ENVIRONMENTAL IMPACTS OF VACUUM COATINGS USED IN THERMAL COLLECTORS

Pierre J. D'Ans (1)(a), Cédric Boly (1), Gilbert G. Descy (2) and Marc Degrez (1)

(1) Université Libre de Bruxelles (ULB), 50 Av. FD Roosevelt, CP194/3, 1050 Brussels, BE

(2) European Sopro Energies, 39 Parc Industriel, 5580 Rochefort, BE

(a) Corresponding author: pdans@ulb.ac.be, +32 (0)2 650 30 28

Abstract

Thermal collectors are widely used to produce sanitary hot water and are expected to provide more and more thermal energy to the heating system of buildings in the near future. Their main component is a thermally conductive panel aimed at: (i) converting light into thermal energy and (ii) extracting thermal energy and transporting it to a heat storage unit, using a fluid and forced convection.

Few materials can fulfill both objectives. Generally, objective (ii) is met using a metallic substrate like copper while objective (i) is reached using a "selective coating". Such a coating, and more generally surface treatments, may be energy-consuming. Besides, they are often associated with liquid pollutions, especially due to surface preparation. However, LCA data concerning surface treatments are still scarce and many of them left yet undocumented.

In this work, we present LCA for a coating dedicated to absorb light in a thermal collector. The coating process consists of a semi-continuous physical deposition. The study includes:

- The inventory of inputs and outputs of a coating chain, including surface preparation (degreasing, etching) and estimates for the target consumption.
- An impact assessment, using Impact 2002+; one stresses the influence of the batch size (i.e. amount of coated square meters), since launching a new production has a significant impact.

Results are expressed per m² of coated sheet and incorporated in a complete collector study. The coating represents less than 2 % of hot water production impact, for all damage categories. The main contributions are the electricity consumption necessary for the vacuum and, to a lesser extent, the steel sheet used to "tune" the process.

Keywords

Metal finishing; vacuum coating; scale effect; solar energy; thermal collector.

IMPACTS ENVIRONNEMENTAUX DE DÉPÔTS SOUS VIDE UTILISÉS DANS LES CAPTEURS SOLAIRES THERMIQUES

Pierre J. D'Ans (1), Cédric Boly (1), Gilbert G. Descy (2) and Marc Degrez (1)

(1) Université Libre de Bruxelles (ULB), 50 Av. FD Roosevelt, CP194/3, 1050 Brussels, BE

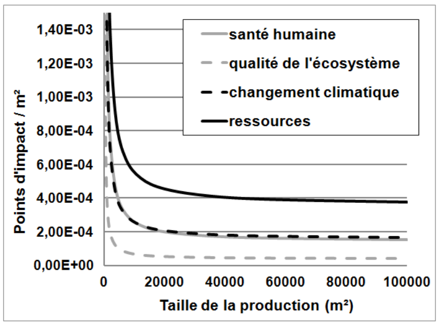
(2) European Sopro Energies, 39 Parc Industriel, 5580 Rochefort, BE

Les capteurs solaires thermiques servent couramment à la production d'eau chaude sanitaire et interviendront prochainement dans le chauffage central. Leur composant principal est un panneau conducteur thermique destiné à : (i) convertir la lumière en énergie thermique et (ii) extraire l'énergie thermique, ainsi que la transporter vers une unité de stockage, par convection forcée d'un liquide.

Peu de matériaux atteignent ces deux objectifs. Généralement, l'objectif (ii) est atteint au moyen d'un substrat métallique, comme le cuivre, tandis que l'objectif (i) est atteint par un « revêtement sélectif », agissant idéalement comme un corps noir vis-à-vis du spectre solaire, et comme un miroir pour les rayons infrarouges. Un tel revêtement, et, plus généralement, les traitements de surface, sont considérés comme énergivores. De plus, ils sont souvent associés à des pollutions liquides, en particulier lors de la préparation des substrats. Pourtant, les données ACV sur ces traitements restent rares, et bon nombre d'entre eux ne sont pas répertoriés dans les bases de données.

Dans ce travail, nous présentons l'ACV d'un revêtement sélectif. Le procédé consiste en un dépôt physique en phase vapeur (PVD) semi-continu. L'étude comprend :

- L'inventaire des intrants et des sortants d'une chaîne de production industrielle, y compris la préparation des surfaces (dégraissage, décapage) et une estimation de la consommation des « cibles » métalliques.
- Le calcul des impacts, par la méthode Impact 2002+. Dans l'étude de sensibilité, l'accent est mis sur l'impact du lancement d'une série, et sur l'importance de produire des grandes séries pour réduire l'impact par m² traité.



Les résultats sont ramenés au m² de feuille métallique traitée et incorporés dans une étude plus large sur les capteurs solaires entiers. Le revêtement représente moins de 2 % de l'impact de la production d'eau chaude, toutes catégories d'impacts confondues. Les principales contributions sont la consommation électrique nécessaire à la mise sous vide et, dans une moindre mesure, la feuille d'acier « sacrifiée » pour régler le procédé, lors du lancement d'une nouvelle série. La figure ci-jointe illustre l'influence de la taille des séries sur l'impact par m² de revêtement produit.

Mots-clefs

Finition des métaux ; revêtement sous vide ; effet d'échelle ; énergie solaire ; capteur solaire thermique.

ENVIRONMENTAL IMPACTS OF VACUUM COATINGS USED IN THERMAL COLLECTORS

Pierre J. D'Ans (1)(a), Cédric Boly (1), Gilbert G. Descy (2) and Marc Degrez (1)

(1) Université Libre de Bruxelles (ULB), 50 Av. FD Roosevelt, CP194/3, 1050 Brussels, BE

(2) European Sopro Energies, 39 Parc Industriel, 5580 Rochefort, BE

(a) Corresponding author: pdans@ulb.ac.be, +32 (0)2 650 30 28

1. INTRODUCTION

Thermal collectors are expected to provide more and more thermal energy to the heating system of buildings in the near future [1]. The main component of the collector is the absorber, aimed at: (i) converting light into thermal energy and (ii) extracting thermal energy and transporting it to a heat storage unit, using forced convection. Objective (ii) is met using a thermally conductive substrate like copper, while objective (i) is met using a "selective coating", ideally acting like a black body in the solar spectrum wavelengths and as a mirror in the long infrared wavelengths spectrum.

If significant LCA data can be found for the most important collector components [2-7], they are mostly missing for selective coatings. An exception is the Ecoinvent database v2.2 [7], where some data is available, but for very specific treatments.

Some papers apply LCA to surface treatments for other applications. Moign has studied several surface treatments, mainly based on lab measurement. He compared copper coatings deposited by PVD, HVOF and electrochemical process [8], and with some coworkers, several nickel coatings: electroplating, wire arc, plasma spray, HVOF and cold spray. The "best" choice strongly depends on the operating parameters [9]. They also examined other technological options for plasma-sprayed zirconia [10]. Other studies deal with aluminum anodizing [11] and alternative treatments for Cr(VI)-based hard electrolytic coatings, like a plasma-sprayed NiCrBSi coating. In the latter case, additional considerations on corrosive and tribological properties were necessary to achieve the study objectives [12,13].

Surface treatments raise some methodological questions like:

(i) What is the influence of batch size and varying practices amongst producers on the total impacts?

(ii) Can the above mentioned parameters be neglected in LCA, in some applications?

(iii) Can the coating base materials be neglected from the inventory; if not, how to account for their specificities?

(iv) How to account for the coatings tailored properties that make comparative LCA more complicated?

In this work, a selective PVD coating is examined w.r.t. questions (i-iii).

2. SCOPE, FUNCTIONAL UNIT AND METHODOLOGY

This study was performed in order to provide a bigger study on thermal collectors and heat storage with data on used materials. In addition, some considerations on eco-design of surface treatments are addressed.

Field data are from a semi-continuous coating chain in Belgium in 2011. The factory is described in §3. Detailed inventory data (LCI) are proprietary. The collection of input and output data of the production chain includes surface preparation and estimates for the consumption of the target (metallic commodity used in vacuum coatings). Due to the influence of the batch size (i.e. amount of coated square meters), LCI data from the startup process are separated from the steady-state data.

The functional unit is 1 m² of coated copper sheet. The results are expressed per kWh of produced hot water, to allow some comparisons. Life-cycle inventory analysis (LCIA) was performed using generic data from EcoInvent 2.2. The impact assessment was performed with Impact 2002+ method [7].

3. PROCESS DESCRIPTION AND LCI

The production chain comprises three zones (fig. 1). The operations consist of 4 steps, during which each zone is switched on or off (table 1). The operations start by generating the vacuum in the « vacuum » zone, then by cleaning the metallic targets using argon sputtering. During parameterization, a dummy steel sheet is coated, until a satisfactory quality is achieved. The three zones are then in operation. In the preparation zone, the sheet is cleaned using soda solution and rinsed 4 times. Wastewater is sent to the sewage treatment. In the vacuum zone, argon generates the plasma, while oxygen is the reactive gas. A metal-oxygen coating is obtained. The coated sheet is recycled in electric steel process. When starting production, steel is replaced by copper. The conditioning zone finally extracts the sheet with a bobbining system and covers it with a high density polyethylene film (HDPE).

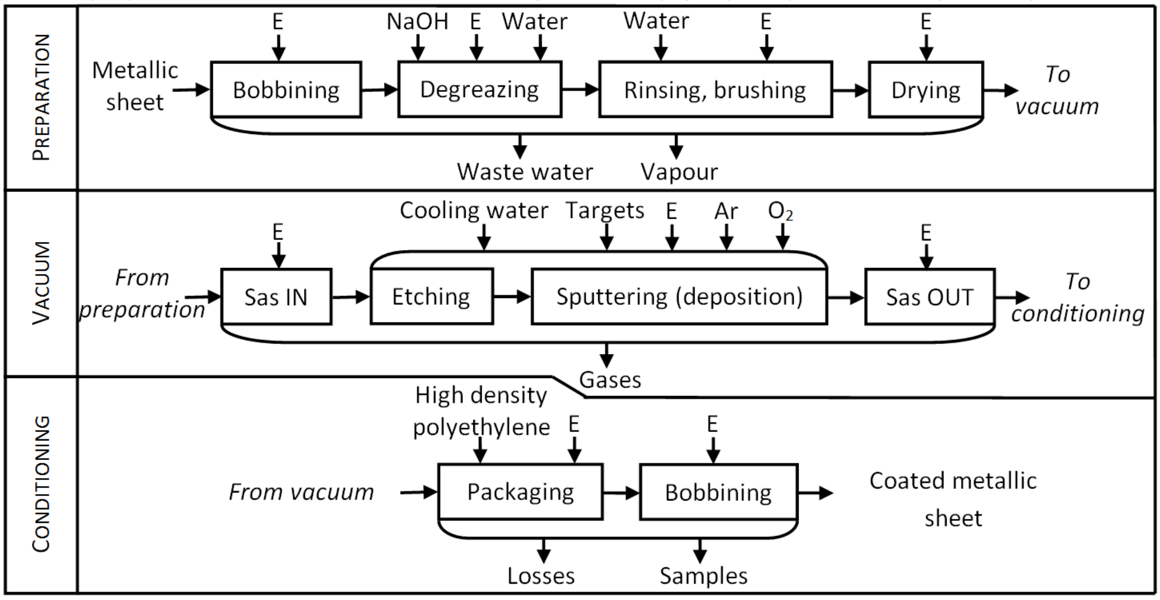


Figure 1: process zones, inputs and outputs (“E” denotes electrical power)

To obtain inventory values, the main assumptions were:

- The copper sheet is excluded from the calculation, since the functional unit is the coating itself. However, since steel is lost during processing, it is included in LCI.
- Gas losses (mainly Ar, O_2, H_2O, N_2) are harmless and were not accounted.
- Samples extracted for quality control were neglected.
- Consumption of the target is an estimate based on the coating thickness e, the treated surface S, the metal density in the coating ρ (kg metal per m³), the fraction of used target at its end of life η_1 and the sputtering yield η_2:

$$m = \frac{eS\rho}{\eta_1 \eta_2} \tag{1}$$

Table 1: Definition of the process steps

Zones:	Vacuum step	Targets cleaning	Parameterization	Production
Preparation			X	X
Vacuum zone	X	X	X	X
Conditioning			X	X

Gas consumption was assessed by comparing the indications on the gas cylinders before and after campaign, and using the ideal gas law. Electrical power was monitored for each process step and zone using electricity meters.

4. LCIA AND DISCUSSION

The main assumptions for LCIA are:

- The exact composition and processing for the targets are unknown; LCIA data are those corresponding to the metallic content.
- The HDPE film processing is unknown; the calculation is based on HDPE granules.
- The steel mix is European; the electricity mix is Belgian.

The three first process steps (setting the vacuum, cleaning the target and parameterization) represent the main contribution to the total impact for all impact categories (fig. 2). In terms of commodities, electrical power represents more than 75% of the climatic impact, followed by the dummy steel sheet used for parameterization (fig. 3). Other contributions are negligible. Using steel for this step instead of copper is environmentally more suitable. The “vacuum step” is the most electricity consuming (3.7 kWh/m² for a total of 9.7 kWh/m²). Next follows sputtering. This contrasts with Moign’s results, who reports high metal losses in his PVD process, but little pumping impact [8]. Eco-design would thus carefully design the vacuum system and then focus on increasing the produced amount of coating, once the system is under vacuum and parameterized. The expected benefit of increasing the produced amount is illustrated in fig. 4, where the impact per m² was modeled by considering a constant part in the batch impact (vacuum, etching, parameterization) and a variable part (production). For instance, increasing the batch size from 2000 to 20 000 m², decreases the climatic impact by a factor > 3.

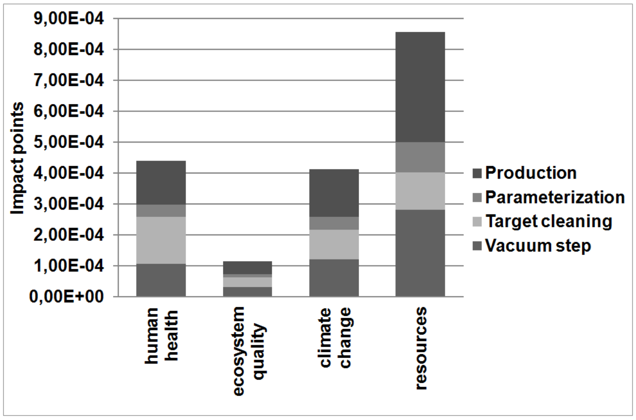


Fig. 2: impact of the process steps.

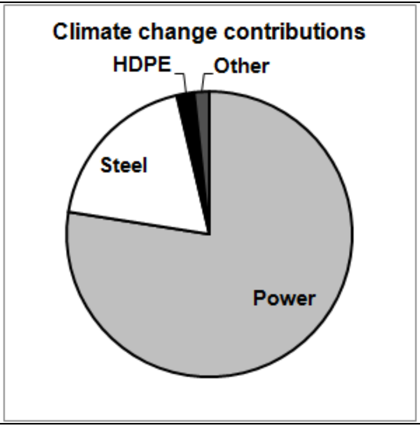


Fig. 3: contribution of commodities.

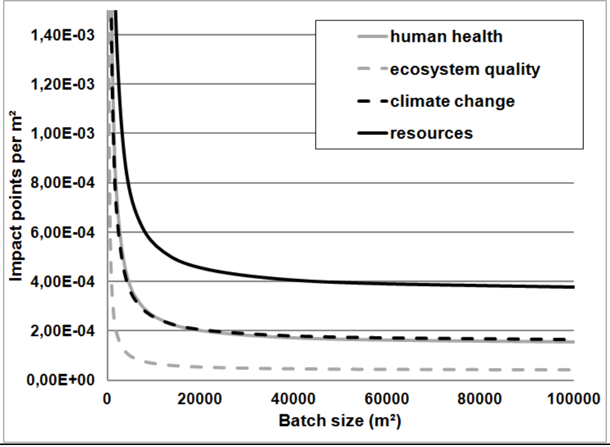


Fig. 4: influence of the batch size on the coating impact (extrapolation).

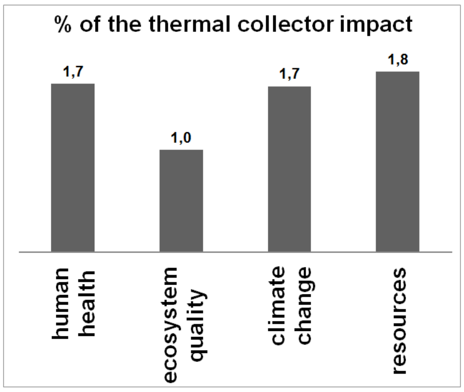


Figure 5: fraction of the collector impact due to the coating.

Does the coating represent a significant part of the hot water provision impacts? LCA for solar heat was made and the ratio between the coating and the collector impacts was calculated (fig. 5). Even if the collector has a low impact, compared with other heat sources, the coating impact represents less than 2 % of the total, which is more affected by the collector frame, the pumping system or the holders.

5. CONCLUSIONS

(i) The main impacts are the electrical energy to produce vacuum and target sputtering during deposition, plus the dummy steel used for parameterization.

(ii) The impacts can be reduced by economies of scale. More generally, this suggests an LCA investigation of the influences of multiplying highly customized products, instead of proposing a reduced selection of environmentally optimized products.

(iii) The coating impact is < 2% of the total collector impact.

ACKNOWLEDGEMENTS

The authors acknowledge the Walloon Region and the Mecatech Pole, for a “Plan Marshall” funding. They also acknowledge the industrial partners who gave them full access to their processes, but who are not named for the sake of confidentiality.

REFERENCES

[1] SOLAUTARK project, information on: www.solautark.com

[2] S. Mirasgedis, D. Diakoulaki and Assimacopoulos, D., Renew. Energ. **7** (1996) 329-338

[3] S.A. Kalogirou, Energy Conversion and Management **45** (2004) 3075-3092

[4] F. Ardente, G. Beccali, M. Cellura and Lo Brano, V., Renew. Energ. **30** (2005) 1031-1054

[5] F. Buttinger, *Entwicklung eines konzentrierenden Vakuum-Flachkollektors zur Prozesswärmeerzeugung (PhD thesis)*, Technischen Universität München, 2009.

[6] G. Tsilingiridis, G. Martinopoulos and Kyriakis, N., Renew. Energ. **29** (2004) 1277-1288.

[7] Ecoinvent Centre (2007), ecoinvent data, v2.2. ecoinvent reports No.1-25, Swiss Centre for Life Cycle Inventories, Dübendorf, 2007, retrieved from: www.ecoinvent.org.

[8] A. Moign, ‘Analyse du Cycle de Vie de procédés de traitement de surface des matériaux’, in: Proceedings of « Matériaux 2010 », Nantes, 2010, paper 405.

[9] A. Moign, A. Vardelle, J.G. Legoux and Themelis, N.J., ‘LCA comparison of electroplating and other thermal spray processes’, in: Proceedings of the ITSC, Las Vegas, 2009 (ASM International) 1207-1212.

[10] A. Moign, A. Vardelle, N.J. Themelis and Legoux, J.G., Surf. Coat. Technol. **205** (2010) 668-673.

[11] E. Harscoet and Froelich, D., J. Clean. Prod. **16** (2008) 1294-1305

[12] N. Serres, F. Hlawka, S. Costil, C. Langlade, F. Machi and Cornet, A., Surf. Coat. Technol. **204** (2009) 187-196.

[13] N. Serres, F. Hlawka, S. Costil, C. Langlade and Machi, F., Surf. Coat. Technol. **205** (2010) 1039-1046.