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Analysis and Treatment of Household and Similar Waste for Energy Recovery

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Abstract:
The recycling and recovery of Household and Similar Waste (HSW) represents a real potential in the Kingdom of Morocco. The quantity generated is important with a significant annual growth of 0.75 Kg/person/day with a total quantity generated in 2013 around 5. 377. 000 t. Therefore, Morocco is facing a real challenge to deal environmental problems. In the present study, an integrated approach has been proposed and validated on real conditions. This approach aims to develop both Alternative Green Fuel (EAF) and high-quality compost. This study is based on a qualitative and quantitative analysis of HSW carried out on two appropriate characterization campaigns to selected Moroccan landfills. The fraction of alternative fuel (AF) with a considerable calorific power represents 38% of the HSW, while the Fermentable Fraction (FF) is approximately 59% of the total amount of HSW. Experimental analysis has been done to determine Lower Calorific Power (LCP) as well as gas emission fractions which showed an LCP of 27 MJ/kg and the presence of antimony and Chloride. The study realized in laboratory on AF shows that these hazardous elements (Sb & Cl) were present mainly in PET, PVC, textile and HDPE (Hight density polyethelene) with content very high than international norms. Therefore it was necessary to remove the aforementioned fraction from AF to provide an eco-friendly combustible with a LCP of 21 MJ/kg and a percentage of 22% of HSW. The FF moisture and trace elements analysis showed that the water content was about 70% and that heavy metals content was conform with international standards for producing compost.

Keywords: Energy recovery, Biomass, Material recycling, HSW, Eco-friendly alternative fuel.

Introduction
Morocco is facing serious difficulties to manage household waste and only a little part has been performed to transform these waste in resources either for energetic or materiel recovery purposes. Furthermore, the annual budget of the collection and logistics of waste is 1936.36 MDA/year [1]. This cost is relatively very high especially that the delayed taxes cannot cover the costs of waste management. The total population served under the management contracts is currently 9.945.770 people for a 3.480.255 tons of deposit [1]. Actually, the quantity of household waste produced in urban area is almost **5.377.000 per/years** [1] while it was only 3.987.654 t in 1998 showing an average increase of 2.8% per year.
This quantity of solide waste represents a real potential for recycling and recovery with the objective to develop a management scheme that is inclusive, sustainable and economically viable. There are different HSW treatment techniques such as: Composting, incineration, pyrolysis, etc. We note that incineration remains one of the most relevant and effective technique, it reduces up to 70% of their mass, 90% of volume and allows the destruction of pathogens and harmful germs [2], however it does not permit energy recovery.
Moreover the present HSW fractions are not separate according to the best recycling and recovery process. As reported in the work of Aloueimine, 2006 [3], the LCP is favored by a high rate in plastics and a small proportion of the biodegradable fraction. It’s the case of Finland as industrialized country whose LCP is about 20 MJ/kg [4] in contrast to Malaysia that has a LCP of House waste between 6 and 10 MJ / kg for a humidity of 55% and a percentage of 60% of fermentable fraction [5]. Furthermore, the elevated content of humidity of HSW decreases the LCP of HSW. In the light of these data, we would like to develop an approach for the

treatment of household waste and assimilates in Morocco by analyzing separately the fraction of the fermentable calorific fraction at the qualitatively and quantitatively characterize the portion of alternative fuels AF on one side and to analyze the biodegradable fraction of the composting material moisture organic matter and heavy metals on the other side. The proposed approach regarding the management of HSW can be adapted to any urban area; however it has been validated on a real case study namely the waste Temara Transfer Center CTT located 10km south of the Moroccan capital Rabat.

1. Sampling and characterization of household and similar waste HSW.
2. Identification of the different fractions of HSW namely: Free water, fermentable fraction, fraction of calorific value (plastics, cardboard & paper, textiles…), metals, glass and other waste.
3. Identification of the lower calorific power and chemical and physical analyzes of the calorific fraction (humidity, LCP, chlorides, antimony) for energy recovery or material recycling.
4. Chemical analyzes of the fermentable fraction (humidity, organic matter heavy metals) for composting.

2. Materials and methods

2.1. Sampling and sorting

The characterization study of Household Waste of the Temara Transfer Center took place mainly during two campaigns; the first one was carried out in summer 2013 and the second performed in winter 2013 to consider the precipitation factor which influences on humidity of the waste. For each campaign one truck per day was treated from different neighborhoods and towns of Temara city (Locals Skhirat and Harhoura, neighborhoods Andaluse and Wifaq).

In total, we worked on five main areas of the region Temara for 10 days according to the method of sampling and characterization of HSW in the French standard AFNOR XP X 30-408 [6] and AFNOR XP X 30-413[7] which takes into account the heterogeneity and represent ability of the sample.

The quantity to be treated was taken directly from the truck from the area under study according to a schedule and weighed in the weigh bridge. It is important to mention that there was a relatively large amount of water in the truck waste. This water was evacuated before discharging waste and channeled into the pond leaching being at Temara Transfer Center.

Furthermore, the amount of waste truck under study is directly discharged to the ground. This "Big Heap" was divided into several "heap" of each $1m^3$ each to be sorted according to the categories and sub-categories, they were separated according to the different fractions.

2.2. Analysis of fraction with calorific power

The objective of this analysis is to determine the tenor of humidity, chloride and antimony which are the parameters that have to be taken into account in the energetic recovery, especially in the case of alternative fuels AF by cement plus the calorific power.

In this way, we distinguish between the waste that can be used as AF and those that can be recycled, knowing that PVC and PET are plastics that can release halogenated derivatives and antimony oxide which are hazardous to the health when burning.

2.2.1. The humidity

The humidity was determined by oven drying of 186 g of the solid fraction (cardboard and wood, plastic bags, LDPE, tetra pack) at 110°C for 12h.

2.2.2. Determination the lower calorific power (LCP)

LCP is defined supposing that the water from the fuel, or smoke during combustion, remains at the final stage in the vapor state. LCP of household waste varies significantly according to moisture waste.

In our calculation of LCP, we took into consideration moisture content that we already determined for a sampling containing: Cardboard, textiles, wood, plastic packaging (LDPE).

2.2.3. Determination of chloride

Analysis of chlorides is done on a homogeneous mixture by alkaline fusion at 450 ° C of 10 g of a homogeneous mixture of Alternative Fuel to a particle size below 2 mm in a crucible with 4 g of NaOH for 6h after mineralization, the hydrolyzed mixture with distilled water and then adjusted in a volumetric flask of 50ml.

The chloride-ions thus liberated are dosed by silver nitrate ($AgNO_3$) according to the Mohr method in the presence of potassium chromate as dye indicator. For aliquot of about 10 ml of the digested sample, the necessary volume of silver nitrate (0.1N) is 9 ml.

2.2.4. Determination of antimony

The antimony oxide is used as catalyst in the manufacture of PET, it is important to note that the content of antimony ranges from 160 to 260 mg per kilogram of PET [8]. Furthermore, antimony oxide is also used as a corrosive for textiles and leather [9]. The combustion of these two fractions leads to release of antimony and its compounds, expressed as antimony (antimony trioxide: Sb_2O_3) are volatile, dangerous and highly toxic to the environment and to human health [10]. The methodology adopted for the analysis of the levels of antimony in the two fractions (PET and Textiles) is firstly based on grinding the two fractions to a particle size less than 2.0 mm and secondly, the mineralization following these two methods:

Method A: The sample is attacked by aqua regia (mixture of concentrated nitric acid and 3-4 parts of hydrochloric acid) followed by the analysis of ICP-MS (Inductively Coupled Plasma Atomic Emission Spectrometry The coupled plasma torch) of UATRS laboratory at CNRST.

Method B: The sample is mineralized at 400 ° C for 6 hours by alkaline fusion followed by solubilization in aqua regia and the same analysis by ICP-MS at UARTS laboratory at National Center for Scientific and Technical Research (NCSTR).

2.3. Analysis of fermentable fraction

The Humidity was determined, by oven drying samples of Fermentable Household Waste (FHW) from neighborhoods Wifaq and Harhoura at 60 °C for 24h. Mineral and organic fractions were measured by the gravimetric method of dry samples in an oven at 800°C for 1h.

The analysis of elements marks of the fermentable portion was performed by atomic absorption to evaluate the possibility of composting this waste fraction [11-12].

3. Results and discussion

3.1. Sampling and tri

The task of sorting showed that HSW consist of approximately 38% of the solid portion, 59% of the fermentable portion and low percentages of metals and glasses (Table1).

Table 1: Average composition of household and similar waste of Temara city

Fractions			(%)
Fraction with calorific power	Plastic	PET with cap	1.7
		HDPE and PP	0.9
		LDPE	10.3
		PVC	0.1
	Carlboard and paper		8.23
	Various fractions (yoghurt , pots, …)		4.26
	Baby diapers		7
	Cardboard tetra pack		3.1
	Textiles		2.6
	Wood		0.2
	Shoes and elastomers		0.1
Fermentable fraction			59
Metals	• Iron		0.8
	• Aluminum		0.1
	• Aluminium powder		0.02
Glasses			1.1
Other wastes	• Demolition waste		0.5
	• WEEE		0.05
	• Medical and Pharmaceutical waste		0.03
	• Batteries		0.02
Total			**100**

The amounts of recyclable materials such as plastics, cardboard and metals are partially influenced by the informal sector activity acting directly on containers of household and similar waste in neighbourhoods, the rate of influence is about 10% [13].

3.2. Analysis of a fraction calorific value

3.2.1. Humidity

An accurate LCP calculation requires the determination of humidity content. This application of the equation defined earlier shows that the calorific power fraction under study presents 32, 8% of the humidity.

3.2.2. Determination Lower Calorific Power (LCP)

The calorific power of the AF was determined taking into account the LCP of each constituent present in the sampling and the corresponding dry weight fraction as is shown in the Table 2. Consequently, the value of AFs LCP was around 27 MJ/kg (Table2.). However, it has been necessary to assess the environmental impact of using this fraction under study as an alternative fuel. In that context combustion was carried out at laboratory scale and the emitted gas was analyzed showing a high presence of Chloride and antimony as is shown in the next paragraph.

Table 2: Calculation of the LCP to the inorganic fraction.

Fraction	**Dry Weight**	**LCP of Dry material [1])**	**AF's LCP**	**Dry Weight**
Unit	**per 100 kg of EHSW**	**MJ/kg**	**MJ/kg**	**per 1 kg of AF**
PET	1.7	45	2.878	0.0640
HDPE	0.9	46	1.558	0.0339
LDPE	6.92	46	11.976	0.2603
PVC	0.1	20	0.075	0.0038
Elastomer	0.1	20	0.075	0.0038
Wood	0.13	16	0.078	0.0049
Textile	1.74	21	1.375	0.0655
Carton	15.21	17	9.728	0.5722
Total	**26.58**		**27.743**	

[1] *The source : Technique ingénieur.*

3.2.3. Determination of chloride:

The determination of chloride into the homogeneous mixture according to the Mohr method gave a value of 1.7% of the chlorides.

The sources of chloride in municipal solid waste and in the fraction with calorific value (FCV) are multiple:

1. Free water and liquid discharges from household and similar waste salts are loaded at the landfill of Rabat. The amount of **chlorides are** of the order of 1.5 g / l [14-15] and because of the humidity content of FCV 32.8% and absorbent textiles, cardboard, paper and **diaper** after drying salts layers to remain caught in the AF.
2. The structures of wood, cardboard and PVC contains chlorine and of polyvinyl chloride has a chlorine content of 56.8% and since the PVC[1]is very dispersed in the HSW can be considered as a source of **chlorides** in the FCV fraction.
3. Diapers contain a lot of feces full of chloride salts.

So the high value of chloride in AF is around 1.7%, hence the need to separate the PVC[2]from AF is preferably recycled, knowing that the presence of chloride in HSW is inevitable and there are between 3.2 to 6.2 g / kg DMA in Quebec (Canadian standards, CAN/BNQ 0413-200 [16]).

[2] The molecule of PVC (CHCI-CH2) $_n$ contains 56.8% chlorine.

3.2.4. Determination of antimony

Table 3 present the different levels obtained after analysis of two samples for both fractions (PET / Textile) under study. European specifications for cement in Europe are 10 mg/kg. Note that the method B presents a total mineralization, which is more reliable since we bring a heater as specified in the standard EN 13656. Moreover, we note that the textile is slightly above the threshold specificity by cement plants in Europe against in PET is above tolerable safe threshold which causes a difficulty used this energy recovery point of view of environmental.

Table 3: Determination of antimony in the PET and textile.

Sample	Method	content Sb (mg /Kg)
PET	A	113.6
PET	B	97.4
Textile	A	12.2
Textile	B	11.64

Thus, the analysis of antimony and chloride **can be** concluded that their concentration is higher than the standard value. Furthermore, we have identified the origin of these hazards substances to be mainly textile, PET and PVC. As consequence in other to produce alternative fuel satisfy the environmental constraint, we should remove textile, PET and PVC from the AF fraction. Taking into the consideration this condition the adapted value AF's LCP is 21 MJ/kg as it‘s can been in table 4.

Table 4: Calculation of the LCP of the EAF.

Fraction	**Dry Weight**	**Dry Weight**	**LCP of Dry material**	**EAF's LCP**	**Dry Weight**	**Dry Weight**
Unit	**per 100 kg of EHSW**	**per 100 kg of EHSW**	**MJ/kg**	**MJ/kg**	**per 1 kg of AF**	**per 1 kg of EAF**
PET	1.7	0	45	0	0.064	0
HDPE	0.9	0	46	0	0.033	0
LDPE	6.92	6,92	46	11.9	0.260	0.260
PVC	0.1	0	20	0	0.003	0
Elastomer	0.1	0,1	20	0.075	0.003	0.003
Wood	0.13	0,13	16	0.078	0.004	0.004
Textile	1.74	0	21	0	0.065	0
Carton	15.21	15.21	17	9.728	0.572	0.572
Total	**26.58**	**22.36**		**21.857**		

The following table shows the main characteristics of alternative fuel in the present work .We note that the AF fraction represents 22% percent of the HSW with 21MJ/kg which gives almost 2 tons of Eco-friendly Alternative Fuel EAF are equivalent to one ton of fuel (Knowing that the LCP of fuel is 40MJ/Kg). It is important to note that the AF proposed depends on environment and dryness (Table5).

Table 5: Quantitative and Qualitative Characteristics of AF obtained.

LCP	22 MJ/kg
Environnemental impact	SATISFYING
1 ton of fuel equivalent	2 tons of EAF
% of AF In HSW	22.5%

3.3. Fermentescible fraction

3.3.1. Humidity, organic and mineral materials

The humidity content of the Wifaq neighborhood (sample 1) is 60%, while that of the Harhoura municipality (sample2) is 79.1% .The average of the two extremes give an average of 70% on H (Table 6).

Table 6: Humidity of Wifaq neighborhood and Harhoura municipality.

	Humid quantity (g)	**Dry quantity (g)**	**Humidity (%)**
Sample1	355	142	60
Sample 2	834	174.3	79.1

The dry matter consists of 15.27% mineral material and 74.7% of the organic material, which gives the advantage of composting the fermentescible fraction of household waste, and that the organic material can absorb water for watering and thus retain that plants draw on those reserves when needed[17].

3.3.2. Analysis of elements marks in the fermentable portion

Table 7 shows the maximum levels of trace elements in the finished compost according to French standard NF U44-051 [18] and the Canadian quality standard CAN / BNQ 0413 -200 [16]. The atomic absorption analysis showed that the fermentable part contains trace elements namely lead, cadmium, nickel, chromium, copper and cobalt with lower rates than the standard.

Table 7: Standards for trace element contents in mg/kg in compost

Heavy Metals (mg/kg)	Cu	Pb	Ni	Cd	Co	Cr
Standard I*	300	180	60	3	-	120
Standard II**	400	150	62	3	34	210
PF***	11.2	22.4	5	--	4	11.2

*: French standard NF U44-051 quality, the application of which is mandatory for all composts on the market.
**: Canadian Standard CAN / BNQ 0413 quality -200
***: Fermentable Party (FP)

Conclusion

This work allowed determining the accurate fraction of an eco-friendly alternative fuel with its corresponding LCP that can be used in industry. This EAF represents 22% in weight of the total amount of HSW with a lower calorific power of almost 21 MJ/kg. Therefore, one ton of this EAF is equivalent to 0.5 ton of fuel that permits a performing industrial solution for energy recovery. Moreover, this proposed solution not only allows the identification of a renewable source of energy but also a way to preserve environment. This is of great importance for Morocco that faces strategic challenge with energy safety and environmental purpose. This work also specifies the appropriate waste selection permitting to obtain an AF free of antimony & chloride avoiding gas emission impact. As a consequence of this waste separation, it is possible to isolate an FF fraction free of trace elements as shown in experimental analysis. This FF is of great interest to produce a compost of high quality.

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