% of tire rejection, 10% of sludge from a paper industry, 30% of rejection of a biologic-mechanical treatment plant of solid urban waste and 40% of HDPE. The SRF 2 will have a HHV of 27.97 MJ/kg, 15.37% of moisture and 13.43% of ash content. It can be included in the classification from the UNE-EN 15359 as a SRF of class 5, being the limiting parameter the Hg content.

Finally, the SRF 3, designed by concerning the demands from a ceramic production plant, it can be formed by 30% of tire rejection, 10% of rejection of a biologic-mechanical treatment plant of solid urban waste and 60% of HDPE. The SRF 3 will have a HHV of 36.58 MJ/kg, only 4.013% of moisture and 6.36% of ash content. It can be included in the classification from the UNE-EN 15359 as a SRF of class 3, being the limiting parameter the chlorine content.

As recommendation, it is crucial for the certification and classification of a new SRF to perform all the analysis directly to the representative sample of SRF already mixed in the chosen solid wastes proportion. In this project, it is assumed that solid wastes maintain the characteristic when mixed so the new SRF can be classified. In addition to that, it could be of relevance to formulate more accurately the SRF by including the data of generation, availability, distances between the waste producer and SRF user and an economic analysis of the costs and benefits.

REFERENCES

Arion, A., Baronnet, F., Lartiges, S., & Birat, J. (2001). Characterization of emissions during the heating of tyre contaminated scrap. *Chemosphere*, 853-559.

C.Vrancken, P. L. (2017). Critical review of real-time methods for solid waste characterisation: Informing material recovery and fuel production. *Waste Management*.

Castro, G. (2008). Materiales y compuestos para la industria del neumático.

Changkook, R. (2012). Potential of Municipal Solid Waste for Renewable Energy Production and Reduction of Greenhouse Gas Emissions in South Korea. Available online: http://www.tandfonline.com/doi/pdf/10.3155/1047-3289.60.2.176 [Accessed March 2017]

Chinnathan, A., Peitao, Z., Dachao, M., Yafei, S., & Kunio, Y. (2014). Alternative Solid Fuel Production from Paper Sludge Employing Hydrothermal Treatment. *Energy&Fuels* .

Colomer, F., Alberola, M., Herrera, L., Gallardo, A., & Bovea, M. (2009). Viabilidad de la valorización energética de lodos procedentes de distintos tipos de depuradoras. Available online: http://repositori.uji.es/xmlui/bitstream/handle/10234/22773/32650.pdf?sequence=1 [Accessed: March 2017]

Dunster, A. (2007). Characterisation of Mineral Wastes, Resources and Processing technologies - Integrated waste management for the production of construction material. Case of study: Paper Sludge and paper sludge ash in Portland cement manufacture. Available online: http://www.smartwaste.co.uk/filelibrary/Portland_cement_paper_sludge.pdf [Accessed: March 2017]

Dunster, A. M. (2007). Characterisation of Mineral Wastes, Resources and Processing technologies - Integrated waste management for the production of construction material. Case of study: Paper Sludge and paper sludge ash in Portland cement manufacture. Available online: www.smartwaste.co.uk/filelibrary/Portland_cement_paper_sludge.pdf [Accessed: April 2017]

ECN. Phyllis2. HDPE. (2012). Available online: www.ecn.nl/phyllis2/Biomass/View/776

EcoStandards. (2017). *ECOS work on Solid Recovered Fuels (CEN/TC 343)*. Retrieved from Co-funded by the European Commission and EFTA.

ERFO. (2016). European Recovered Fuels Organisation. Available online:https://www.erfo.info/ [Accessed: February 2017]

European Comission, Environment, Waste. (2017). Available online: http://ec.europa.eu/environment/waste/ [Accessed February 2017]

European Committe for Standarization. (2013). CEN/TC 343 Solid Recovered Fuels.

Frankenhaeuser, M. (2011). European standardization of Solid Recovered Fuels.

Hari D. Sharma, K. R. (2014). CHAPTER 8: Waste characteristics. In *Geoenvironmental Engineering and Waste Management.*

IDAE. (2011). Situación y potencial de valorización energética directa de residuos. Estudio Técnico.

IPPCguidelines. (2006). *Vol. II, Section 1.4.1.2, Box 1.1.*

Izquierdo, A. G., Alcón, N. E., Cuquerella, J. M., & Vinuesa, P. P. (2013). Generación de rechazos en las plantas de clasificación de residuos de envases en España.

Izquierdo, A. G., Parra, A. M., Mendoza, F. J., Alcón, N. E., & Vinuesa, P. P. (2013). Design of a SRF from refuses from a municipal waste treatment plant.

Juma, M., Markoš, Z. K., Annus, J., & Jelemenský, L. (2006). Pyrolysis and combustion of scrap tyre. *Pet Coal*, 15-26.

Lela, B., Baristic, M., & Nizetic., S. (2016). Cardboard/sawdust briquettes as biomass fuel: physical-mechanical and thermal characteristics. .

López, F. A. (2012). Aprovechamiento energético de residuos: el caso de los neumáticos fuera de uso. Año internacional de la Energía Sostenible para todos. *Energía* .

Lorea, C., & VanLoo, W. (2005). Aprovechamiento energético de neumáticos usados en la industria cementera europea.

Marín, D. (2016). Evaluación de un lodo deshidratado de papelera como sustrato de cultivo para plantas ornamentales.

Mendoza, C., Alberola, M., Herrera, L., Gallardo, A., & Bovea, M. (2009). Viabilidad de la valorización energética de lodos procedentes de distintos tipos de depuradoras.

Residuos Gencat. (2017, May). Available online: http://residus.gencat.cat/web/.content/home/ambits_dactuacio/recollida_selectiva/residus_municipals/materia_organica__form_-_fv/jornades__estudis_i_enllacos/metalls_bosses_es.pdf

Scott, G. M., & smith, A. (1995). Sludge characteristics and siposal alterntives for the pulp and paper industry. *Proceedings of the 1995 International Environmental Conference*.

SITA, S. E. (July 2013). A guide to Solid Recovered Fuel. Putting waste to good use and producing a sustainable alternative to fossil fuel. *Berkshire, United Kingdom.*

Tecnoambiente. (2014). Internal Analysis of paper mill sludge.

UNE-CEN/TS 15103:2007 EX. Biocombustibles sólidos. Métodos para la determinación de la densidad aparente de pila (AENOR Diciembre 2007).

UNE-CEN/TS 15149 EX - Biocombustibles sólidos. Métodos para la determinación de la distribución de tamaño de partícula. (AENOR Mayo 2011).

UNE-EN 14774-3. Norma española. Biocombustibles sólidos. Determinación del contenido de humedad. Método de secado en estufa. (AENOR Julio 2010).

UNE-EN 14775. Biocombustibles sólidos. Método para la determinación del contenido en cenizas. (AENOR Septiembre 2010).

UNE-EN 14780. Biocombustible sólidos. Preparación de muestras (AENOR Mayo 2012).

UNE-EN 14918. Norma española. Biocombustibles sólidos. Determinación del poder calorífico. (AENOR Febrero 2011).

UNE-EN 15104. Norma española. Biocombustibles sólidos. Determinación del contenido total de carbono, hidrógeno y nitrógeno. Métodos instrumentales. (AENOR Noviembre 2011).

UNE-EN 15148. Norma española. Biocombustibles sólidos. Determinación del contenido en materias volátiles. (AENOR Septiembre 2010).

UNE-EN 15289. Norma española. Biocombustibles sólidos. Determinación del contenido total de azufre y cloro (AENOR Noviembre 2011).

UNE-EN 15359. Norma española. Combustibles sólidos recuperados. Especificaciones y clases. (AENOR Junio 2012).

UNEP. (1999). Basel convention technical guidelines on the identification and management of used tyres,.

ANNEXES

I. Present Status of CEN/TC 343

In detail below it is presented the 6 Technical Reports, 16 European Standards and 6 Technical Specifications mentioned in chapter 1.1.

6 Technical Reports (CEN/TRs) have been published

- 14980:2004 Report on relative difference between biodegradable and biogenic fractions of SRF
- 15441:2006 Guidelines on occupational health aspects
- 15508:2006 Key properties on solid recovered fuels to be used for establishing a classification system
- 15591:2007 Determination of the biomass content based on the 14C method
- 15716:2008 Determination of combustion behavior
- 15404:2010 Methods for the determination of ash melting behavior by using characteristic temperatures

The following European Standards (EN) have been published:

- 15357 Terminology, definitions and descriptions - 15358 Quality management systems
- 15359 Specifications and classes (decided on 2011-10-19)
- 15400 Method for the determination of calorific value
- 15402 Determination of content of volatile matter
- 15403 Determination of ash content
- 15407 Methods for the determination of C, H and N content
- 15408 Methods for the determination of S, Cl, F and Br content
- 15410 Methods for the determination of major elements
- 15411 Methods for the determination of trace elements
- 15414-3 Determination of moisture content using the oven dry method
- 15415-1 Determination of particle size distribution
- 15440 Methods for the determination of biomass content
- 15442 Methods for sampling
- 15443 Methods for the preparation of the laboratory sample
- 15413 Methods for the preparation of the test sample from the laboratory sample
- 15590 Determination of potential rate of microbial self-heating using the real dynamic respiration index

The following Technical Specifications (TS) have been published:

- 15401:2010 Determination of bulk density
- 15405:2010 Determination of density of pellets and briquettes
- 15406:2010 Determination of bridging properties of bulk material
- 15412:2010 Methods for the determination of metallic Al
- 15414-1:2010 Determination of total moisture by a reference method
- 15414-2:2010 Determination of total moisture by a simplified method

II. Analytical methods for characterization

Annex II presents a summary of the methods used to characterize solid waste. They are all Standard Methods based on the norms from CEN/TC 343.

1. Moisture

Materials

- Drying oven (temperature control of (105±2) °C and air renovation 3 to 5 times per hour)
- Weighing plate (temperature and corrosion resistant with a dimension that the total surface is ≤ 0.2 g/cm^2)
- Balance (to measure the sample with a precision of ± 0.1 mg)
- Desiccator (to avoid the sample absorbing moisture from atmosphere)

Procedure

- Prepare the sample applying the Technical Specification (CEN/TS 14780) with a particle size of 1mm or less. Mix the sample using mechanical methods.
- It must be determined two samples for the test.
- Dry the weighing plate with its cover (105±2) °C until constant weigh and then cool it to room temperature.
- Weigh the plate with its cover with an approximation of ±0.1 mg
- Place at least 1 g of the sample in the plate and weigh it with its cover with an approximation of ±0.1 mg.
- Warm the plate with the sample and the cover (105±2) °C until a constant weigh. Constant weigh is defined with a variation of ±1 mg during the subsequent 60 minutes after the warming. Usually, the drying period is about 2 or 3 hours.
- Put the cover to its plate inside the oven. Move the covered plate to the desiccator and let it cool to room temperature.
- Weigh the plate with its cover and the sample with an approximation of ±0.1 mg. It is important to weigh rapidly after it cools because the small size particles of biofuels are hygroscopic.
- Finally, to determine the moisture content it must be used the following formula (2):

$$M_{ad} = \frac{w_2 - w_3}{w_2 - w_1} x\ 100 \qquad (2)$$

w1: weigh in grams of the plate and cover
w2: weigh in grams of the plate, cover and sample before drying
w3: weigh in grams of the plate, cover and sample after drying

2. Ash content

Materials

- Electric oven (it must achieve in a certain time a uniform temperature; the ventilation must provide the enough oxygen for the combustion during the process)
- Plate (inert material as porcelain, silica and platinum with a dimension that the total surface is ≤ 0.1 g/cm^2)
- Balance (to measure the sample with a precision of ±0.1 mg)
- Desiccator (to avoid the sample absorbing moisture from atmosphere)

Procedure

- Prepare the sample applying the Technical Specification (CEN/TS 14780) with a particle size of 1mm or less. Mix the sample using mechanical methods.
- It must be determined two samples for the test.
- Warm the empty plate in the oven (550±10) °C during at least 60 minutes. Let the plate cool in a resistant surface for 5-10 minutes. Place the plate in to the desiccator and cool it with room temperature. Weight the plate with an approximation of ±0.1 mg.
- Mix the sample carefully before weight it. Place 1 g of the sample in the plate and spread it uniformly. Weight the plate with the sample with an approximation of ±0.1 mg.
- Place the plate in a cool oven. Warm the sample increasing the temperature until 250°C for 30-50 minutes. Let it warm for 60 more minutes. Keep increasing the temperature until (550±10) °C for 30 minutes and let it warm for 120 more minutes.
- Cool the plate for 5-10 minutes in a resistant surface and place it in the desiccator until it cools to room temperature. Weight the sample with an approximation of ±0.1 mg.
- Finally, determine the ash content using the following formula (3):

$$A_d = \frac{(w_3 - w_1)}{(w_2 - w_1)} x\ 100\ x\ \frac{100}{100 - M_{ad}} \quad (3)$$

w1: weigh in grams of the plate
w2: weigh in grams of the plate and sample before drying
w3: weigh in grams of the plate and the ash
M_{ad}: moisture percentage

3. Volatile content

Materials

- Electric oven (uniform temperature of (900±10) °C)
- Thermocouple (a sheathed thermocouple permanent in the oven close to the warming camera and a thermocouple to calibrate)
- Crucible (crucible with a cover both of silica with a weigh of 10-14 g. Rub the crucible and its cover to obtain a flat and even surface)
- Crucible holder
- Balance (to measure the sample with a precision of ± 0.1 mg)

Procedure

- Calibrate the temperature: using a thermocouple calibrated and checking the temperature at regular intervals of time.
- Prepare the sample applying the Technical Specification (CEN/TS 14780) with a particle size of 1mm or less. Mix the sample using mechanical methods.
- Place the crucibles with its covers in the oven and maintain it (900±10) °C for 7 minutes. Let the crucibles cool in a resistant surface to room temperature.
- Weight the crucibles and weigh 1 ±0.1 g of sample. Place the crucible with the sample in the oven for 7 min ± 5 s. Let it cool until 30-50 °C in a resistant surface and then let it cool in the desiccators with room temperature.
- Weight the crucibles with the sample with an approximation of ±0.1 mg.
- Use the following formula (4) to calculate the volatile content

$$V_d = \left[\frac{100\,(w_2 - w_3)}{w_2 - w_1}\right] x \left(\frac{100}{100 - M_{ad}}\right) \quad (4)$$

w1: weigh in grams of the crucible and cover
w2: weigh in grams of the crucible, cover and sample before warming
w3: weigh in grams of the crucible, cover and content before warming
M_{ad}: moisture percentage

4. Elemental analysis

Reagent and calibration substances

- Carrier gas (Helium or any other gas specified in the instrument by the producer)
- Oxygen (specified by the producer of the instrument)
- Additional reagents (specified by the producer of the instrument)
- Calibration substances (Acetanilide, atropine, benzoic acid, diphenyl amine, EDTA, phenylalanine, sulfanyl amide, sulphanilic acid or TRIS)

Materials

There is a variety of instruments that could be used for an elemental analysis. Nevertheless, they must accomplish some functional requirements:

- Combustion conditions of the sample must convert carbon, nitrogen and hydrogen into CO_2, vapor, N_2 and NO_x.
- Eliminate or separate from the combustion gas any component that could interfere in the detection and measurement of CO_2, vapor, N_2 and NO_x.
- The hydrogen as hydrogen halides and sulfur oxyacids must be removed from the vapor before the determination of water vapor.
- Any NO_x must be converted into N_2 before detected.
- It must provide lineal correlation of the measurements of the gas combustion concentrations.

Procedure

- Prepare the sample applying the Technical Specification (CEN/TS 14780) with a particle size of 1mm or less. Mix the sample using mechanical methods.

- Test portion preparation: weight the recommended weigh of sample by the producer of the instrument.
- Instrument calibration.
- Sample analysis: analysis of the samples according to the instructions of the instrument producers. Calibrate the instruments with a control samples. They must have carbon, hydrogen and nitrogen content comparable to the samples.
- Use the following formula (5), (6) and (7) to calculate the elemental composition:

Carbon content:

$$C_d = C_{ad}\ x \frac{100}{100 - M_{ad}} \quad (5)$$

Nitrogen content:

$$N_d = N_{ad}\ x \frac{100}{100 - M_{ad}} \quad (6)$$

Hydrogen content:

$$H_d = \left(H_{ad} - \frac{M_{ad}}{8.937}\right) x \frac{100}{100 - M_{ad}} \quad (7)$$

d: dry mass
ad: as it is determinate
M_{ad}: moisture percentage

5. Chlorine and sulfur

Materials

- Analytical balance
- Flasks and test tubes
- Pellet press
- Combustion bomb (it can be the same as the used for determining the heating value)
- Reagents: deionized water, oxygen (purity 99.5%), combustion/enhancer coadjunvant and certified reference materials (CRM).

Procedure

- Prepare the sample by pelletizing 1g of the waste. If the heating value is analyzed at the same time, apply the Norm EN 14918.
- Add the liquid combustion coadjuvant drop by drop into the pellet.
- To determine the weight of the sample by using a combustion bag or capsule, add the combustion solid coadjuvants. Add a carbonate/bicarbonate, diluting it will act as the absorbent dilution.
- Add 1ml of water in the bomb as receptor dilution. After the combustion, free the air slowly before opening the bomb. Transfer the absolvent dilution to a volumetric flask (50 or 100 ml)
- The detection method used is the Ion chromatography by the methods in the Norm EN ISO 10304-1.
- Use the following formula (8) and (9) to calculate the elemental composition:

Chlorine determination:

$$w_{Cl,d} = \left[\frac{V x\,(c - c_0)}{m}\right] x\ 100\ x\ \left(\frac{100}{100 - M_{ad}}\right) \qquad (8)$$

C: chlorine concentration in the dilution (mg/l)
Co: chlorine concentration in the control dilution (mg/l)
V: volume of the dilution (l)
m: weigh of the sample (mg)
M_{ad}: moisture percentage

Sulfur determination:

$$w_{S,d} = \left[\frac{V x\,(c - c_0)}{m}\right] x\ 0{,}3338\ X\ 100\ x\ \left(\frac{100}{100 - M_{ad}}\right) \qquad (9)$$

C: sulfate concentration in the dilution (mg/l)
Co: sulfate concentration in the control dilution (mg/l)
V: volume of the dilution (l)
m: weigh of the sample (mg)
0.3338: Stoichiometric ratio of molar masses of sulfur and sulfate

III. Pictures of the experimental tests

The last Annex presents different pictures taken during the laboratory test of the characterization of the different solid waste.

1. Density

Firstly, it is shown pictures presenting the calculation of the density. Figure 2 is a tire rejection sample, Figure 3 the sample of the sludge from a paper industry and Figure 4 the sample of HDPE.

Figure 2. Tire rejection sample

Figure 3. Sludge from paper industry sample

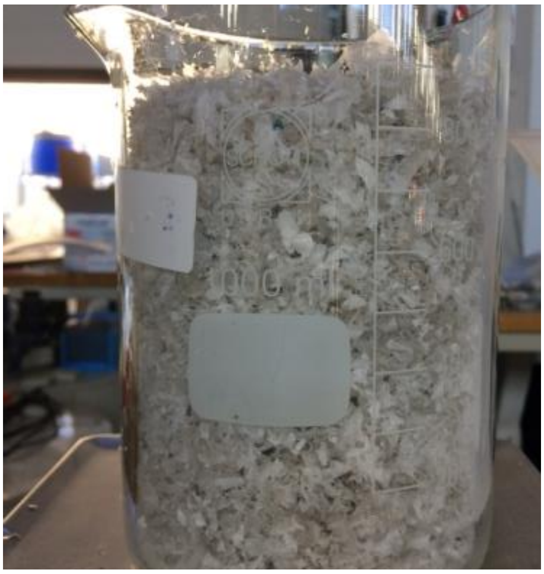

Figure 4. HDPE sample

2. Grain size analysis and particle size distribution

It is shown below different pictures taken during the particle size distribution and the grain size analysis. Figure 5 shows the instrument used, a vibrational sieve. Figure 6 shows the particle size distribution of the tire rejection sample, Figure 7 the particle size distribution of the paper industry sludge and Figure 8 the particle size distribution of the HDPE sample.

Figure 5. Vibrational sieve with sieves of 200 mm of diameter with the following mesh openings: 1.8mm, 2.8mm, 2cm and 4cm.

Figure 6. Particle distribution of tire rejection sample

Figure 7. Particle distribution of paper industry sludge sample

Figure 8. Particle distribution of HDPE sample

3. Moisture and Elemental analysis

To calculate the moisture, it is necessary the use of an electric oven (Figure 11). Figure 9 presents the prepared sample of sludge from a paper industry ready to be introduced into the electric oven. Figure 10 shows the prepared sample of the tire rejection; ready as well, to be introduced in the electric oven.

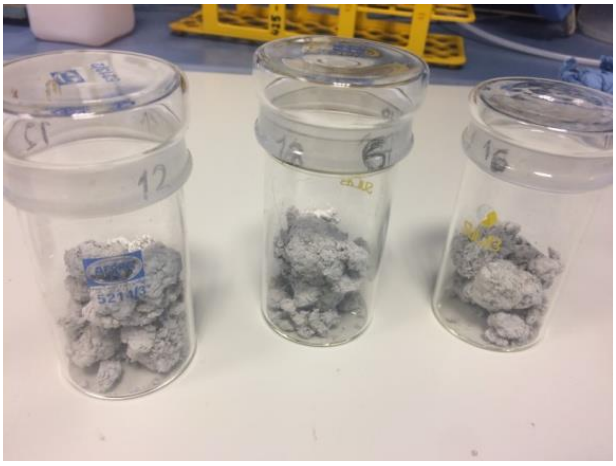

Figure 9. Prepared sample for the analysis of moisture and elemental analysis of sludge from a paper industry.

Figure 10. Prepared sample for the analysis of moisture and elemental analysis of tire rejection.

Figure 11. Electric oven for the determination of moisture, volatile content and ash content.

4. Sample Preparation of Solid Urban Waste rejection

Finally, for the characterization of the rejection from a biological-mechanical treatment plant of solid urban waste it was necessary to prepare a representative sample. Figure 12 and Figure 13 show the initial state of the sample.

Table 28 shows the classification of the different groups of solid waste from the initial sample. It was classified by plastic, metal, paper + aluminum, organic matter, paper, non-combustible, foam, sanitary textile, textile and fine particle. The preparation of the representative sample was done by manually.

Figure 12. Initial sample of the rejection from a biological-mechanical treatment plant of solid urban waste

Figure 13. Rejection from a biological-mechanical treatment plant of solid urban waste

Table 28. Classification of the different types of waste from the rejection from a biological-mechanical treatment plant of solid urban waste

Types of solid waste	Pictures	Types of solid waste	Pictures
Plastic		Metal	
Paper - aluminum		Organic matter	
paper		Non-combustible	
Foam		Sanitary textile	
Textile		Fine particles