Proceedings of SEEP2014, 23-25 November 2014, Dubai

THERMOGRAPHY INCREASES LCA RELIABILITY: A CASE STUDY OF A PROCESS FOR HDPE NETS

F.Intini[1*], M.Chimienti[2], M. Dassisti[3], L. Ranieri[4], G. Starace[4]

[1]DICEM, Università degli Studi della Basilicata (francesca.intini@unibas.it)
[2]Scientific Manager of Laboratorio Kad3 Scarl
[3] DMMM, Politecnico di Bari
[4]DII, Università del Salento, Italy

Abstract
Assessing sustainability of manufacturing processes through LCA tools is a common approach today, but it suffers some limitations, mainly due to the use of standard databases. Deepening the assessment of sustainability is, instead, a new field of interest. This paper shows how LCA can be optimized, based on the results of a thermographic analysis supplying detailed information to a traditional LCA tool. The aim is to test this this approach observing a real industrial case of an Italian company producing High Density PolyEthylene (HDPE) nets for agriculture. A thermographic analysis of the critical processes helps in assessing the in-progress eco-profile of the process under investigation. The approach is intended as an iterative procedure to make both LCA analysis much more pertinent to the specific application and decisions on process sustainability more adherent to real practice. The improved LCA allowed to balance the specific energy savings intervention (recognized by the grace of thermographic analysis) by benchmarking the potential process quality improvements with standard reference processes. These balanced design choices and improvements can avoid useless over-dimensioning of the devices. In turn this can help to reach sustainable quality of both products and processes.

Keywords: LCA, Woven net, Thermography, Agriculture.

1 INTRODUCTION

Life Cycle Assessment (LCA) method is one of the most internationally recognized approach for environmental assessment of products and processes. The two most important features of LCA are the analysis from 'cradle-to grave' and the use of a functional unit for comparative studies [1]. Several LCA methodologies have been developed and somewhat matured during the last decades: say, attributional and consequential, hybrid, and I/O LCA's [3]. Current activities regarding databases, quality assurance, consistency, and harmonization of methods contribute to this maturation process.

The retrospective use of LCA has an accounting perspective while its prospective use is adopted for modelling the effects of changes [2]. While it is clear that the choice of elements of the physical system to be modelled depends on the definition of the goal and scope of the study [4], this process still remains subjective, since ideally all flows should be followed until they are elementary, i.e., up to the boundaries of the technical system. As a consequence, typically analysts neglect flows mainly for their relevance in terms of quantities (accounting perspective) more than the potential effects (impact perspective).

LCA provides the basic modelling framework for evaluating the environmental load and impact throughout the entire process life cycle, from material acquisition to disposal.

The main drawback of LCA is the fact that databases, to which they are referred, cannot be considered as a standard for a particular process, since they cannot take into account the context they are in. Accordingly, it is clear that LCA might serve as one possibility for assessing process sustainability, i.e., a benchmark to contextualize specific assessments of sustainability related to efficiencies or to other technical problems appreciated on site with appropriate approaches.

One interesting advantage of using LCA approach is actually endeavoring the standardization of process perception, that can be important in effectively comparing different operating (or even design) solutions.

The aim of the paper is to present a novel approach to address production processes sustainability by means of an improved LCA analysis, where regular data coming from standard databases are fostered by dynamical process-footprint information derived from a thermographic analysis.

This approach is presented by referring to a real industrial case concerning a manufacturing process of plastic nets for agriculture. Products are made of high density polyethylene (HDPE) yarns twisted to form a woven or knitted fabric that consists of a regular porous geometrical structure allowing fluids to pass through. Plastic nets are used for the protection from hail, wind, snow, or strong rainfall in fruit-farming and ornamentals; shading nets for greenhouses and nets moderately modifying the microenvironment around a crop are the most common cases. Nets for the protection against virus-vector insects and birds, as well as for harvesting and post-harvesting practices, are also widely used [5].

2 THERMOGRAPHY FOR ENERGY ASSESSMENT OF STANDARD PROCESSES THE CASE STUDY

Thermography is a measurement technique that allows to investigate complex temperature fields by means of infrared radiation collection. Based on the radiation reaching an infrared detector and after an appropriate determination of the surface properties of the object being observed in terms of its radiosity (that comes from the conjunct effect of body emissivity and reflectivity), a temperature estimation can be done over a wide field of test.

Thermo cameras are measuring instruments that only with a shot (and so with a temperature field image) can give important, extended, and precise (if correctly interpreted and processed) information about the thermal state of the surface of a body. Current available instrumentations developed by major companies, provide image processing tools that allow a careful post processing only limited by the optical used to take the single shot.

In addition, a deep analysis of thermal state can also be associated to the stress state of a body (depending on the transformation of mechanical energy into heat release caused by either friction or hysteresis) or to an increased electrical resistance due to imperfect contacts. Thus, the thermography technique can also be applied for assessing or analyzing the decay related to machines aging or for manufacturing processes.

Thermography can really help since process state changes are always detectable through temperature fields investigations. Isothermal distribution can help, for instance, in highlighting high friction occurring at mechanical connections or in fluid dynamic fields. In a word, this technique, if properly applied, can allow better input to LCA analysis made on a process or even to correct some assumptions concerning its footprint.

A drawback of this technique is that the high quantities of information coming from a single thermographic shot, makes its use hard as an in-line feedback instrumentation capable of direct influence to the process control. In line expert image processing should be needed and high complexity should be reached in recognizing the thermal phenomena to be adjusted in real time.

Pyrometers that acquire point measures about temperature (based on radiation collection as well) are used instead in in-line process management, when even limited intrusion of probes are not admitted in the studied phenomenon.

3 THERMOGRAPHY AND LCA

An industrial case will be here adopted to illustrate how the thermography can supply precise inputs to LCA. In order to assess the sustainability of the net production process under analysis, a standard LCA was performed. The most critical points of the manufacturing process from a sustainable point of view became evident.

A thermographic analysis was then performed to focus possible improvements to the quality of the picture derived from LCA and to have a most effective measure of the whole production process sustainability.

This approach was successful as in the proposed action, recorded temperature fields - over a wide range of inspected areas and the thermal distributions in process fluids on those critical phases - were used to add information about inefficiencies occurring during HDPE monofilaments manu-facturing.

In addition, Standard LCA technique does not allow to capture the dynamical drift of those process parts that are critical to the whole manufacturing activity. By iteratively considering LCA and thermographic information, it becomes possible to be aware of the process evolution, and thus to perform a progressive sustainability of the selected process. At the same time, the technique can be used for benchmarking technical solutions for the manufacturing process, to be compared over their life cycle.

In the next paragraph, the basic assumptions and outcomes of the initial LCA are presented, by focusing on a reference unit of net as process output.

3.1 LCA of the woven net

The LCA model developed seeks to identify the main environmental of a woven net for insect protection, made of HDPE monofilament .

The nets production starts with the HDPE yarn extrusion, quench, stretching, and stabilization. The filaments are then supplied to looms to weave the nets. The main goal of the LCA has been to define the environmental profile of the finished products.

According to the standard ISO 14044, the functional unit is defined as the reference unit through which a system performance is quantified in a LCA. The functional unit, in this case, is an area of 1 m^2 of the agriculture net with a unit mass of 130 g/m^2.

The data were considered on an annual basis and were referred to the year 2011. The geographic location is a production plant in the South of Italy. As for the technological boundaries, five steps of the whole production cycle were analysed:

1. extrusion;

2. quenching, stretching, and stabilization of the monofilament;

3. warping;

4. weaving;

5. finishing and packaging.

The environmental impacts have been assessed starting from the production of raw materials all the way to the end-product manufacturing. This analysis included: extraction and production of raw materials; manufacturing of semi-finished goods; manufacturing of components; manufacturing of resources for packaging (i.e., PE bags, labels, PE film); all transportations and the final use.

Here emissions to ambient air are not present and the very small consumption due to an almost manual installation of the net in the field can be neglected. The nets, at the end of their life, are often reduced to granules and recycled in sectors even different from agriculture. For this reason the end of life is here only qualitatively estimated.

The inputs were allocated on the various production steps according to defined procedures. The allocation was avoided or at least follows a procedure based on the mass criteria. The energy sources break down, according to the loads of each plant. The cut-off criterion established the maximum level of detail. The processes contributing for less than 1% of the total environmental impact for each impact category have been omitted from the inventory (e.g., labels, big bags for waste, etc.). The data collection was performed on site, under the direct supervision of managers responsible of the different plant departments. The analysis uses the Ecoinvent 2.2 database of SimaPro(R) ver. 7.2. A significant portion of electricity, equal to 17%, is produced by a photovoltaic plant (PV) inside the area. In the case of raw materials supplied from abroad, reference was made to the European mix or the energy mix of the country of origin.

As for the transportation, all conveyance from suppliers, internal handling, and movements to the waste treatment plants have been considered.

3.2 Life Cycle Impact Assessment

The general framework of a Life Cycle Impact Assessment (LCIA) method is composed of two mandatory elements (i.e., classification and characterisation) that convert LCI results into an indicator for each impact category. Optional elements (i.e., normalization and weighting) lead to a unique indicator across impact categories using numerical factors based on value-choices.

Results of the LCA are often used for process optimisation. The table below shows the overall impacts of the woven net made of HDPE with unit mass of 130 g/m^2. The impacts assessment according to the CML 2001 scheme is reported in Table 1, in terms of functional unit.

Table 1 Life Cycle Assessment: 1 m^2 of agriculture net (u.f.)

Impact category	Unit	Total
Abiotic depletion	kg Sb $_{eq}$	0.0069
Acidification	kg SO_2 $_{eq}$	0.0021
Eutrophication	g PO_4^{---} $_{eq}$	0.43
Global warming 100y	kg CO_2 $_{eq}$	0.553
Ozone layer depletion 20y	mg CFC-11 $_{eq}$	0.0268
Human toxicity 100y	kg 1,4-DB$_{eq}$	0.062
Photochemical oxidation	g C_2H_4 $_{eq}$	0.014

CML 2001 is an impact assessment method which restricts quantitative modelling to early stages in the cause-effect chain in order to limit uncertainties. Results are grouped in midpoint categories according to common mechanisms (e.g., climate change) or commonly accepted groupings (e.g., ecotoxicity) [6].

The major contribution to Global Warming Potential (GWP) has been found to be the use of HDPE granulates and electricity.

3.3 Thermographic analysis to get improved energy data input to LCA

Thermographic analysis has been here adopted to integrate process information concerning efficiency of the most critical points of the process. Thermography allowed to understand the causes and to evaluate the entities of the thermal inefficiencies on those points of the process recognised as most critical to process sustainability by the LCA analysis: namely, the extrusion and the quenching processes.

For the idea here presented, this action should be performed over time to follow the evolution of the process, so that to appreciate the decay and to consequently react according to the benchmark provided by the LCA analysis. This is actually the main point of the approach here presented that allows to add specificity (i.e., customise) to the LCA analysis, which typically does not reflect the true state of a production system, with its dynamic drifts over time.

For the case here presented, on the other hand, the iteration was not performed because the approach was not definitively implemented in the company. Therefore, the evolutionary image of the process will not be discussed.

In Figures 2, 3, and 4 three thermographic images are reported, referred to the water tanks where the monofilament quenching occurs after the extrusion process. Pictures allow to highlight significant discontinuities into the thermal fields, proofing the existence of potential inefficiency, not easily recognised by the LCA indicators. This is an example of the high potential of the thermography that can be applied to all the sub-processes in the production of the plastic monofilaments.

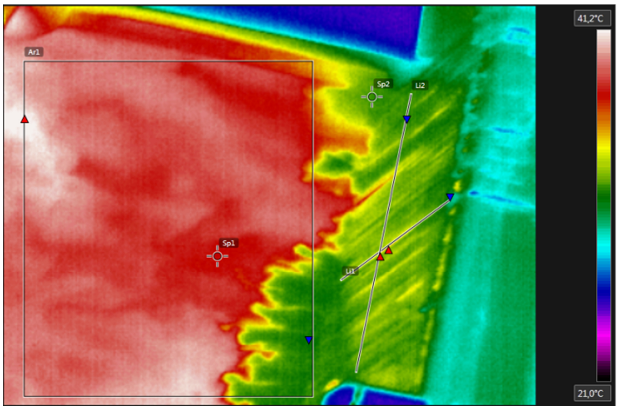

Figure 1: Line 1 (non-optimized) quenching water bath

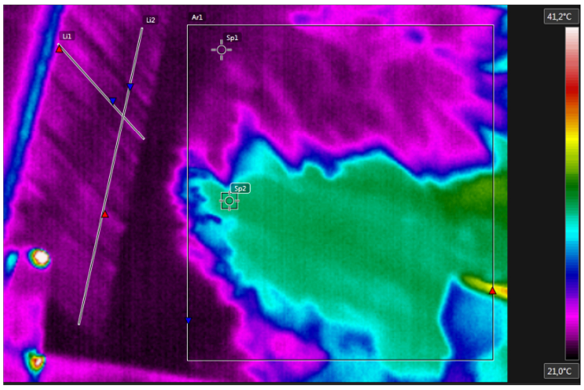

Figure 2: Line 2 (non-optimized) quenching water bath

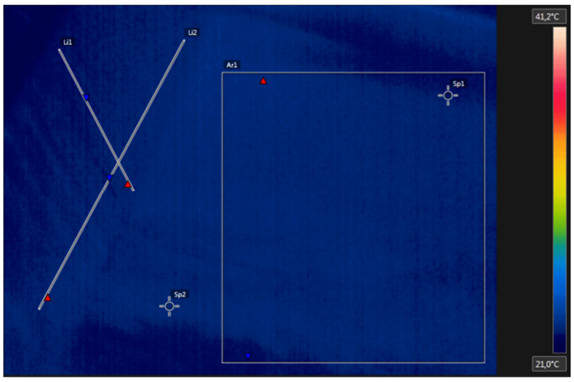

Figure 4: Line 3 (non-optimized) quenching water bath

Figures 2 and 3 are pictures of non-optimized quenching water tanks of two older monofilament production lines (lines 1 and 2, respectively); evident observations can be made about the thermal inefficiencies in comparison with Figure 4 where an optimized quenching water tank of a newer and optimized line (line 3) is shown.

It must be pointed out that all the three lines are supplied by the same cooling water coming from a common cooling system, so that the delivery cooling temperature is perfectly the same. Cooling water flow rates are actually supplied proportional to the HDPE flow rates (number of monofilaments of the same diameter to be produced) having, in this comparison, the same heating cycle to be melted and extruded through the dies. The shell and tube heat exchangers serving the water tanks, are dimensioned in the same way, so that a constant number of transfer unit and approach temperatures are kept the same on the three lines.

Figure 2 represents line 1 water tank seen from a point of view about 2 m up from the water surface. Quenched monofilaments coming out from the tank are on the right and Li1 is a segment that indicates the direction of the out-coming monofilaments. The Li2 segment (perpendicular to the monofilaments direction) shows the temperature difference among the monofilaments exiting the quenching bath. The surface of the water tank is contoured by an area called Ar1 Ar1(see Figure 4). Minimum, average, and maximum temperature are reported in Table 9 together with the correspondent values of the other production lines. Sp1 and Sp2 are spots to get the reader aware of some important temperature levels. The difference between the design temperature of the bath (26°C) and the actual one is evident.

Figure 3 is organized as Figure 2. It shows what happens in the production line 2 quenching water bath seen from a point of view about 2 m up from the water surface. Quenched monofilaments coming out from the tank are here on the left. Li1 and Li2 are segments as depicted in Figure 2. The Ar1 is referred to the line 2 quenching water tank surface as well.

Figure 4 shows what happens in the optimized production line 3 quenching water tank seen from a point of view 2 m up on the water surface as well. Here the temperature distribution is highly uniform and its average level is perfectly consistent with the design one.

The temperature colour range common to the three thermographic images allows to directly inspect the differences in the levels and bath temperatures distributions.

A deep examination of the real configurations in the quenching system considerably helped in assessing exact temperature fields, and thus in benchmarking design temperature distributions and in avoiding thermal insulation defects in this process phase. The findings of this combined analysis led, particularly when performed frequently over defined time intervals, to significant energy savings in the refrigeration management by increasing the temperature setpoint (i.e., the evaporation temperature in a vapour compression refrigeration cycle), being more effective in the temperature levels actually reached.

Further solutions were implemented as the use of free cooling in place of electric refrigerators in winter season when outside temperature made a direct heat transfer to cold air worthwhile.

The energy savings in the new configuration have been measured; savings were found to be around 20%, namely the 10% of the total energy consumption of that extrusion line.

For the simple case here presented, only at the first stage of implementation, thermography has led to a 2% energy saving with respect to the total consumption. Similar optimization actions if performed at a process design stage might allow to achieve savings even higher of those found here (up to 25% of the overall electric energy consumption - 2% in the extrusion phase and 23% in the quenching to winding phase, respectively).

5. CONCLUSIONS

The paper presents a case study of a real industrial application where thermography helped to reach lower environmental impacts measured with the LCA method. This because the experimental analysis supplied environmental calculations with more precise information. This allowed also to detect potential process sustainability evaluation by means of pertinent information added from a thermographic analysis performed on process selected critical phases. Derived information were adequate enough to recognise improvements to reach good environmental product performance.

Thermographic data were helpful to recognise actual inefficiencies in several parts of the complex production process of HDPE monofilaments.

Actual process information are rarely used as input for LCA analyses, provided this methodology is performed by referring to standard databases. Actions consequent to the standard use of LCA are typically less interesting for real processes since they are not referred to actual sustainability performances.The outcomes of an LCA study for a netting company, leader in the production of textiles for agricultural uses, were also discussed. The LCA analysis was performed by quantifying the environmental impacts referred to a standard unit of 1 m^2 of net.

6. ACKNOWLEDGMENTS

The innovative contents described in this paper are disclosed after the permission of Sachim S.r.l company, which committed to Laboratorio KAD3 S.c.a.r.l. the research project called “Analisi di sostenibilità del processo produttivo delle reti in HDPE”, co-funded by Italian Government (Legge 12 luglio 2011, n. 106 – Credito di imposta per le imprese che finanziano progetti di ricerca in Università o enti pubblici di ricerca)”.

REFERENCES

[1] Klöpffer W (2008) Life Cycle Sustainability Assessment of Products. Int J Life Cycle Ass, 13 (2): 89–95 .

[2] Finnveden G, Hauschild MZ, Ekvall T, Guinee J, Heijungs R, Hellweg S, Koehler A, Pennington D, Suh S (2009) Recent Developments in Life Cycle Assessment. J Environ Manage, 91 (1): 1–21.

[3] Tillman AM (2000) Significance of Decision-making for LCA Methodology. Environ Impact Asses 20 (1) (February): 113–123. doi:10.1016/S0195-9255(99)00035-9.

[4] Clements RB (1996) Complete Guide to ISO 14000. Prentice Hall Englewood Cliffs, NJ.

[5] Castellano S, Scarascia Mugnozza G, Russo G, Briassoulis D, Mistriotis A, Hemming S, Waaijenberg D (2008b) Design and use criteria of netting systems for agricultural production in Italy. J Agric Eng, 3:31-42.

[6] Guinée J.B., Gorrée M., Heijungs R., Huppes G., Kleijn R., Koning A. van de Oers L., Wegener Sleeswijk A., Suh S., Udo de Haes H.A., Bruijn H. de, van Duin R., Huijbregts M.A.J. (2002) Handbook on Life Cycle Assessment. Operational Guide to the ISO Standards. I: LCA in Perspective. IIa: Guide. IIb: Operational Annex. III: Scientific Background. Kluwer Academic Publishers, ISBN 1-4020-0228-9, Dordrecht, 692.