

CHICKEN FEATHERS BASED COMPOSITES: A LIFE CYCLE ASSESSMENT

G. Molins^{1*}, M.D. Álvarez¹, N. Garrido², J. Macanás¹, F. Carrillo^{1,3}

¹Department of Chemical Engineering, Universitat Politècnica de Catalunya, Colom 1, 08222 Terrassa, Spain

²Department of Heat Engines, Universitat Politècnica de Catalunya, Colom 1 08222 Terrassa, Spain

³INTEXTER, Universitat Politècnica de Catalunya, Colom 15, 08222 Terrassa, Spain

*gemma.molins@upc.edu

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Abstract

Chicken feathers (CFs) are a waste material generated from poultry industry in large quantities. A composite material constituted of polylactide and CFs is proposed in order to prepare a biodegradable composite with low environmental impact. In order to evaluate its environmental impact, a Life Cycle Assessment (LCA) is performed. The results show that, from the environmental point of view, the more chicken feathers in the material, the greater is its impact. This is mainly due to the non-inclusion of the impact data regarding CFs current waste management treatments required in accordance with the European Directive CE 1069/2009 (in study) and to the high energy consumption of the pre-treatment stages (cleaning and sanitizing) required to transform CFs waste into a CFs technical material that can be used for the preparation of CFs/PLA composites material, which needs to be optimized.

1. Introduction

Plastic is part of our life; in fact, it is difficult to imagine our daily activities without furniture, kitchenware, automotive items, etc. made of plastic. In recent decades many polymers have been developed combining plastics with other substances (plasticizers, stabilizers, reinforcing fibers ...) to improve their properties [1].

Plastic composite materials are made of a polymer with different reinforcements (e.g. fibres), which originally were synthetic (such as fiberglass, aramid or carbon fibres). Nevertheless, after 1990's natural fiber reinforcement alternatives have been proposed. These natural fibers are mainly of vegetable origin such as hemp or flax [2]. An alternative to these natural fibers may be natural fibers of animal origin such as chicken feathers (CFs)[3].

Global production and consumption of chicken meat world has grown by 16% in the last 5 years [4]. Accordingly, the waste generated in the production process has increased at the same extend. CFs are a part of such waste, representing 5.5-7% [5] of the live weight of the animal. For instance, about 95.000 tones were generated in 2008 in Spain and about 800.000 tones are produced annually in EU-27 [6]. Thus, if CFs were combined with a biodegradable plastic, such as polylactide (PLA), a biodegradable composite material that does not come from fossil fuels could be obtained. However, the use of CFs for composites application

required the pre-treatment of CFs waste to transform this waste into a stable technical material. In this sense, in the literature there are studies that discuss the waste management of feathers [13] [14], but no quantitative data on its impact is presented. Also, the prepared CFs/PLA composite material is expected to offer a more environmental friendly solution compared to other plastic composites currently manufactured. In order to corroborate the a priori environmental expected benefit of the CFs/PLA materials a LCA study was proposed in this work.

1.1. Life cycle assessment (LCA)

Brundtland Commission defined “sustainable development” as “social and economic advance to assure human beings a healthy and productive life, but one that did not compromise the ability of future generations to meet their own needs” [7]. The European Council adopted and confirmed sustainable development as a fundamental objective in European Union Sustainable Development Strategy [8].

Building sustainable development requires profound changes in thinking, in economic and social structures and in consumption and production patterns. So, the implication of scientific, technological and industrial field, and the creation of methodologies to evaluate sustainability in each specific case are necessary. Among the different existing methodologies to evaluate and measure environmental impact, Life Cycle Assessment (LCA) is very useful to evaluate and compare the environmental impacts of different systems, taking into account all stages of product life, from extraction of raw materials to final disposition as waste. LCA consists of a set of techniques articulated in a systematic objective procedure to identify, classify, and quantify the pollutant loads and the environmental and material resources and energy associated with a product, process or activity from conception to disposal. All these stages are called the product life cycle or more graphically, “*from the cradle to the grave*”.

The main aim of this work is applying the LCA methodology to identify and quantify pollutant loads, environmental impacts and material resources and energy associated with the manufacture of composite materials with CFs and PLA to propose the best production scenario, to be economically and technologically feasible, involving an environmental benefit.

2. Materials and testing methods

2.1. Goal, functional unit and, scope

The goal of the study is to analyze the environmental impact of CFs/PLA composite materials containing pre-treated CFs in different amounts (from 0% to 35% v/v of CFs). The impact of each composite has been studied from cradle to gate, considering all inputs and outputs of the different alternatives (several pre-treatments and different percentages of CFs).

The environmental impact of these materials is compared using LCA methodology [9] applied to a plate of 184 x 184 x 2.2 mm³ made of CFs/PLA composite material as a functional unit. Inventory data for the CFs pre-treatments and composite fabrication were obtained from own data collected in the laboratory as well as from different international databases.

The following processes lie beyond the scope of our study and their environmental impacts were not considered:

- raising of poultry, as CFs are a worthless waste of the chicken meat production;
- transportation.

2.2. Life Cycle inventory (LCI)

A LCA was carried out for each percentage of CFs tested and each pretreatment considered using SimaPro version 7.3

2.2.1. Pretreatments

A pre-treatment is always required to stabilize and transform CFs into a stable technical material. There are several pre-treatments proposed [10], mainly based on washing CFs with different cleaning agents or steam sterilization. Here, two pretreatments are tested: cleaning and sanitizing with a surfactant and sterilization with steam in autoclave (**Figure 1**).

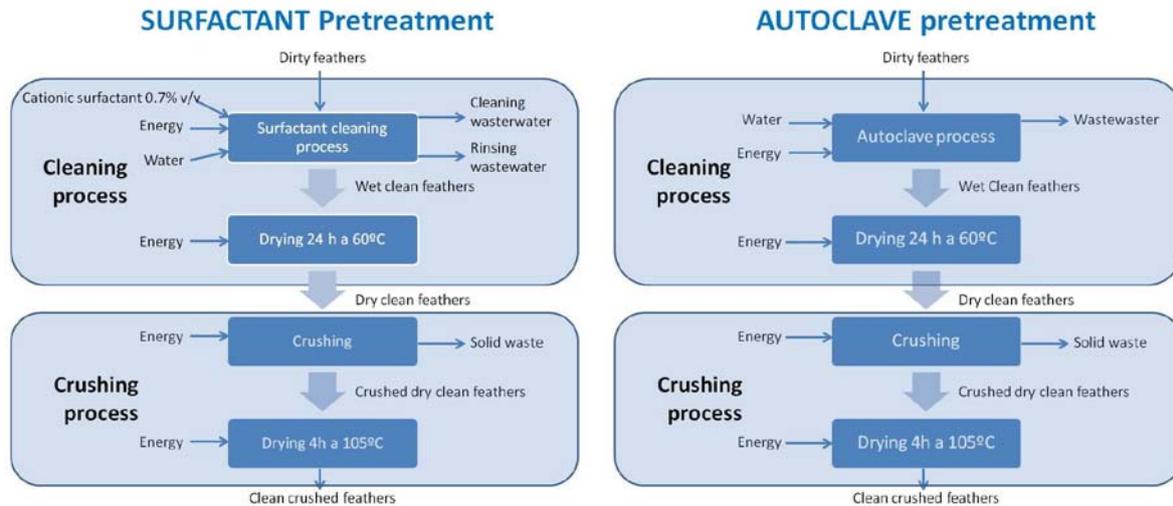


Figure 1: Surfactant and autoclave cleaning process

Surfactant pretreatment of CFs consists of washing with a surfactant solution (Tetryl BC-80 from Kao Chemical at a concentration of 0,7% v/v) during 1 hour with a bath ratio of 40:1, followed by a rinse with 500 ml of deionized water. Once washed, CFs are dried at 60 °C for 24 hours and then crushed with a Cutting Mill SM 100 (RETSCH) to a maximum size of 1 mm (see **Figure 1**). Besides, autoclave pretreatment consists in a sterilization process with saturated steam at 135 °C for 20 minutes. Then CFs are dried and crushed in the same way as it was done after the surfactant treatment (see **Figure 1**). **Table 1** and **2** show the inventory data of both pretreatments. The following assumptions were made:

- the oven is working on steady state, so the energy consumption to put on and reach the set-point temperature is not considered in the LCI;
- the oven and the autoclave occupation are 50% of its whole capacity (e.g. 13.5 kg of CFs for the autoclave and 36 kg of CFs for the oven);
- emissions of volatile compounds are not considered;
- avoided emissions due to CFs waste treatment such as incineration, composting and redering for pet food production are not considered due to lack of data. We are working to obtain them.

Inventory data (per g of dry cleaned CFs)		Surfactant Treatment (Figure 1)	Autoclave treatment (Figure 2)
Inputs	Chicken feathers (g)	2.35	2.07
	Surfactant (ml)	0.7	0
	Deionized water (ml)	563	1.23
	Total Electricity (Wh)	97.9	90.4
	Processing	7.8	0.3
	Drying 60°C	90.1	90.1
Outputs	Clean feathers	1	1
	Wastewater:		
	Chemical Oxygen Demand, COD (mg O ₂)	1832.6	2.73
	Biological Oxygen Demand, BOD ₅ (mg O ₂)	117.7	1.48
	Suspended solids (mg)	116.7	0.124
	Oils (mg)	0.047	0.248
	Kjeldalh-N (mg)	33.9	2.15

Table 1: Inventory data of pretreatment process per g of clean feather

Inventory data (per g of cleaned crushed CFs)		CFs crushing
Inputs	Clean CFs (g)	1.15
	Total Electricity (Wh)	53.2
	Crushing (Wh)	6.5
	Drying (105°C) (Wh)	46.7
Outputs	Clean crushed CFs	1

Table 2: Inventory data of crushing CFs per g of crushed feather

Once we have clean and crushed CFs, the CFs/PLA composite material can be prepared. A Brabender W50EHTPL mixer (Brabender GmbH & Co) and a Collin Mod P 200E hot plates press (Dr. Collin GmbH) are used to prepare a plate of 184 x 184 x 2.2 mm³ of composite material. The preparation of the plate is described and schematized (Figure 2) below:

PLATE manufacturing process

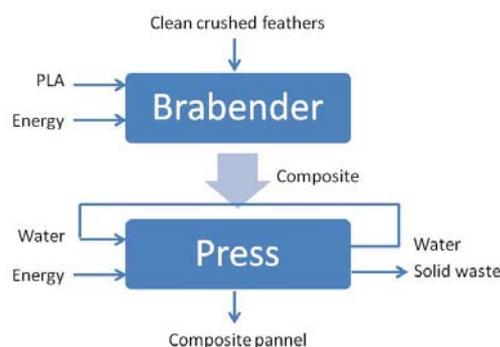


Figure 2: Plate manufacturing process

Composite specimens were obtained by mixing the previously crushed and dried CFs (three compositions: 10, 20 and 35 % v/v) with PLA matrix. The components were mixed using a Brabender mixer type W 50 EHT PL (Brabender® GmbH & Co. KG, Germany) heated at 180 °C for 5 min at 50 rpm. After the mixing, the blend was then consolidated at 100 kN and 180 °C for 5 min in a Collin Mod. P 200E (Dr. Collin GmbH, Germany) hot plates press forming

square plates, measuring 184 x 184 x 2.2 mm³. The cooling process was carried out under pressure using cool water until room temperature. In **Table 3** it is shown the inventory data of the processes in front of the percentage (v/v) of CFs used:

Inventory data (per g of composite material)		0% CFs	10% CFs	20% CFs	35% CFs
Inputs	Clean crushed CFs (g)	0	7.87	15.7	27.5
	PLA (g)	102	92.2	81.9	66.6
	Electricity (kWh)	124.1	124.1	124.1	124.1
Outputs	Plate	1	1	1	1

Table 3: Inventory data of prepared composites plates (184x184x2.2 mm3)

Several energy measures have been done and it has been found that the energy consumption of both the mixer and the hot plate press devices is independent of the CFs percentage (from 0 to 35%) used to prepare each plates. Energy consumption has been studied under steady state conditions and taking into account the time taken for plate manufacturing.

3. Impact assessment

Impact assessment is a technical process where input and outputs of elementary flows are translated into impact indicator results. Only classification and characterization steps were considered. For classification, all data from the inventory are assigned into impact categories according to their contribution to different environmental problems, whereas for characterization, elementary flows are modeled to quantify their contribution to each impact category. The results are aggregated per impact category [9].

Although there is no scientific consensus regarding which impact categories should be considered when assessing the environmental impacts associated with biopolymers and composites [1], the most of researchers use impact categories included in Guinée's list [11]. According to that list, six impact categories have been selected in this work: abiotic depletion, acidification, eutrophication, global warming potential, ozone layer depletion and photochemical oxidation.

4. Results

4.1. Pretreatment phase

Previous studies conducted by our team, revealed that the type of CFs pre-treatment does not significantly affect the mechanical properties of the composites within the CFs compositions studied [12]. However, there is not quantitative information about the environmental impacts produced by those CFs pre-treatments which will be studied in this section. As the crushing process is common to both surfactant and autoclave pre-treatments, then the results only show the unit processes where both pre-treatments differ. The impact characterization shows that the autoclave sterilization process have less environmental impact for all impact categories that the surfactant cleaning process. It is worth to highlight the great eutrophication of the surfactant cleaning process due the wastewater effluent generated in this pre-treatment (**Figure 3**).

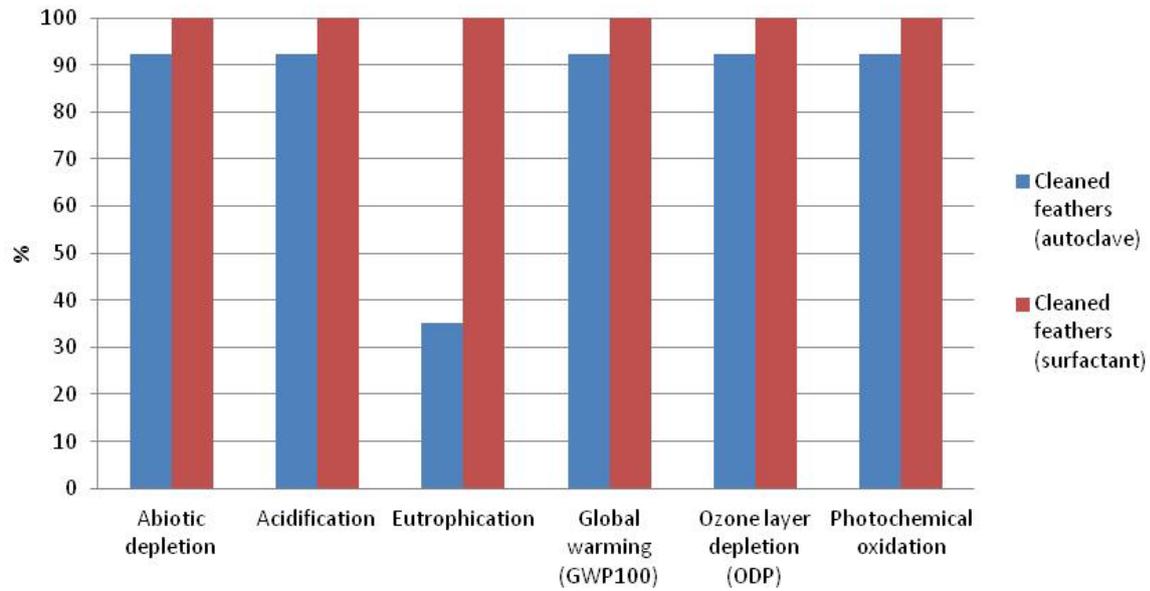


Figure 3: Cleaning process comparison. 1 kg clean CFs (autoclave) vs 1 kg clean CFs (surfactant). Method CML2 baseline 2000 V2.04, World 1995, Characterization.

As it is shown in **Figure 4** and **5** the major impacts for both cleaning processes correspond to the electricity consumption, due to the drying process step.

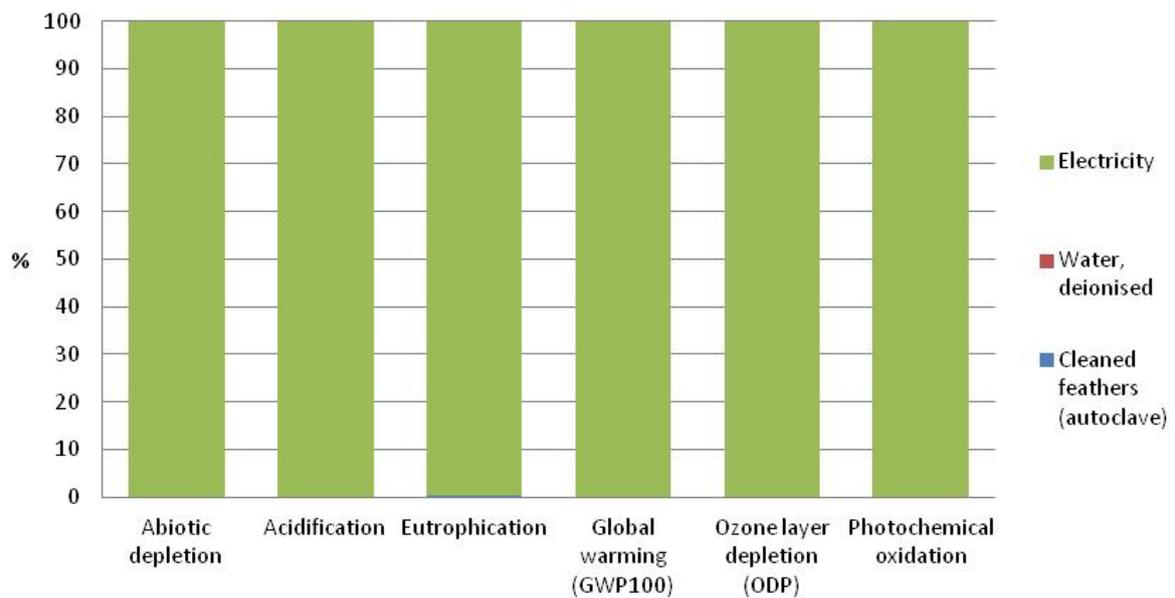


Figure 4: Inputs contribution to autoclave cleaning process.

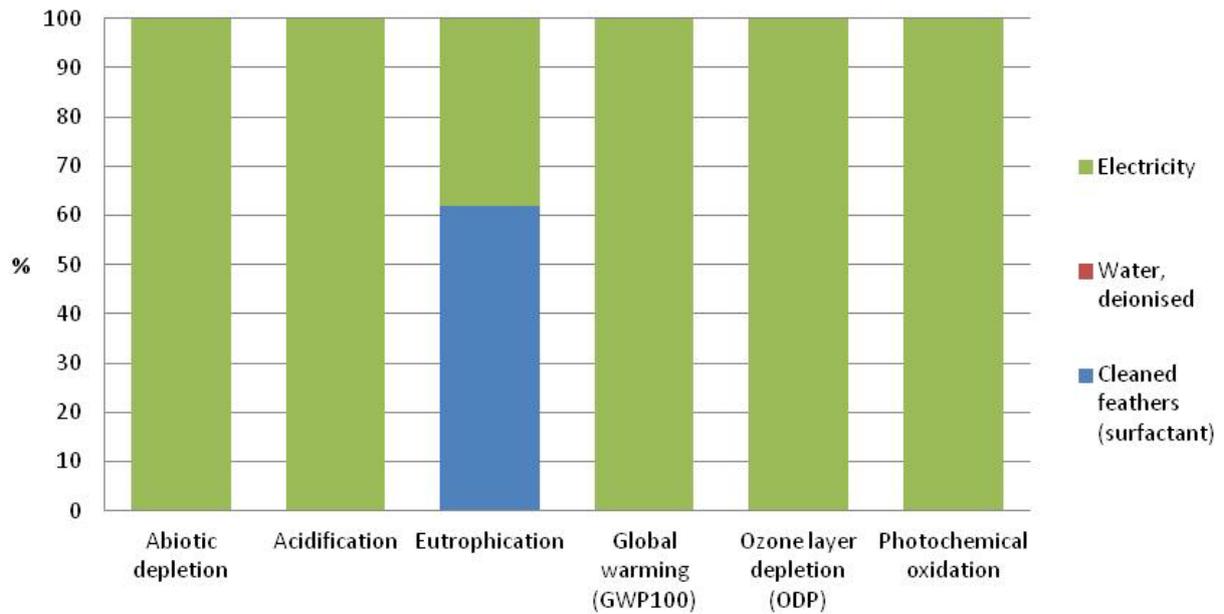


Figure 5: Inputs contribution to surfactant cleaning process.

From the presented results, one can conclude that, from the environmental point of view, the best cleaning method is the autoclave process.

4.2. Composite preparation phase

The process of CFs/PLA composite preparation using autoclave pretreated feathers was analyzed in terms of environmental impacts. From the results it is observed that when increasing the mass of CFs in the plate, the environmental impact increase proportionally (see Figure 6). A deeper analysis reveals that this trend is due to the energy consumption produced during the drying processes of the CFs.

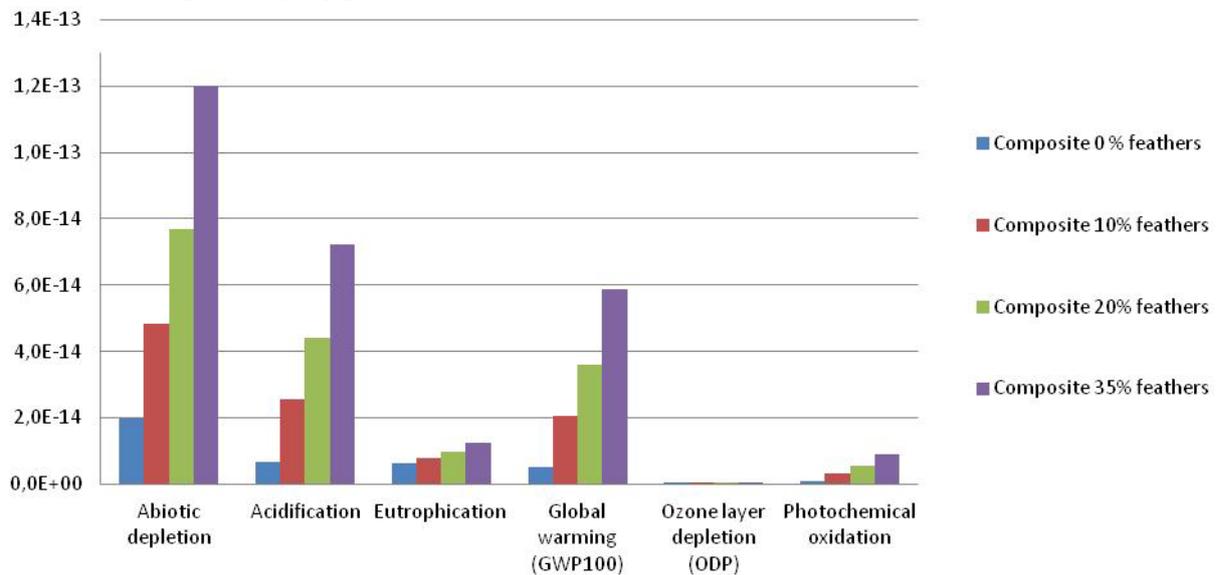


Figure 6: Environmental impacts of CFs/PLA composite materials containing different percentages of CFs.

5. Conclusions

These results from the environmental study related to the CFs pretreatment reveal that the CFs pre-treatment processes are an important point to be considered in terms of environmental impacts. Show that it is necessary to study the environmental impacts due to the treatment of

feathers as waste. Pre-treatment stages, especially CFs drying, are the crucial step that cause the higher environmental impact of CFs/PLA composite material so it is essential an optimization of those pre-treatment process.

It is important to remark than in this study it has not been considered the avoided burdens due to the management the feathers as a waste (normally by incineration). Probably, if it this type of avoided burdens had been considered, the differences between the environmental impacts of the composite plate and the plate made of 100% PLA would have been less important. Due to the lack on bibliographic data related with the quantification of the environmental impacts caused by the management of the feathers as a waste; it will be interesting and important to continue this work in the future to constitute a database supported by experimental studies.

6. Recommendations and perspectives

Please note that this study has not included the impact of the material as a waste after its use as it was outside of the scope of the work. But it would be advisable to do it in the future to get the full life cycle material and more accurate conclusions.

7. References

- [1] Vidal R. Life cycle assessment of composite materials made of recycled thermoplastics combined with rice husks and cotton linters. *The international journal of life cycle assessment*, **14**, pp. 73-82 (2009) .
- [2] Joshi S, Drzal L, Mohanty A, Arora S. Are natural fiber composites environmentally superior to glass fiber reinforced composites? *Composites. Part A, Applied science and manufacturing*; **35**, pp. 371-376 (2004).
- [3] Wool R, Hong C. Development of a bio-based composite material from soybean oil and keratin fibers. *J Appl Polym Sci*, **95**, pp. 1524 (2005).
- [4] AVEC. *Annual report of the Association of Poultry Processors and Poultry Trade in the EU countries* (2011).
- [5] Salminen E, Rintala J. Anaerobic digestion of organic solid poultry slaughterhouse waste-- a review. *Bioresour Technol*, **83**, pp. 13-26 (2002).
- [6] Vermeeren C. *Estimation of the production of different poultry animal byproducts as feathers* (2010).
- [7] Comissió Mundial sobre el Medi Ambient i el Desenvolupament. *Our common future*. Oxford University, Oxford (1987).
- [8] Presidency report. Review of the EU Sustainable Development Strategy - Presidency report 16818/09. (2009).
- [9] Joint Research Center, Institute for environment and sustainability. International reference Life Cycle Data System (ILCD) *Handbook - General guide for Life Cycle Assessment - Detailed quidance*. Publications Office of the European Comission, Luxembourg (2010).
- [10] Gassner G, Schimdt W, Line M, Thomas C, Walters R. Fiber and fiber products produced from feathers. US Patent, 5,705,030. (1998).
- [11] Guinée JB. *Handbook on life cycle assessment*. Kluwer Academic Pub., Dordrecht, (2002).
- [12] Carrillo F, Macanás J, Cañavate J, Molins G, Álvarez MD, Garrido N. Use of chicken feathers waste for the fabrication of composite materials. This issue. (2012).
- [13] Matsui T, Yamada Y, Mitsuya H, Shigeri Y, Yoshida Y, Saito Y, et al. Sustainable and practical degradation of intact chicken feathers by cultivating a newly isolated thermophilic *Meiothermus ruber* H328. *Appl Microbiol Biotechnol*, **82**, pp.941-950 (2009).
- [14] Dudyński M, Kwiatkowski K, Bajer K. From feathers to syngas - technologies and devices. *Waste Manage*, **32**, pp.685-91 (2012).