Life cycle assessment of the electroconductive textiles functionalized by advanced technologies (plasma) and metallic micro/nanoparticles deposition

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RALUCA MARIA AILENI
RAZVAN ION RADULESCU
LAURA CHIRIAC
LILIOARA SURDU

REZUMAT – ABSTRACT

Evaluarea ciclului de viață al textilelor electroconductoare funcționalizate prin tehnologii avansate (plasmă) și depunere de micro/nanoparticule metalice

Această lucrare prezintă mai multe aspecte privind evaluarea ciclului de viață al textilelor electroconductoare funcționalizate prin tehnologia avansată cu plasmă RF pe bază de argon și oxigen și depunerea de micro/nanoparticulele metalice. Pentru a obține textile cu proprietăți electroconductoare, planul nostru preliminar a constat în funcționalizarea textilelor prin utilizarea tehnologiei cu plasmă RF pe bază de argon și oxigen și a proceselor de depunere a micro/nanoparticulelor, cum ar fi fulardarea, imprimarea directă și depunerea de pelicule subțiri. S-a analizat inventarul ciclului de viață (LCI) și s-a elaborat studiul pentru evaluarea ciclului de viață (LCA) folosind software-ul SimaPro și Eco-indicator 99. Pentru a obține LCI, s-au utilizat datele tehnice de intrare și ieșire din procesele cu plasmă și software-ul SimaPro pentru generarea LCI și LCA. Datele de intrare despre materia primă, energia, substanțele chimice au fost colectate prin măsurători directe pe echipamente, manuale de utilizare și specificațiile echipamentelor (cărți tehnice) și procese. Datele de ieșire au fost obținute utilizând software-ul SimaPro conectat la baze de date de pe internet. Obiectivul studiului a fost studierea evaluării ciclului de viață al textilelor electroconductoare funcționalizate prin tehnologia cu plasmă RF în comparație cu tratamentele de funcționalizare clasice.

Cuvinte-cheie: tehnologia cu plasmă, microundă, microparticule, electroconductor, LCA, textile

Life cycle assessment of the electroconductive textiles functionalized by advanced technologies (plasma) and metallic micro/nanoparticles deposition

This paper presents aspects concerning the life cycle assessment of the electroconductive textile functionalized by advanced RF plasma technology based on argon and oxygen gases and deposition of the metallic micro/nanoparticles. In order to obtain the textiles with electroconductive properties, the preliminary plan consisted functionalization of the textiles by using RF plasma technology based on argon and oxygen gases and processes for micro/nanoparticles deposition such as foulard, direct printing, and thin film position. It was analyzed the life-cycle inventory (LCI) and was provided the study for life-cycle assessment (LCA) using SimaPro software and Eco-indicator 99. In order to obtain the LCI, we used to input and output technical data, from the plasma process, and the SimaPro software for generating the LCI and LCA. The input data about raw material, energy, chemical substances, have been collected by direct measurements on machinery, device log, and specifications of the equipment (technical books) and processes. The output data was obtained using SimaPro software connected to internet-specific databases. The purpose of our research has been to study the life cycle assessment of the electroconductive textiles functionalized by RF plasma technology in comparison with classical functionalization treatments.

Keywords: plasma technology, microwave, microparticles, electroconductive, LCA, textile

INTRODUCTION

The recent studies concerning the harmful effect of chemicals for health, land, water, air or GES (greenhouse gases) disposal in the atmosphere, conclude that is a direct influence between industrial revolutions and occurrence of the diseases such as cancers and climatic changes. According to Global Climate Report, NOAA, 2018, in 2018, 11 months at global land and ocean level, the temperature departures from average ranked among the five warmest for their respective months. Also, the years 2015–2017 each had a global temperature departure from average that was more than 1.0°C above the 1880–1900 average, a period that represents the pre-industrial conditions [1]. The greenhouse gases such as carbon dioxide, methane, nitrous oxide, and fluorinated gases, when are emitted become trapped in the Earth ‘atmosphere, and therefore, the heat becomes trapped inside greenhouse [2].

However, from the end of the 1700s, the net global effect of human activities has generated a continual increase in greenhouse gas concentrations and global warming of the past 50 years [3–5]. The greenhouse gases affect climate, including surface air and ocean temperatures, precipitation, and sea levels. Besides, human health, agriculture, water resources, forests, wildlife, and coastal areas are all vulnerable to climate change [5]. The greenhouse gases remain in the atmosphere for tens to hundreds of years after being released [4–5].

Also, emissions in the atmosphere decrease the ozone layer, and this promotes increased UV-B level that has adverse effects on human health because it generates immune suppression, skin cancers, and cataract [6].

Life Cycle Assessment (LCA) has the objective to study the impact of the products to the nature, health, resources, without geographic borders, in terms of the raw material and energy supplies [6–8]. The first step in obtaining the LCA is to generate the LCI (Life Cycle Inventory) based on input and output data about the processes.

Besides, LCI involves data collection about water, energy, and chemical substances necessary to obtain textiles for antistatic effect. For the evaluation of the life cycle for textiles, products finished using traditional and advanced processes and technologies we consider the following inputs and outputs (figure 1):

– inputs: energy, water, chemical substances (acquisition → production → usage)
– outputs: waste, wastewater, emissions (recycling | reuse)

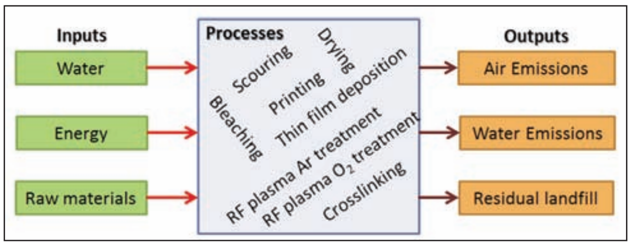

Fig. 1. Simplified map LCI: input-output data and processes

EXPERIMENTAL PART

In order to evaluate the environmental impact of the electroconductive fabrics, were designed the technological flows based on the advanced processes such RF plasma functionalization using oxygen gas, respective argon gas and based on classical processes for copper microparticles deposition using direct printing, film coating and foulard methods. The input data were obtained by life-cycle inventory (LCI) for these processes and inventory of the used resources, taking into account the constraints imposed by the nature of the processes and equipment used.

In order to obtain LCA for fabrics with conductive and antistatic effect, has been designing technological flows based on advanced plasma processes (advanced functionalization by RF plasma generated at low pressure in argon, respectively in the oxygen) and based on classical processes for the copper deposition by foulard method, thin film deposition and direct printing. Requested data for LCA were obtained following the completion of the life cycle inventory (LCI) for these processes and the calculation of the resources used, taking into account the constraints imposed by the nature of the processes and equipment used.

For the conduct of the LCA study by comparing the effect of RF plasma argon with standard treatment, respective by comparing RF plasma oxygen with standard treatment, we have selected several technological flows (TF):

1. Scouring → Bleaching → Drying → RF Plasma (Argon) → treatment by foulard method (Arristan EPD + copper microparticles) → Thermal condensation
2. Scouring → Bleaching → Drying → RF Plasma (oxygen) → thin film deposition (Tubicoat A 41 + Tubivis DL 650 + copper microparticles) → Thermal condensation
3. Scouring → Bleaching → Drying → RF Plasma (Argon) → Printing (Tubifast AS 30 + Tubivis DL 650 + Tubifix ML 55 + copper microparticles) → Thermal condensation

The input data for LCI and LCA, are presented in tables 1–3 for standard technologies for copper microparticles deposition by printing, foulard method, and thin film deposition. Also, data for LCI and LCA concerning RF plasma oxygen and RF plasma argon are presented tables 4–5.

Table 1

INPUT DATA – PRINTING PROCESS		
Data about the industrial process	**U.M.**	**Value**
1. Data about fabric consumption		
Fibrous composition	100% cotton	
Mass	g/m^2	401
	g/ml	602
Mass (the fabric used in the industrial process)	kg	100
2. Data about the printing process		
Printing device	-	-
2.1 Data about chemicals substances consumption		
Tubifast AS 30	kg	0.060
Tubivis DL 650	kg	0.003
Tubifix ML 55	kg	0.0015
Copper microparticles	kg	0.06
3. Data about printing equipment consumptions		
3.1 Water for treatment solution	L	0.176
3.2 Wastewater	L	0
3.3 Process duration	min	3

LCA has been obtained using the program SimaPro7 and the method ECO-Indicator 99 (E)/Europe EI 99 E/E. The method ECO-Indicator 99 provides for the quantification of the environmental impact processes using categories of impact such as: carcinogenic substances, organic and inorganic chemicals harmful by breathing, climatic changes due to the greenhouse effect gases, radiation, ozone layer level, ecotoxicity, acidification/Eutrophication, land use, minerals and fossil fuels consumed for production of electricity [9–10].

For LCA, using SimaPro7 [11–12] can be used in the following methods:

- Normalization method;
- Weighting method;
- Specification method;
- Damage assessment method;
- Characterization method.

Table 2

THIN FILM DEPOSITION PROCESS		
Data about the industrial process	**U.M.**	**Value**
1. Data about fabric consumption		
Fibrous composition	100% cotton	
Mass	g/m^2	401
	g/ml	602
Mass (the fabric used in the industrial process)	kg	100
2. Data about the thin film deposition process		
Thin film deposition device	-	-
2.1 Data about chemicals substances consumption		
Tubicoat A41	kg	0.12
Tubivis DL 650	kg	0.0027
Copper microparticles	kg	0.06
3. Data about thin film deposition equipment consumptions		
3.1 Water for treatment solution	L	0.117
3.2 Wastewater	L	0
3.3 Process duration	min	3

Table 3

FOULARD METHOD PROCESS		
Data about the industrial process	**U.M.**	**Value**
1. Data about fabric consumption		
Fibrous composition	100% cotton	
Mass	g/m^2	401
	g/ml	602
Mass (the fabric used in the industrial process)	kg	100
2. Data about foulard process		
Thin film deposition device: – Power	kWh	0.15
– Time	min	1
2.1 Data about chemicals substances consumption		
Arristan EPD + 20g/l Cu	kg	0.048 + 0.012
3. Data about foulard equipment consumptions		
3.1 Water for treatment solution	L	0.6
3.2 Energy	kW	0.0025
3.3 Wastewater	L	0
3.4 Process duration	min	1

Table 4

RF PLASMA OXYGEN PROCESS		
Data about the industrial process	**U.M.**	**Value**
1. Data about fabric consumption		
Fibrous composition	100% cotton	
Mass	g/m^2	401
	g/ml	602
Mass (the fabric used in the industrial process)	kg	100
2. Data about the RF plasma oxygen process		
RF plasma device: – Power	kWh	4.16
– Time	min	5
2.1 Data about chemicals substances consumption		
Oxygen gas	g	67
3. Data about foulard equipment consumptions		
3.1 Water for treatment solution	L	0
3.2 Energy	kW	21
3.3 Wastewater	L	0
3.4 Process duration	min	5

Table 5

RF PLASMA OXYGEN PROCESS		
Data about the industrial process	**U.M.**	**Value**
1. Data about fabric consumption		
Fibrous composition	100% cotton	
Mass	g/m^2	401
	g/ml	602
Mass (the fabric used in the industrial process)	kg	100
2. Data about the RF plasma oxygen process		
RF plasma device: – Power	kWh	4.16
– Time	min	10
2.1 Data about chemicals substances consumption		
Argon gas	g	130
3. Data about foulard equipment consumptions		
3.1 Water for treatment solution	L	0
3.2 Energy	kW	41
3.3 Wastewater	L	0
3.4 Process duration	min	10

In figure 2 is presented the comparative LCA for cotton fabric functionalization by RF plasma, generated at low pressure in argon (Ar), and treated with a copper microparticles by foulard method (technological flow no. 1), vs. cotton fabric functionalization by RF plasma, generated at low pressure in oxygen (O2), and treated with copper microparticles by thin film deposition method (technological flow no. 2). In the case of comparative analysis of LCA for technological flow no. 1, and technological flow no. 2, it should be noted that in the case of technology no. 1, based on the RF plasma Ar and foulard method, the impact is 100 % on all categories of impact (carcinogenic substances harmful, harmful chemicals through breathing, radiation, climate change, ozone depletion, ecotoxicity and consumption of fossil fuels necessary for producing electricity) and technology no. 2, based on RF plasma O2 and thin film deposition, the

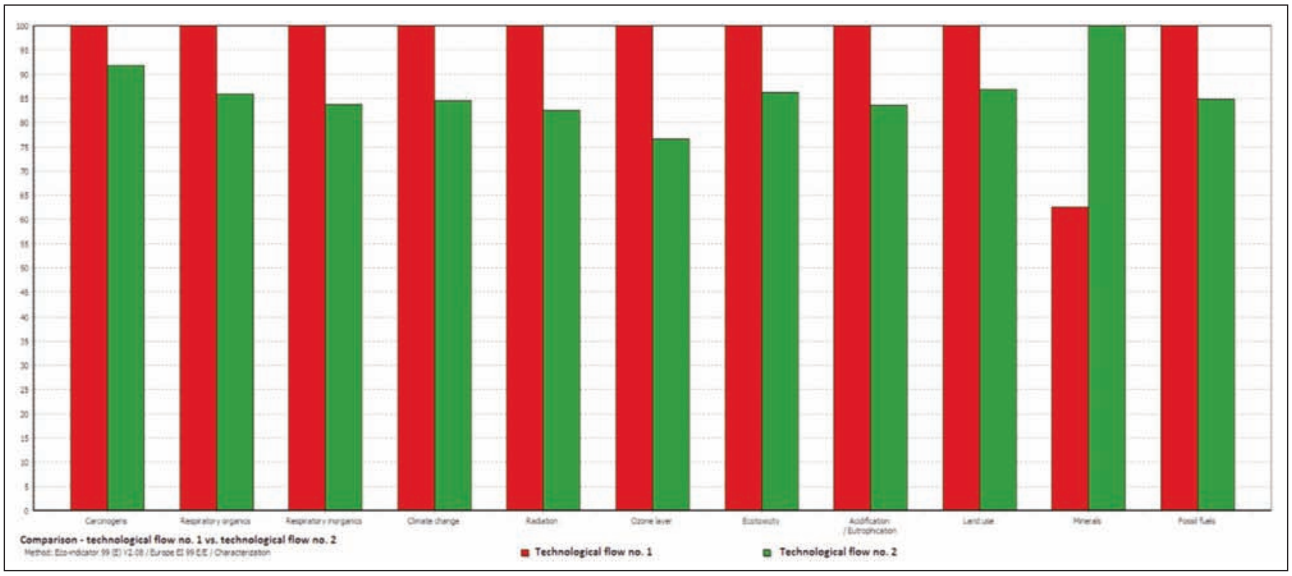

Fig. 2. Characterization method: comparative LCA – Technological Flow no.1 vs. technological flow no. 2

impact is less than 25% for the same categories of impact. The technological flow no. 2 has the value of impact 100% for the consumption of minerals, while for the technological flow no. 1 (TF no. 1) the impact on the consumption of minerals is 35% smaller.

In figure 3 is presented the histogram of the comparative LCA for cotton fabric functionalization by RF plasma Ar, and treated with copper microparticles by the foulard method (technological flow no. 1), vs. cotton fabric functionalization by RF plasma Ar and treated with copper microparticles using the printing method (technological flow no. 3). Analyzing LCA for TF no. 1 vs. TF no. 3 we mention that in the case of TF no. 1, the impact is 100% on seven categories of impact (organic and inorganic chemicals with harmful effect through breathing, radiation, climatic changes due to CO_2 emissions, ozone level, increase the acidity of the atmosphere because of greenhouse gases emissions and consumption of fossil fuels for the electricity production) and for the TF no. 3 the impact is less than 5% for the emitted radiation, respectively, with 15% less on ozone level minimizing. In the case of TF no. 1 the impact is less than 37% for the carcinogenic substances in comparison with the case TF no. 3, with 13% less than for ecotoxicity, and with 53% less than for minerals consumed.

In figure 4 is presented the histogram of the comparative LCA for cotton fabric functionalization by RF plasma O2 and treated with copper microparticles by the thin film deposition method (TF no. 2), vs. cotton fabric functionalization by RF plasma Ar and treated with copper microparticles printing method (TF no. 3). Within the framework of the histogram shown in figure 4, is highlighted the impact on the environment for the TF no. 2 in comparison with the TF no. 2.

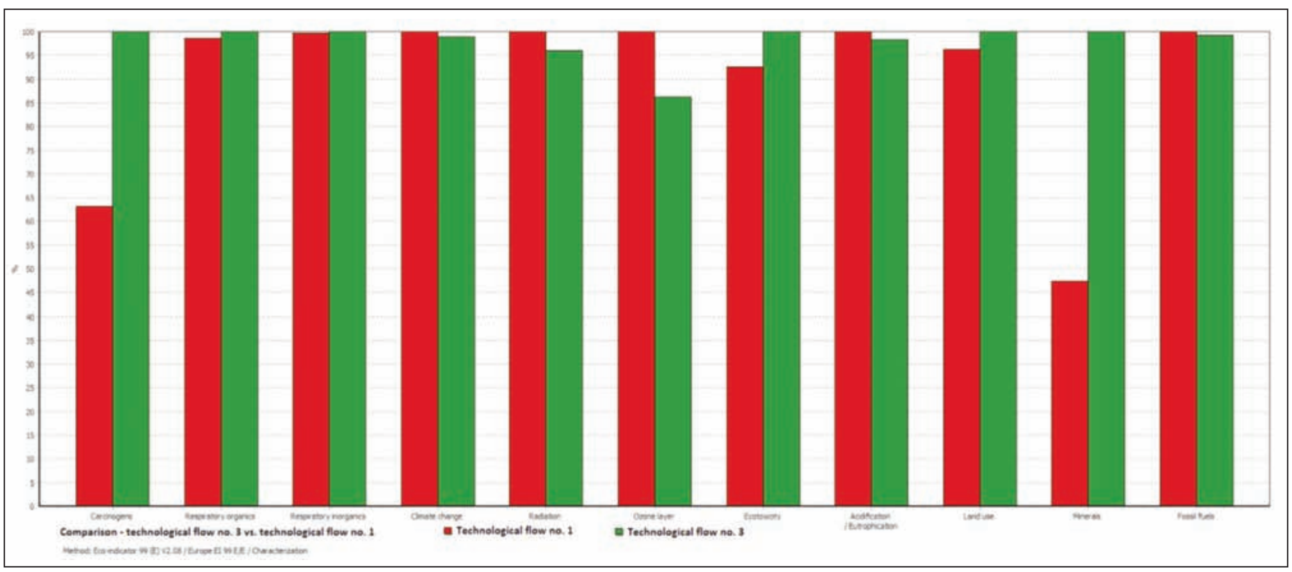

Fig. 3. Characterization method: comparative LCA – Technological Flow no.1 vs. technological flow no. 3

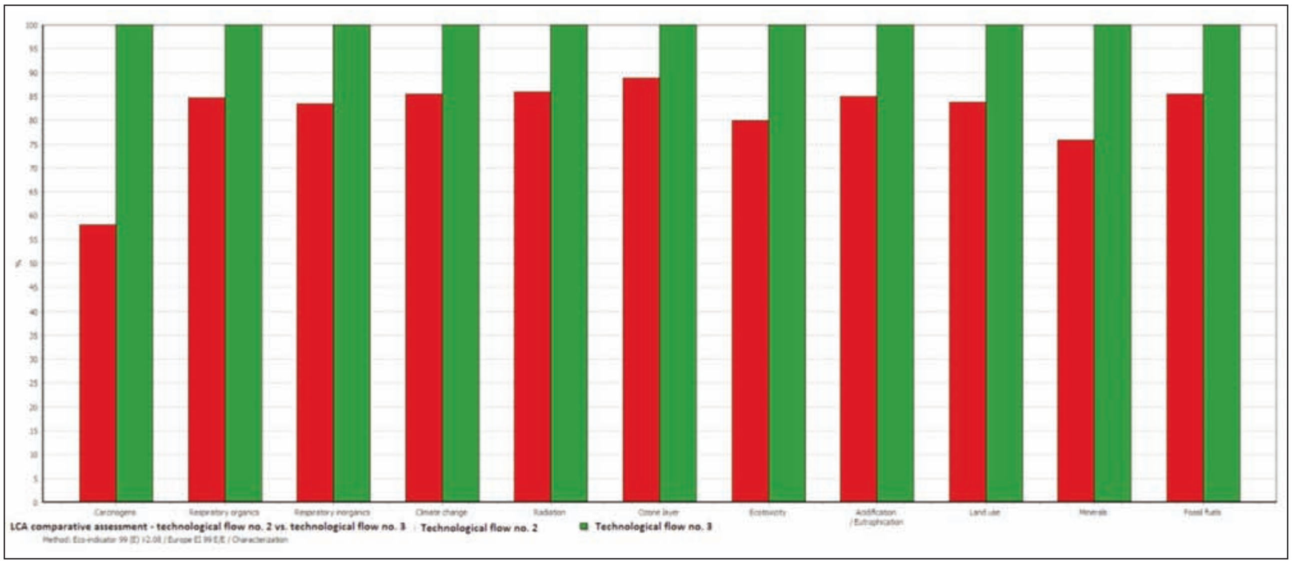

Fig. 4. The histogram of the comparative LCA – Technological flow no. 2 vs. technological flow no. 3

Therefore in comparison with the TF no. 3, TF no. 2 has an impact with more than 42 % in carcinogenic substances and with 15–17% less than in organic and inorganic chemicals with harmful effect by breathing. TF no. 2 has an impact with approximately 15% less than TF no. 3 in the radiation and climate change, with 11% less on the reduction of the ozone layer, with 15% less in atmosphere acidification, with 20% less on ecotoxicity, with 16% less on the land use, with 25% less than on the minerals and with 15% less than in fossil fuels consumption for electricity production.

In the case of TF no. 2 (for thin film deposition), the energy consumption and the gas is 50% less than TF no. 1 and TF no. 3, because it uses the RF plasma O2 it is used just for 5 min, and the water consumption (0.117 l) is more than 80.05% compared to consumption that corresponds to TF no. 1 (0.6 l), i.e., with the 9.83% less than TF no. 3 (0.176 l).

CONCLUSIONS

By analyzing the TF no. 3, we can mention that RF plasma Ar presents an electricity consumption by 50% higher than the TF no. 2 and water consumption with 70.67% higher than TF no. 1. By analyzing the comparison between the 3 TFs, we conclude that the TF no. 1 has the most significant environmental impact due to the massive consumption of water, electricity, and gas. It can be concluded that the TF no. 2 has the lowest impact on the environment.

The classic processes based on the foulard method generates toxically vapor, heat, and wastewater, while RF plasma does not generate wastewater generate some harmful emission discharged in the atmosphere. In comparison with the traditional process, the technology RF plasma is more expensive as device and maintenance, and request high-qualified engineers, but is more efficient in cleaning and functionalization of the surface, being less time consuming and zero wastewater generators in comparison with classic surface activation.

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Authors:

RALUCA MARIA AILENI
RAZVAN ION RADULESCU
LAURA CHIRIAC
LILIOARA SURDU

National Research & Development Institute for Textiles and Leather,
Lucretiu Patrascanu no.16, 030508 Bucharest, Romania

Corresponding author:

RALUCA MARIA AILENI
e-mail: raluca.aileni@certex.com