ENGINEERING CONTRIBUTIONS TO THE IMPROVEMENT OF LIFE CYCLE ANALYSIS OF METALLIC MATERIALS AND PRODUCTS

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În articol se arată că pentru operaționalizarea standardelor despre ciclurile de viață sunt necesare cunoştinţe noi. Într-un asemenea context în lucrarea de față se abordează următoarele aspecte:

- prezentarea unor scurte observații cu privire la structura şi conținutul actual al LCA;

- prezentarea unor propuneri de perfecționare a conținutului LCA şi a metodologiilor utilizate, se insistă asupra rolului pe care îl au fazele de utilizare şi scoatrea din uz a produsului;

- caracterizarea influenței poluării şi a poluanților de proces asupra componentelor LCA;

- aspecte de natură socială privind ciclul de viață;

The paper notes that operational standards about life cycle are required new knowledge. In such a context the present paper addresses the following issues:

- present some brief observations regarding the structure and actual content of LCA;

- present some improvement proposals for the content of LCA and the methods used, insists on the role of their stages of use and scrapping of the product;

- prove the influence of pollution and process pollutants upon LCA components;

- social aspects regarding life cycle;

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1. Introduction

Worldwide, technologies of manufacturing metallic materials reached a high level of performance within the last decade, proving a great capacity of adjustment to transformations occured in the circumstances imposed to raw materials and energy, in the necessity of increasing productivity and extraction indicators. Also, there is a great importance given to consumption reduction, as well as to complying with certain environment regulations, which are more and

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more severe. Remarcable results obtained in modern plants were due to the implementation of environmental management systems (EMS) in the industrial activity, systems which imposed the analysis, the evaluation and selection of modifications on the level of technologies and installations, from the point of view of specific EMS instruments, among which one of the most complex is undoubtedly Life Cycle Analysis or Life Cycle Assessment (LCA).

Being a relatively new tool for environmental management, LCA represents a support in taking decisions, giving the posibility to select best manufacturing variants, respectively to carry out the most adequate modifications in the actual operating processes, that can lead to consumption minimization and impact reduction upon the environment. As a result, LCA ensures the integration of pollution prevention strategies and resources preservation within the global strategies of carrying out efficient production systems in terms of economic and ecologic aspects.

LCA operationalization on the level of an institution is made by complying with the provisions of an important number of standards: ISO 14040 – ISO 14043 [1]. However, more and more specialists argue for the difficulty and complexity of bringing into force these standards and there will be many years until necessary information is gathered in order to make complete the data basis which is nedeed for LCA performance to various industrial products [3]. In such circumstances, in order to have fast but scientifically proven appreciations, about LCA, in the metallurgic area there is the need to adjust some simplified methodologies which might help in drawing the right conclusions about the importance of LCA components.

Starting from the above mentioned premises, the present paper will:

- present some brief observations regarding the structure and actual content of LCA;
- present some improvement proposals for the content of LCA and the methods used;
- prove the influence of pollution and process pollutants upon LCA components.

2. Brief observations regarding the objectives, structure and actual content of LCA

See below some opinions regarding the current knowledge of LCA.

- It has to be mentioned that in Romanian literature LCA is also known as evaluation of life cycle (ECV).[2]. The present paper will use the LCA term.
- Current standards recommend to have in view the global life cycle, which, might have its structure made up of the following stages for the industrial area: [5,6,4]

- structure - development, which refers to the outline of resources and materials;
- product design, which considers the product's model design, the technologic project and the development project;
- product manufacture (description of product manufacturing procedure);
- usage, which refers to the moment when the product fulfills the needs for which it was manufactured (performance of product's functional size);
- after-usage, particularly referring to reintegration of secondary materials, by means of 3Rs policy (recirculation, recycling, regeneration);
- neutralization (idleness) requires toxic wastes handling in order to annihilate a possible negative impact upon the environment;
- storage means storing unrecoverable wastes in specially designed places so that the quality of the environment is not affected.

• It is admitted that there are partial life cycle analysis, without making any remarks for particular cases;
• Requirements of the standards refer particularly to processes and installations which generate new products;
• Referring to the industrial domain, standards pay attention particularly to the product manufacturing stage;
• Typical analysis of life cycle does not consider economic or social aspects of the process or product.

3. Some conclusions and improvement proposals for the content of LCA

See below some suggestions regarding the possibility to improve LCA usage in real analysis.

• An accurate definition of the LCA objectives is essential, especially when it is important to take a fast decision, focusing all the efforts on the critical areas, which leads to an increase of the efficiency of the optimization analysis.
• In the case of very complex problems, taking a fair decision can be done only when they are divided into distinct parts that can be easily characterized. The best results are acquired when attention is focused on important elements and the analysis of the connection between these ones and their effects upon the environment is conducted in a logical way.
• The development of the analysis on the entire life cycle will provide the greatest opportunities of impact reduction, thus, when an analysis is conducted, one usually starts from the premises of carrying out this type of analysis. A complete analysis is not always required, in some cases a partial analysis may be the right option, therefore ignoring insignificant stages.

- The degree of itemizing the analysis is strongly connected to the objective set in the beginning of the analysis. In relation with this objective, the life cycle analysis can focus on:
  - an entire life cycle;
  - a partial cycle;
  - independent activities or stages;
- LCA methodology has to be ready to include new scientific discoveries and to improve analysis procedures.
- Based on the above mentioned, at least for the metallurgic industry, one recommends a partial life cycle analysis, that can be structured on the following stages:
  - product manufacturing;
  - product use;
  - reintegration of auxiliary materials;
- Product manufacturing is usually characterized by the fact that it brings the most significant contribution to energy and raw materials consumption and also by the fact that it has the most relevant impact upon environmental factors. Generally, the process of product manufacturing and particularly, the process of metallic products manufacturing is involved in air, water and ground pollution, thus resulting various consequences. This assertion explains the reason why in LCA a great attention is paid especially to this stage.
- Product use stage affects to a lesser extent the environment and human health. Only after the product ends its life cycle, it contributes towards wastes storage, if the product cannot be re-used. Generally, worn-out metallic products do not create such problems due to selection, separation, processing and wastes recycling technologies, which are currently finalized.
- Although the above mentioned remarks are still valid, it can be noted that lately, more and more specialists, among which engineers, consider that a greater attention has to be paid to the product use stage. Thus, it is stated that it is not enough to consider only parameters related to metallurgic manufacturing. Subsequent influence factors are also important: product use and auxiliary materials reintegration [7].
- The importance of product use also results from the fact that the main objective of LCA is represented by system – product with a clear prediction of product performance characteristics.
- In a partial stage of LCA, metallurgical engineers may also pay attention to social and economic aspects. This is even more important, as two new fields of knowledge developed lately:
  - metallurgical econology, field which studies the optimization of ecology – economy – energy correlations (3e or E3 correlations) [8];

- metallurgical ecosociology, field of study, which, according to the authors of the present article, considers the optimization of society – environment correlations in the actual outline of the metallurgic industry.

The basic principle to govern the econological activities can be expressed as fallows: *the economic performance should not be restricted (enclosed) by the ecological performance or by the energetic performance.* Under metallurgical strict terms, this means that metallic materials need to be produced, even if this process implies a certain level of pollution or of resource consumptions.

In the event of econology begin the TE^3 scientific branch, the governing principle is: *the technological performance should not be resticted (enclosed) by the economic performance, the ecological performance or by the energetic performance.* Under metallurgical strict terms, this means that the technological performance should be reached, even if this implies financial and natural resources or reaching a particular level of pollution.

- Removal from use is not considered to be a distinct activity or stage in current standards. Nevertheless, authors consider that it has a great importance in materials and products life cycle analysis. In this respect, LCA is suggested to be made up of the following stages:
  - product manufacturing (p.m);
  - product use (p.u);
  - removal from use (r.u);
  - reintegration of secondary materials (r.s.m).

Removal from use makes reference to a very important performance characteristic, the wear, that has to be approached from two perspectives: depreciation and obsolescence. The latter is considered to be a preparatory stage in wearing a lot of segments of the socio-economic life.

The steps mentioned shall be placed in the global chart of life cycles as shown in Fig. 1.

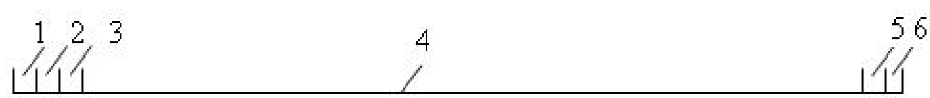

Fig. 1. *Life cycle planning of a urethane product.*
1 – design of the product; 2 – quality processing of the resources; 3 – manufacturing of the product;
4 – use; 5 – disuse; 6 – readmission of secondary materials.

The ecometallurgical actions, by which the life cycle of the metallic product positively influences the lifetime of the product, aim basically in two directions:

- Simultaneous reduction of the $I_{i.l.c}$ şi $I_{i.s.l.c}$ indicators;
- Increase in the physical-mental comfort generated by the product used.

4. Some new indicators in life cycle analysis

For engineering assessments in the field of life cycles, see below several suggestions of indicators which might be used in this respect.

- Endurance may provide significant information with reference to life cycles. Moreover, in standards which comply with environmental requirements there are the following recommendations:
  - extension of endurance of production systems;
  - extension of endurance of materials.
- Duration is usually the measure of endurance.
- Life cycle duration, $D_{l.c}$, measured in [years life cycle] may be a measure for endurance. It is mentioned that current standards do not refer to the necessity of having a life cycle assessment by means of its duration.

The duration of the life cycle is:

$$D_{l.c} = D_{p.m} + D_{p.u} + D_{r.u} + D_{r.m.s}\text{, [years life cycle]}, \qquad (1)$$

where the components represent the duration of the four stages previously mentioned.

From experience, it is stated that a major importance is given to the product use stage. The following judgement may be submitted:

$$D_{l.c} \cong 1{,}1 D_{p.u} \qquad (2)$$

- The assessment indicator for life cycle impact may be considered a quantization of the life cycle impact. Given the following definition:

$$I_{i.l.c} = \frac{Q_{pollutants}}{D_{c.v}}, \left[\frac{m_N^3; kg\ \ polluant}{(t \cdot product) \cdot (years\ \ life\ \ cycle)}\right] \qquad (3)$$

where Qpollutants $\left[\frac{kg; m_N^3 pollutants}{t \cdot metallurgic\ \ product}\right]$ represents the specific pollutants emission assigned to the material (product) which is analyzed.

The two indicators prove the great importance given to use duration in life cycle analysys. With reference to this kind of indicators, it is explainable why, considering:

- the use duration of an industrial product and
- the quantity of released pollutants,

a steel part is superior to a wooden part [4]. Namely, $\left(I_{i.l.c}\right)_{steel} < \left(I_{i.l.c}\right)_{wood}$

5. Characterization of endurance depending on the pollutant impact. Process pollution and process pollutants

Life cycle analysis indicates that the laws which characterize pollution may be applied to other fields, too.

This statement is based on the fact that one of the meanings allotted to the pollution phenomenon is the meaning of contamination. As a matter of fact, etymologically speaking, pollution means contamination (in Latin, poluo-poluare is translated by contamination).

From the engineer's point of view, soiling may represent the alteration of material quality, leading to breakage. In most cases, as far as metallic material industry is concerned, contamination may be considered as a process of reducing the purity degree of materials.

Having in view the applicability of the above mentioned in the life cycle impact analysis for the use stage, see below some possibilities.

- Soiling of metallic materials qualities in the stage of manufacturing. See an example: SO_2 and SO_3 waste gases resulting from fuel combustion in a steel smelting furnace causes, by means of dissolution, the sulphuration of metallic smelt, thus influencing in a negative way steel properties;
- Soiling the properties of use of industrial components in the stage of utilization. See an exemple: FeO from the metal dross forms a destructive reaction with SiO_2 from the refractory material of the inner lining of the furnace, thus influencing in a negative way the endurance of the refractory lining.
- The contamination of steel with residual elements (Cu, Sn, Zn) from scrap is characterized in a paper as a steel pollution process [4].

The conclusion resulting from what was already stated is that processes similar to the above mentioned can be characterized as polluting processes. In addition, it can be stated that there is process pollution and process pollutant.

Process pollutants (in the above mentioned examples, SO_2 and SO_3 or FeO) are substances which, by means of alteration interactions and failure, may influence in a negative way the quality of products which will be delivered to the market or endurance of installations' constructional parts.

Process pollution (in the above mentioned exemples, sulphuration of metallic smelt or corrosion of the furnace refractory lining) is the phenomenon which causes the damage of the quality of materials and of the endurance of constructional parts during production or utilization.

Process pollution phenomena represent in fact pollution of material-pollutant interaction..

See two examples below: (fig. 2 and fig. 3).

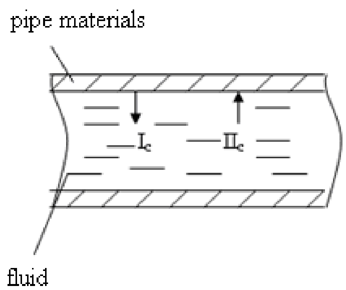

Fig. 2 . Process pollution for a pipe

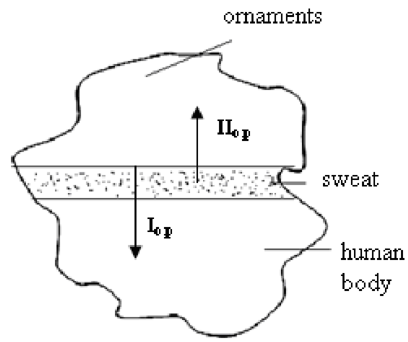

Fig. 3 . Process polution when using accessories

The analysis means the following:

I_c – regular pollution phenomenon; it deals with the negative impact of the tube’s material upon the environment, representing the fluid which is carried; pollution consists of the transfer of some unwanted elements from the tube into the fluid;

II_c – process pollution of fluid-tube interaction; it deals with the interaction which causes an alteration of the quality of the tube and even its breakage; this type of process pollution has to be studied in order to characterize the duration of the use stage from the life cycle of the tube; in this case, the fluid is the process pollutant.

$I_{o.p}$ – regular pollution phenomenon; it deals with the negative impact (skin irritation, for example) of the material upon the human body;

$II_{o.p}$ – process pollution of skin (by means of sweating) – accessory interaction; it deals with the interaction which causes an alteration of the quality of the accessory used; this type of process pollution has to be studied in order to characterize the duration of the use stage from the life cycle of the accessory; in this case, the sweating is the process pollutant. Statements as the ones above can also be made when using metallic implants in various parts of the human body.

From an engineer’s point of view, it has to be emphasized the fact that, in most of the cases, process pollution, as it was defined in the present paper, refers to well-known technological phenomena: contamination, corrosion, solid deposits, stress generation, peeling, breakage, etc.

The process pollution can also be analyzed based on two new notions:

- Conventional pollution, to include the classical cases known in the cycle of pollutants → overall factors → quality of life;

- Non-conventional pollution, to include interaction processes between environment and special objects, whose changes in quality may be studied based on certain ecology principles; reference is made to the examples previously shown in this paper.

6. Social aspects

The present analyses of the life cycle have been previously proven not to approach economical aspects and, especially, social ones. As far as the social aspect is concerned, the life cycle social analysis, the present paper suggests the introduction of two new notions:

- Social lifetime ($D_{s.u}$);
- Life cycle social impact index ($I_{i.s.l.c}$).

The social lifetime, in a simplified definition, is the time wherein the product reaches the customer's socio-cultural expectations. It mostly depends on the obsolescence of the product.

The obsolescence of a metallic product is the process of its performance decrease under new quality limits imposed by a new product, superior from the social comfort point of view. It represents an obvious social meaning event, an actual life quality perception act.

The $D_{u.s}$ assessment is a difficult task and is not the object of the present paper.

The life cycle social impact index shall be defined by

$$I_{i.s.l.c} = \frac{Q_{polluant}}{D_{s.u}} \tag{4}$$

Shall be expressed in $\left[\dfrac{[waste\,mass, kg]}{[product\,mass, kg]\cdot[social\,utility\;years]}\right]$

7. Conclusions

- During the analysis of products and materials life cycle a great attention has to be paid to the use and removal from use stages.
- In order to accomplish the mentioned goal, two new indicators may be used: duration of stages, D and the cycle impact indicator, Ii.c.v.
- Analysis of the use and removal from use stages can be performed based on knowing process pollution and process pollutants.

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