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ENVIRONMENTAL IMPACT ASSESSMENT USING THERMODYNAMIC CONCEPTS

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Abstract: *In the specialty literature a mathematical analogy is established of the relations for the flow of heat pollution and the exergy. On this basis it is tried to use certain methods of exergetic analysis for the assessment of the harmfulness of products. To establish an industrial product's ecoprofile, the method developed by OFEFP (Office Fédéral de l'Environnement, des Forêts et du Paysage -* Confédération suisse*) is used. In order to specify certain concepts and to verify the methodology, an example-application based on statistical data in the consulted literature is presented.*

Key words: *energy value, exergy, ecofactor, ecopoint.*

1. Introduction.

The interactions of any industrial process with the environment shall be placed either upstream, when considering the scarcity of resources consumed or downstream, when considering the discharges of sub-products and harmful elements resulted. The assessment of the quality of resources is done based on specific criteria. In this paper some criteria used in assessing forms of energy are given. Comparing the mathematical expressions of the flow of harmfulness related to a material issued by an industrial process and the flow of residual hot water, using the notions of **intensity** and **natural intensity** of a polluting agent, respectively **exergy** and **anergy** of heat, an analogy may be determined which suggests that it could translate, in the case of ecological balance sheets, a number of methods developed for establishing and analyzing the exergetic balance sheets.

2. Assessment Criteria of the Energy's Value.

According to the required precision and to the targeted aspects during an analysis, there is the possibility of choosing adequate criteria regarding the value of various forms of energy.

a). **Equal values criterion** is a simple criterion that states the fact that all forms of energy (thermal – v_t , mechanical – v_m , electrical – v_e) have the same value:

$$v_t = v_m = v_e = 1 \tag{1}$$

According to this criterion the same value of a joule of electricity can be given to a joule of heat at +80 ^{0}C and to a joule cold at 0 ^{0}C!

b). **Criterion based on two values** which gives to every joule of *noble* energy (mechanical or electrical) a unitary value (v_m = v_e = 1), and a smaller value vt to each joule of *thermal* energy, regardless of its temperature. Generally, it is taken into

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consideration the value v_t = 0,34 corresponding to the average efficiency for producing forms of *noble* energy on an industrial scale, starting with the *thermal* energy. On a similar assumption, it is admitted that a «negative calorie» has a value three times higher than a calorie.

c). **Exergetic criterion** takes into consideration the fact that thermal energy has a value which is higher when the available temperature is higher. For this purpose an increasing function can be considered of the following form v_t (T). Practically, the function can be expressed with the help of the CARNOT factor:

$$v_t = 1 - \frac{T_0}{T} \tag{2}$$

where T_0 is reference arbitrary temperature generally considered equal to the environment's temperature. The value of a form of thermal energy is given by its EXERGETIC content:

$$Ex_t = Q_t\left(1 - \frac{T_0}{T}\right) \tag{3}$$

For mechanical and electrical energy, it is considered the unitary value ($v_m = v_e = 1$).

d). **Economic criterion** takes into consideration the monetary value of each form of energy, and it can be expressed in three different ways:

- value = production cost
- value = national market price
- value = international market foreign exchange price.

e). **Ecologic criterion** assesses the value of any consumed resource according to its scarcity on a global level. Thus, the value zero is given to direct solar energy and it secondary products (hydraulic, aeolian, thermal, sea, etc...) and another value, different from zero, for all the energies that cannot regenerate, representing the limited energetic capital of the planet (petrol + coal + gas) which is slowly consumed by mankind every day. A simple solution resides in giving the value one, irrespective, to all energetic resources that cannot regenerate.

f). **Environmental criterion** takes into consideration the environmental pollution produced by every form of energy. The environmental value of an energetic resource is equal to its relative non-polluting degree. Therefore the value of energy is smaller as the degree of pollution is higher. Next, I would like to present a type of environmental criterion that combines pollution indicators with elements of exergetic analysis.

3. Products' Harmfulness.

We consider $\dot{m}$ the mass flow of a matter, emitted by an industrial process, which contains an "agent" polluting the environment. May there by g_i *the intensity* of this pollutant. The flow of harmfulness will be:

$$G_i = g_i \cdot \dot{m} \tag{4}$$

Let's assume as a first example that is the flow of smoke emitted from a combustion room of a coal type with a high content of sulphur and that g_i is the concentration of smoke in SO_2.

As a second example, let's assume that $\dot{m}$ is the residual hot water flow evicted from a certain thermal apparatus, and $g_i = c_p \cdot T$ is its thermal content.

We note with g_{io} the *natural* intensity of the polluting agent in the receiving environment. This corresponds, for instance, to the balance concentration between the SO_2 "naturally" produced and the one absorbed by the sea environment. In the case of the thermal effluent, there results: $g_{io} = c_p \cdot T_0$ where T_0 is the average environmental temperature.

Therefore, equation (4) can be written:

$$G_i = \underbrace{(g_i - g_{io})}_{polluting\ fraction} \dot{m} + \underbrace{g_{io}\dot{m}}_{non-polluting\ fraction} \quad (5)$$

From equations (4) and (5) the expression of $\dot{m}$ can be extracted:

$$\dot{m} = \frac{G_i}{g_i} = \left[1 - \frac{g_{io}}{g_i}\right]\dot{m} + \frac{g_{io}}{g_i}\dot{m} \quad (6)$$

In the case of the residual hot water, the heat flow $\dot{Q}$ circulated by hot water is:

$$\dot{Q} = \underbrace{\left[1 - \frac{T_0}{T}\right]\dot{Q}}_{exergy} + \underbrace{\frac{T_0}{T}\dot{Q}}_{anergy} \quad (7)$$

In this particular case it can be noticed that the *thermal pollution flow is identified with the exergy flow.* The mathematical analogy of relations (6) and (7) is interesting. It suggests the fact that it could be transposed into the ecological balance sheets, into various methods developed in order to establish the exergetic balance sheets.

The above-mentioned relations can be capitalized with the help of certain concepts defined by the Federal Office for Environment, Forests and Landscape from Switzerland (OFEFP).

Current flow – F expresses the limits of natural endurance (ecological saturation); the current flow overcomes the critical flow (F > Fk) when an over-exploitation of resources is realized.

Critical flow – Fk represents the maximum polluting load that cannot produce irreversible damages in the analyzed eco-systems.

Saturation – generally, this term expresses the ration between the quantity of available resource and the achieved exploitation.

Ecological saturation – or ecological limits: the ration between the stresses on nature and its ability to absorb or eliminate them.

Eco-factor – the extent of the limit or of the natural resource, defined by the ratio between the actual exploitation (F) and the maximum admissible exploitation (Fk). (the expression „maximum admissible" means that from this limit irreversible damages will start to occur).

Eco-point – ecological load unit; resulted from the calculation of the eco-balance sheet (the higher the figure, the greater the stress). Eco-point is the product between the eco-factor and the polluting load.

OFEFP published a list of values for the flows of Gi for the main polluting agents, expressed in tons per year, at the level of Switzerland. The values are mentioned in the 3rd column of table 1.

The table's second column includes the maximum admissible values (estimated by OFEFP):

$$G_i^* = \dot{m} \cdot g_i^*$$

where g_i* represents the maximum acceptable intensity.

The values of the maximum admissible harmfulness for various polluting agents are relative arbitrary measures. They can be specified in internal legal regulations, by international conventions or based on subjective estimations, deduced from the experience of similar technical situations.

In the 4th column the values of the ratio (Gi/Gi*), are marked, often called „degree of ecological saturation". When this ratio is improper, energetic measures for fighting pollution are required.

The various elementary harmfulness must be *regulated* namely expressed in common units in order to sum them up for the calculation of the *total harmfulness* produced by an assembly of polluting matters.

Once solution was offered by OFEFP, who defined a harmfulness unit for every polluting agent called ECO-POINT, representing the harmfulness of one ton of product, at acceptable maximum intensity.

Finally, the expression (4) of the harmfulness flow can be written as follows:

$$\begin{pmatrix} \textit{FLOW OF} \\ \textit{HARMFULNESS} \\ \textit{in number of} \\ \textit{eco-points} \\ \textit{per year} \\ G_i \end{pmatrix} = \begin{pmatrix} \textit{Mater flow} \\ \textit{in tons} \\ \textit{per year} \\ \dot{m} \end{pmatrix} \times \begin{pmatrix} \textit{ECO-FACTOR} \\ \textit{in number of} \\ \textit{ecopoints} \\ \textit{per ton} \\ g_i \end{pmatrix}$$

The eco-factors' values for various polluting agents are given in column (5) of table 1 in number of eco-points per gram (and not per ton) in order to simply the example's presentation.

The assemblies of eco-factors which give a picture of the harmfulness' repartition due to the various components of a product represent the product's ECO-PROFILE.

For exemplification, it is presented the inventory of various polluting agents for air, water and soil, resulted from the production of one kilogram of steel (table 1).

Eco-profile for 1 kg. of steel Table 1

Environmental effects	**Number of eco-points**
Energy consumption: 6075 MJ	60,75
Air pollution	1061,073
Water pollution	0,436
Solid wastes	54812,64
TOTAL	55934,899

On the itinerary of operations starting with the natural resources (rocks) and finishing with the metal pieces (sheets, profiles) used for manufacturing cars, the following stages can be distinguished:
- extraction of minerals;
- concentration of minerals;
- transport of minerals;
- transformation into metal.

During each of the previous stages, the consumption for energetic resources and raw materials in direct or indirect for is determined. Also the polluting components are inventoried. The final result is centralized in table 2, which represents the eco-profile related to one kg of steel. In table 3 there are included elements of the eco-balance sheet for: air, water, soil pollution by solid wastes and the environmental effect related to energy consumption. The numeric values are based on the data in the literature specified in the bibliography, the purpose of the paper being to establish certain concepts and to verify the method.

3. Conclusions.

The proposed method tries to use a mathematical expression for the harmfulness' balance sheet by extending the classic energy and matter balance sheets to an industrial procedure.

The difficulties of this method reside in:
- collecting the experimental data;
- defining the system's frontier to which the balance sheet applies. Conclusions are different, during the analysis of a thermal heating unit that uses coal, when the location is in a basin, in a hilly area or in an open field;
- defining the maximum admissible harmfulness;
- taking into account the local environmental features;
- harmonizing the national regulations with the international ones;

- achieving a compromise between regional and global interests.

The advantages offered by this method of approach materialize in:

- using exergetic balance sheets' concepts and analytical tools;
- obtaining synthetic values which represent the global ecological load exercised by the analyzed system on its own environment;
- the method allows for comparisons between different solutions concerning the manufacturing of a product;
- providing information in respect of the ecological importance of an ecosystem and in attaining alarm thresholds;

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