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ECOTECHNOLOGIES – A MAJOR ROUTE FOR DURABLE-SUSTAINABLE DEVELOPMENT IN THE METAL MATERIALS INDUSTRY

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ABSTRACT

The paper shows that the durable and sustainable development depends on the quality of the events occurring in the convergence area between the natural ecological system (N.E.S.) and the technological system (T.S.) represented by the metal materials industry. The analysis is carried out in the following situations:

- decrease in the level of negentropy (nS) of N.E.S., due to the consumption of natural resources by T.S., and

- increase in the level of entropy (S) of N.E.S., due to the discharge into the environment of the pollutants generated by T.S.

Ecotechnologies constitute a major tool for optimizing the correlations N.E.S.-T.S. Our study proposes a classification of ecotechnologies in four categories, according to their influence on nS and S. The role of ecotechnologies in reducing the environmental entropisation phenomenon is also highlighted.

KEYWORDS: sustainability, durability, ecotechnologies, environmental (neg)entropy

1. Introduction

At present, development is considered a complex process able to optimize the *interactions and interconditionings* found in the convergence areas of the four fundamental systems (*natural-ecological, social, economical and technological*) that make the *eco-socio-economic-technological mega-system (M.S.),* the actual form in which the *sphere of human existence* manifests itself.

The designing of a new development model must propose qualitative and quantitative improvements regarding the *conception, dissemination and operationalisation of the new knowledge*. The following targets become compulsory:

- to use *multi and interdisciplinary integration tools* so that the new model provide the theoretical framework for understanding the adaptive and evolutionary transformations, i.e. the design and management of new methodological tools [1];

- to achieve the *integration of sectoral knowledge* offered by a wide range of disciplines, in order to understand the integrative events at the mega-system level; within the same framework, it becomes important to use the confirmed theoretical elements of all the partial theories for developing and explaining the organization, complexity, dynamics and evolution of nature [1, 2];

- to replace, especially in engineering, the *gogglewise knowledge* with the *fanwise knowledge* [3].

The new development model is operationalised on the basis of two modern principles of evolution: sustainability and durability.

The **sustainability** refers to the ability of the new development model to *create, sustain and maintain* processes of evolution and adaptation within the eco-socio-economic-technological complexes.

The main item used to make assessments on the system sustainability is the *carrying capacity*, which measures the ability, mainly of the natural-ecological system, to provide the resources and services needed to develop the other systems.

Durability, as a characteristic of the new development model, aims at:

- the co-development potential of the systems through *long-term* adaptive transformations, i.e. also at the *level of future generations*;

- the ability of the systems to be resistant; in this context, it is not about the notion of *resistance* within the mechanical engineering meaning, but about a special form represented by what is called *system resilience,* which measures the system's ability to withstand the action of disturbing items (shock actions). At present, it is considered that the main disturbing item acting in MS is *pollution*;

- the systems' opportunities to develop as *viable entities*.

Environment resilience is another parameter sometimes used to assess durability. It is the *maximum disturbance limit* permissible for an ecosystem, over which this one would cease to operate as environment stabilizer [1, 10].

As a global disturbing item, pollution includes many other disturbing items ($M_{per.}$) whose disturbance limits should not be exceeded. Some of them are mentioned below [11]:

- increase of CO_2 concentration in the atmosphere, which now exceeds 0.033%;
- disappearance of species of living creatures and plants;
- intensification of agriculture by exaggerate use of chemical fertilizers;
- deforestation;
- ozone layer depletion;
- aerosol release into the atmosphere;
- excessive consumption and wastage of freshwater;
- ocean acidification;
- growing volumes of anthropogenic waste disposed into the environment.

From the above context, we note that the society has already gone through the third period of history. Especially after 1950, the world passed from *Holocene* to *Anthropogenic era* (period in which man becomes the main modeller of the natural-ecological system).

The disturbing items, $M_{di.}$, mentioned above, present a *hockey stick* type development (Figure 1).

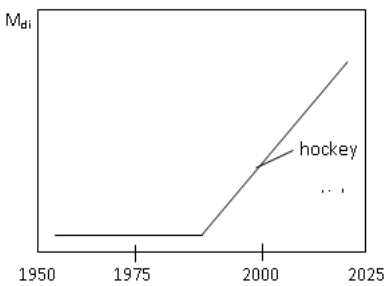

Fig. 1. *Increase of disturbing items*

The differences between the two principles are also standing out when we take into account the assessment tools. Therefore:

- sustainability is based on carrying capacity, and
- durability is based on system resilience.

It is obvious that a differentiation as the above is not absolute, because there are many areas in which the two principles are intertwined.

Based on the above, we can briefly define the new development model as *that development that meets the needs of the present* (mainly by *sustainability*), *without compromising the ability of future generations* (mainly by *durability*) *to meet their own needs.*

As the new model is unitarily defined and operationalised based on the principles of durability and sustainability, this paper proposes the model to bear the name of ***durable-sustainable development*** **(D.S.D.)** [4].

2. Materials and products manufactured in metallurgical industry

2.1. Definition of the categories of materials

The **material** is the substance which, through a technological manufacturing process, generates *socially useful goods*. Steel is a material.

The **product** is the object (body) which, through a technological manufacturing process, *acquires social utility*. The steel sheet is a product.

Using the two notions interchangeably is not a serious mistake.

The materials listed below are manufactured in the metallurgical industry.

a) The **primary material (product), M.P.**, is the material subject to a technological manufacturing process. If it is a *complex process*, represented by a flow of more *sequences*, the following items can be found:

- *primary sequential material (product), P.S.M.;*
- *final sequential material (product), I.S.M.*

The steel made within the integrated flow consisting of *ore mine - blast furnace – steel plant - rolling mill* is a sequential primary product. Sometimes, this is referred to as *semi-finished product*. The steel sheet delivered to the beneficiary at the end of the above-mentioned flow is a final primary product.

b) The **pseudo-primary material (product), P.P.M.**, is the material used in the analysed process, but obtained in an adjacent manufacturing flow (cycle). The ferrosilicon used to make steel in the integrated flow is a pseudo-primary material, because it is obtained in the ferroalloy plant adjacent to the integrated flow.

c) The **secondary material, S.M.**, is the material which, for technological reasons, accompanies the primary material. The following items are included in this category:

- The *by-product, B.P.*, is the secondary material that can be used within the technological flow that generated it. Ingot cut ends and mill scales are examples of by-products;

- The *waste, W.*, is the secondary material which leaves the technological flow that generated it, but has recovery potential, i.e. it can be used in other manufacturing cycles.

There are two categories of waste:

- The *manufacturing waste (technological waste)* is the waste that leaves the primary material manufacturing perimeter. Blast furnace slag is a manufacturing waste;

- The *usage waste (degradation waste)* is the waste generated by using the primary product, due to its degradation (transformation of the primary material into secondary material). Scrap is a degradation waste. The degradation product and the degradation waste must be assessed based on *degradation properties (characteristics).*

- The *residue, R (final waste)* is the secondary material disposed into the environment without usage possibilities. The *disposal* is the deposition of the secondary material into the environment (possibly after a neutralisation treatment) in all the three states of the material:

- disposal in gaseous state (e.g. emission of CO_2 into the atmosphere);
- disposal in liquid state (e.g. wastewater discharge);
- disposal in solid state (e.g. slag dumping).

Pollutants are residues which, by disposal into the environment, have a negative impact on its quality.

The modality of placing the categories of materials into the manufacturing cycles is shown in Figures 1 and 2.

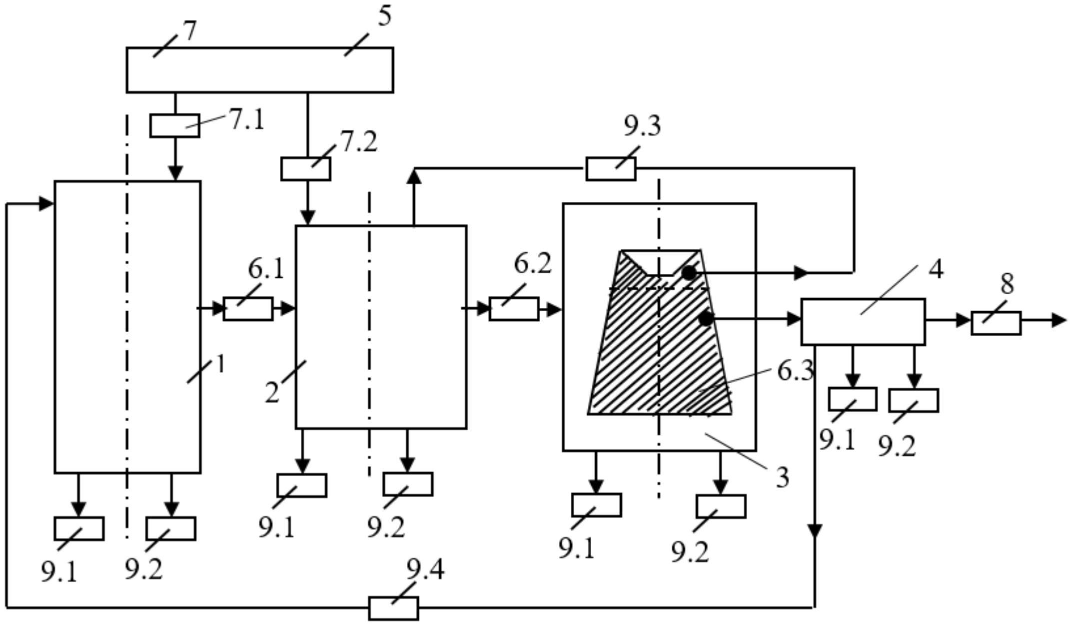

Fig. 1. *Modality of placing materials (product) in a steel-making flow based on ore and coke. 1 - blast furnace; 2 - steel-making furnace; 3 - casting mould; 4 - rolling mill; 5 - facilities for auxiliary (pseudo-primary) materials; 6 - sequential primary materials: 6.1 - pig-iron; 6.2 - steel, 6.3 - ingot (semi-finished product); 7 - pseudo-primary materials: 7.1 – coke; 7.2 – ferroalloys; 8 - final primary material; 9 - secondary materials: 9.1 – waste; 9.2 – residues; 9.3 - by-product (cut ends); 9.4 - by-product (scale briquettes).*
(Note: In this drawing, the perimeters are disproportionate)

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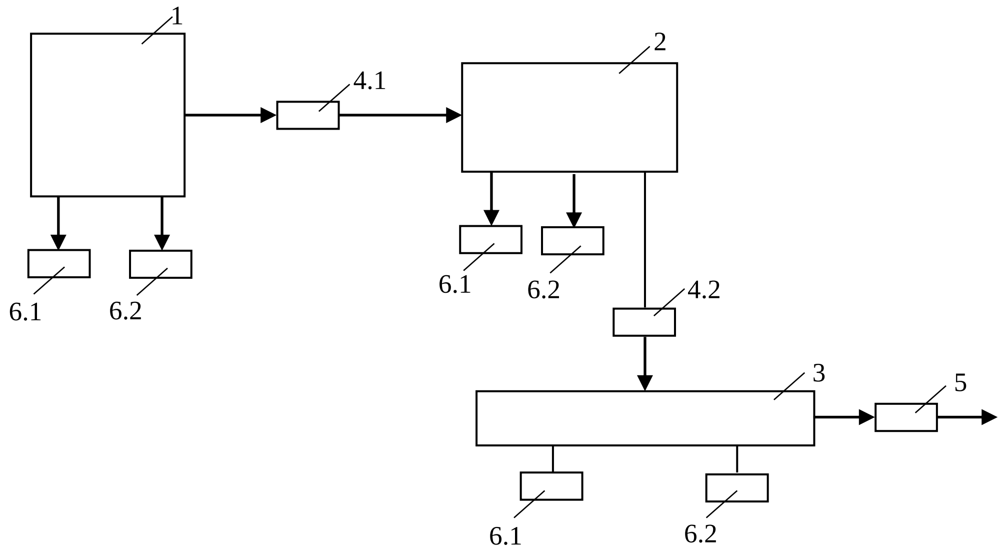

Fig. 2. *Modality of placing the materials (product) in a steel-making flow based on scrap. 1 - EAF; 2 - continuous casting machine; 3 - rolling mill; 4 - sequential primary materials: 4.1 – steel; 4.2 - semi-finished product (billet); 5 - final primary material (steel tubes and pipes); 6 - secondary materials: 6.1 – wastes; 6.2 - residues.*
(Note: In this drawing, the perimeters are disproportionate)

2.2. Characterisation of materials as thermodynamic system element

The technological system of metal materials manufacturing operates as a thermodynamic system (being a high temperature process, it is determined by heat exchange).

The modality of placing the materials into a thermodynamic system is shown in Figure 3.

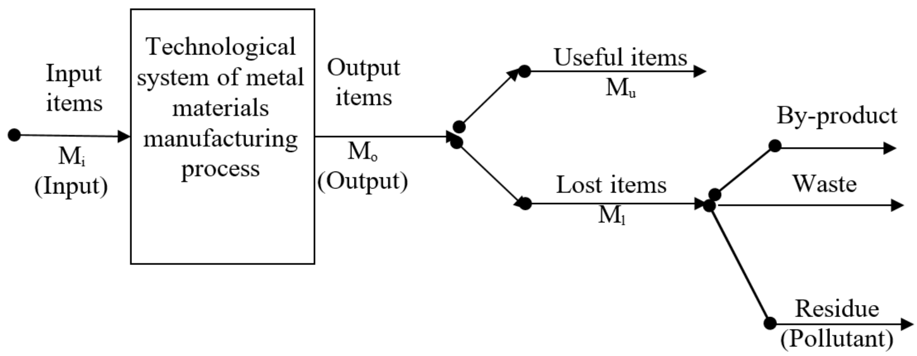

Fig. 3. *Thermodynamic structure of a technological process*

In terms of material balance or energy balance, we are working with:

- *input items, M_i,* represented by natural resources (*n.r.*), which can be:
  - material resources;
  - energy resources (real fuels and energies).
- *output items,* which are:
  - *useful items, M_u,* represented by raw materials;
  - *lost items, M_l,* represented by secondary materials; more specifically, they are:
    - by-products;
    - wastes;
    - residues.

It can be concluded that:

- From the thermodynamic point of view, as residues, *pollutants are lost items.*

- Because, according to the first law of thermodynamics, there are no zero loss systems, it follows that the metal materials manufacturing process is an objectively pollutant process.

- For the same reason as above, pollution projects such as *zero pollution* or *zero waste plant* are not thermodynamically justified, but they must be accepted as targets.

- From the ecological point of view, we are interested in the waste and residues leaving the technological system and being discharged into the environment.

3. (Neg)entropic characterization of materials

The changes in entropy or negentropy may be a possibility to characterise the transformations of materials when they undergo the life cycle (*l.c.*) [12].

Entropy (S) is the thermodynamic parameter that measures *the degree of matter disorder and degradation* in the environment. *The disorder degree and degradation increase* are measured by the entropy increase (*S)*.

The **negentropy (nS)**, or **anti-entropy (aS)**, is the thermodynamic parameter that measures the degree of matter ordering in the environment. The increase of the ordering degree is measured by the increase of negentropy *(nS)*.

Below, we are going to briefly characterise the variation of (neg)entropy when the material undergoes the life cycle.

a) Provision of resources

Resources (e.g. iron ore) represent the matter with a certain degree of ordering, i.e. a certain degree of negentropy $nS_{n.r.}$. It is admitted that underground resources are a low entropy reserve [6, 7]. The consumption of resources has therefore resulted in *lowering the environmental neg(entropy)*.

b) Manufacturing of material (product)

The technological process of material manufacturing results in enhancing the ordering of matter, hence the increase of the material negentropy. For example, we can write that:

$$nS_{steel\ sheet} > nS_{ore},$$

or that the *technological process is a negentropy producer* $nS_{t.p.}$ [5].

Materials engineers are a social category apt to create social neg(entropy).

c) Usage of material

In the use phase, *material degradation* occurs, which means the decreasing of the matter ordering degree.

d) Waste generation and disposal in the environment

Material degradation causes *waste generation*, which is considered a *disordered state of matter* (i.e. entropy carrier), equal to S_R.

Since some waste can be recovered, we are interested in the entropy $S_{R.}$ of the finally disposed wastes.

e) Waste reintegration is a process of matter reordering from the state of secondary material in *resource material*. Therefore, we are speaking about negentropy recovery through reintegrated material, $nS_{r.m.}$. It is also called *reintegration negentropy*.

Environment entropisation, as a process that must be prevented or minimised, is assessed by decreasing its negentropy basin, $(\Delta nS)_{env}$, calculable with the expression:

$$\left|(\Delta nS)_{env}\right| = \left[\left|nS_{n.r}\right| + \left|S_R\right|\right] - \left[\left|nS_{t.p}\right| + \left|nS_{r.m}\right|\right] \quad (1)$$

At the limit, the condition $\left|(\Delta nS)_{env}\right| = 0$ should be satisfied. But, the laws of thermodynamics and the history of civilization proved that $\left|(\Delta nS)_{env}\right| > 0$, fact that characterizes an *irreversible phenomenon of environmental entropisation* [7, 8].

In reality, there is a situation characterized by the expression:

$$(|nS_{n.r} + |S_R) > (|nS_{t.p.} + |nS_{r.m}) \quad (2)$$

4. About ecotechnologies

The *ways to operationalise the concept of durable-sustainable development* in industry constitute a fundamental component of the activities performed by metallurgical engineers. Practically, the D.S.D. model is a target for optimising the interactions and interconditionings between the natural-ecological (N.E.S.) and technological (T.S.) systems, aimed at maximizing life quality indicators in terms of economic efficiency increase.

Ecotechnologies represent the major vector based on which we can achieve the above objectives, whose content means the minimisation of $(\Delta nS)_{env}$, fact achievable through the minimisation of $\left|nS_{n.r}\right|$ & $\left|S_R\right|$ and maximisation of $\left|nS_{t.p}\right|$ & $\left|nS_{r.m}\right|$.

Based on the above assumptions, the possible correlations in the natural-ecological systems (N.E.S.) and technological system (T.S.) are plotted in Figure 4.

There are four situations:

A. The T.S. upstream area represents the N.E.S.-T.S. correlation, defined by the functions of these systems:

- SNE having the function of *basin (supplier) of natural resources;*
- ST having the function of *resource consumer*.

The negentropic content of the environment is decreasing with $nS_{r.n.}$. The correlation optimisation depends on the *environmental sustainability* assessed through the *carrying capacity* in ensuring the resources.

Applying **ecotechnologies** to **minimise the consumption of resources (ETmC)** is the main way of maintaining the carrying capacity of the environment. The *ecotechnologies for preservation and conservation of resources* are specific variants for ETmC.

Preservation is the provision of natural resources over a period as long as possible by minimum consumptions.

Conservation is putting under the ban of any anthropogenic interference within the natural resources perimeter, over a transitional period.

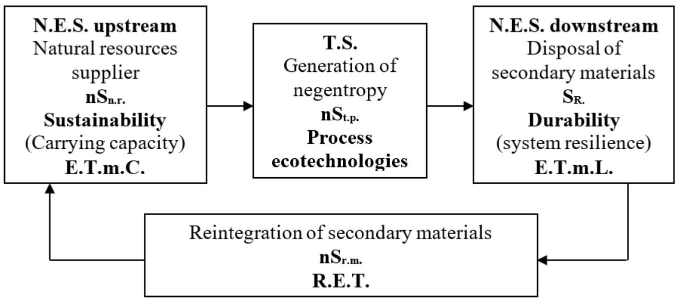

Fig. 4. *Ecotechnological interconditionings between N.E.S. and T.S.*

B. The SN downstream area represents the T.S.-N.E.S. correlation, defined by the functions of these systems:

- T.S. having the function of *pollutant generator*;
- SNE having the function of *takeover, processing and disposal of pollutants*.

Hypo-polluting ecotechnologies are the key industrial methods for optimising the N.E.S.-T.S. interconditionings on the foundation represented by the negative impact exerted by the pollutants.

Hypo-polluting ecotechnologies are the technologies applied to prevent or decrease the *negative impact of the pollutants on the quality of the environment*.

The **ecotechnologies** applied for **minimising the losses (ETmL)** are the industrial-scale operationalisation solution for hypo-polluting ecotechnologies. We adopt this name because, in the material and energy balances, pollutants are *lost quantities* from the T.S. perimeter to N.E.S.

Because ETmL finally concerns pollution, which is the main environment disruptive item, they constitute the major policy to improve the *system resilience* of N.E.S. for the future generations.

C. The intermediate zone

This situation is given by the upstream-downstream bilateral interconditioning, defined by the complex recovery function of reintegration in the industrial circuits of the secondary materials.

The **reintegration ecotechnologies (R.E.T.)** of the secondary materials (especially of the waste) are the major route to accomplish a double purpose:

- improving the N.E.S. carrying capacity (upstream area) by using reintegrated materials as substitutes for the natural resources;
- improving the N.E.S. system resilience (downstream area) by reducing the quantity of polluting waste discharged into the environment.

The positive effect of waste reintegration is assessed through *reintegration negentropy*, $nS_{r.m}$. Waste reintegration is carried out through the *3R technologies* (recirculation, recycling, regeneration).

Recirculation is the recovery achieved by reintroducing the materials or secondary energies in the same manufacturing flow. An example of recirculation diagram is shown in Figure 5. The object of recirculation is the *by-product.*

Recycling is the recovery of secondary materials by using them in other manufacturing cycles than those which generated them. An example of recycling diagram is shown in Figure 6.

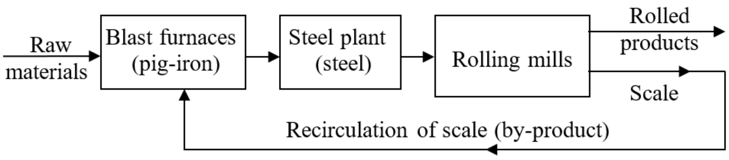

Fig. 5. *Recirculation diagram*

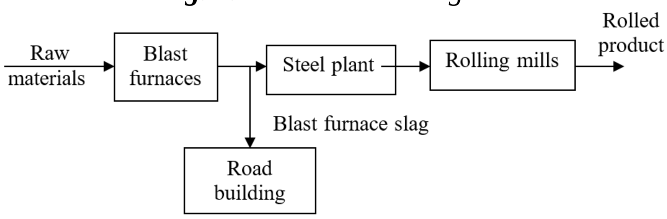

Fig. 6. *Recycling diagram*

The object of recycling is the *waste*.

Regeneration is the process of regaining the original properties of the secondary materials by physical, chemical, thermal or mechanical processing, for reuse in the manufacturing process. Regeneration is compulsorily followed by recirculation or recycling.

Regeneration is a term that should be used with caution, as shown below.

Regarding material resources, it appears that they are renewable. For example, the foundry sand which, after its degradation by use, is reintroduced in the manufacturing process thanks to the *sand regeneration technology*.

Regarding energy resources, the situation is more complicated. As we know from thermodynamics, the energy which follows a cycle of *generation - use - discharge into the environment* finally turns irreversibly into *degraded energy*, spread (dissipated) into the environment as *unusable entropy*. A simple example: In the history of civilization, there was no man, found outside a technological oven, able to take over the energy (heat) discharged into the environment, to regenerate it and to reintroduce it into the plant. We can say that the *dump of the energy (heat) discharged from the oven is the infinite environment*.

We can conclude that energy cannot be regenerated and, therefore, the term *renewable energy* is incorrect. For non-conventional energies, we recommend the term *renewable energies* [9]. This name highlights the fact that, for example, an amount of solar energy is permanently replaced (renewed) by another amount generated by the sun.

D. The technological process perimeter

As shown above, the process is generating negentropy $nS_{t.p.}$. Practically, this means the increase of the *added value*, V_a, through continuous technological processing. It can be writen as

$$nS_{ore} < nS_{steel} < nS_{black\ sheet} < nS_{tin\ sheet} \quad (3)$$

or as

$$V_{a\,ore} < V_{a\,steel} < V_{a\,black\ sheet} < V_{a\,tin\ sheet} \quad (4)$$

It follows that:

$$\Delta V_a = f\left(\Delta nS_{t.p.}\right) \quad (5)$$

Process ecotechnology is the technology which, by advanced technological processing, causes the increase of MS negentropy, reducing therefore the environmental entropisation process.

5. Conclusions

- The current development concept is based on two distinct pillars: sustainability (characterised by the carrying capacity of the environment) and durability (characterised by the environment system resilience), reason why we propose the name of *durable-sustainable development*.

- The events developed in the convergence area N.E.S.-T.S. must be assessed taking into account their influence on the *environmental entropisation* processes.

- Ecotechnologies are technologies used to minimise the environmental entropisation processes related to human activity.

- We define and characterize four categories:
    - ecotechnologies with minimisation of natural resources consumption;
    - ecotechnologies with minimisation of the polluting losses from the technological process perimeter to the environment;
    - ecotechnologies of secondary materials reintegration;
    - process ecotechnologies.

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