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The technological processes optimization according to the sustainable technology procedure

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Cleaner production

ABSTRACT

Purpose: The paper presents a possibility of the optimization includes in the sustainable technology designing and modernization.
Design/methodology/approach: To the estimation of the technological processes towards the sustainable technological processes used four environmental criteria. The possibility of the optimum technological process choice was proposed.
Findings: The conclusion of the work is the modified sustainable technology (MSTP) procedure elaborated. In this case the BREFs were used as a standard for the technological processes estimation.
Research limitations/implications: As a reference unit, except BREF, can be used other standards. One of the possibilities is the sustainable technology creation to which all the analysed technological processes can be related.
Practical implications: The work is an example of the least environmental influences technological processes searching. It gives the basis of the sustainable technological processes designing and the life cycle of the technological processes creation and analyse.
Originality/value: The paper presents the sustainable technological processes procedure and its modification with regard of the polyoptimization. This article shows the possibility of the computer aid used.
Keywords: Cleaner production; Industrial application of cleaner production methods; Sustainable technological process; Optimization; BREF

1. Introduction

One of the greatest threats of all lives on Earth is the degradation of the environment. In the endeavour to the satisfaction of their own needs the society forgets that destroyed the nature. The problem is the very short term of existence among other things energy resources, as well as high issues of pollutions during the combustion of mineral fuels. This causes that increasingly of states accept rules of the sustainable development (SD) and radically ceased to use of the unsustainable model of the production and the consumption (the Earth Summit in Rio de Janeiro 1992, The World Summit in the matter of the Sustainable Development - Johannesburg 2002).

At present we can notice that the sustainable development notion is universally used, but not clear. It is because of the complexity and multi-layered structure of the SD.

An idea of the sustainable development is the development of the society in „the harmony" with a nature. The disturbing factor of

the socially-economic development adaptation to environment changes is the dynamic character of the sustainable development and the global frame of all leading activities to its success. In the reason of fact are many proposals concept of the sustainable development leading to contestations among followers of different options. The representatives of these options consider that politics and practical activities of SD must have the local „character". We can assume that the technological process is found at least local, individual (elementary) areas having the influence on realizing of rules of the sustainable development in the total scale.

Nevertheless that all activities undertaken toward SD on a level of the technological process will not solve all problems but these are activities making possible reduction of the negative environmental influences. Because of that it is necessary to elaborate of the better processes selection methodology. Accordingly essential is using and modifying of existing tools of the sustainable development to the technological process level and especially to the materials technological process level. The modification among other things of the life cycle assessment of the product and the sustainable technological process procedure (which searching for the no waste technological process) can lead to creation the quantitative estimation methods of the technological process.

In regard to BAT Reference Documents (BREF) [1] can propose the estimation procedure of the environment changes caused by using materials technological processes. Also we can propose the selection method of the better technological processes.

One from the possibilities of different technological processes selection is the use of the multicriteria optimization. In the case of the multiobjective optimization, in selection of the technological process with the minimal negative environmental influences [2], the part of the environmental criteria realize:

- the minimal use of added materials (Z_Z),
- the minimal energy consumption (Z_E),
- the minimal waste quantity (solid, gas and liquid) (O),
- the minimal technological process costs (K).

2. The methodology and the notion of the optimal technological process

In the contemporary world, in all parts of life there appears to be the necessity of search for better solutions - best to achieve success in given conditions and for accepted criteria. The effect of such the best (the optimum Latin - best) solutions search, especially in the production sphere, is searching of better solutions than till well-known now. Thereby during the design, and even during the formation of the technological process concept we can take into consideration the negative influence of the technological process on the environment (this is important because of the minerals deposit exploitation and natural raw materials, and also waste). All activities connected with searching of optimal solutions which characterize the lack of the negative environmental influences (also quality and the functionality) of the products and the technological processes put new requirements for the materials engineering.

In the endeavour to the creation and use of the sustainable technological process it is necessary to regard of the full life cycle of the technology, and the life cycle of the technological process.

It extorts the right analysis of the technological process with regard to all influences on the environment. To the estimation should be subject not only the machines for the realization of the technological process, but also the working environment of the workers. All these activities lead to improvement of the existing technological process in the production and environment sphere or to search new, unknown, technological solutions (e.g. insert in BREF) [1].

The culmination point of this should be attaining of such technological process efficiencies level which make possible maximum reduction of used recourses, energy consumption and the pollution reduction, with the total exclusion of poisonous substances. On this stage we can talk about the adaptation of designing or using technological process to requirements of BREF, which restrictive negative environmental influences at the simultaneous maintenance of the firm financial form.

By the analogy to the market life cycle of the product, the environmental life cycle of the technological process can consists of four main phases (Fig. 1) [3]:

- phase of designing and implementation,
- phase of modernization and development,
- phase of maturity (requirements reached),
- relative decadent phase.

In the phase of designing and implementation, at the moment of a new technology appearance we can observe the term of the intensive progress, the innovation development and the implementation of new machines. At this time appear sometimes completely different, projects of the product (technological process) to the moment, when will not appear the dominant technology project. Than investigate all influences of designed technological process on the environment and particularly analyze concrete raw and added materials quantities, the energy consumption and the waste quantity.

The only full standardization, the production efficiency and the stress on the economics production, favour the innovation, both in the production and the environmental sphere.

The maximum environmental and economic advantages are brought by the maturity phase. On this stage the technological process attains the level of environmental influences in accordance with BREF (or with other normative values) or better.

These factors lead to attainment of the best level - the optimal technological process, at least peaceable with requirements of BREF.

The technological process progress toward at least environmental weights, greatest advantages of economic and optimal technical parameters, relate to the knowledge development, especially ecological and experiences in application of the technological process. Because of that BEST AVAILABLE TECHNIQUES (BAT) also change in time. To equal to higher requirements of BREF, necessary becomes changes observation in the range of appointed limits and the adaptation them to technological process parameters across modernization treatment.

However it occur that existing technological processes with their own products become obsolete and the environmental influences considerably cross the norms and modernization treatment do not bring already waited results. In this case the technological process attains the relative decadent phase which leads to resignation from the use.

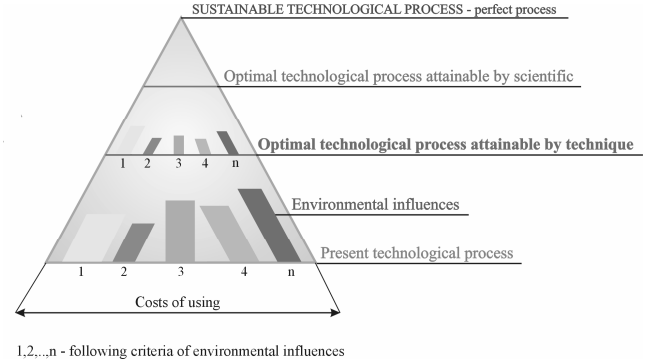


Fig. 1. Environmental life cycle of the technological process [3]

The only alternative solution is the change of the existing technological process to new, which can be more expensive but more environmentally profitable (realizing higher requirements of BREF) and economically.

The environmental life cycle of the technological process shows that the highest costs are carried in two first phases: designing and implementation, the modernization and the development, instead the greatest environmental effects in the use bring the maturity phase.

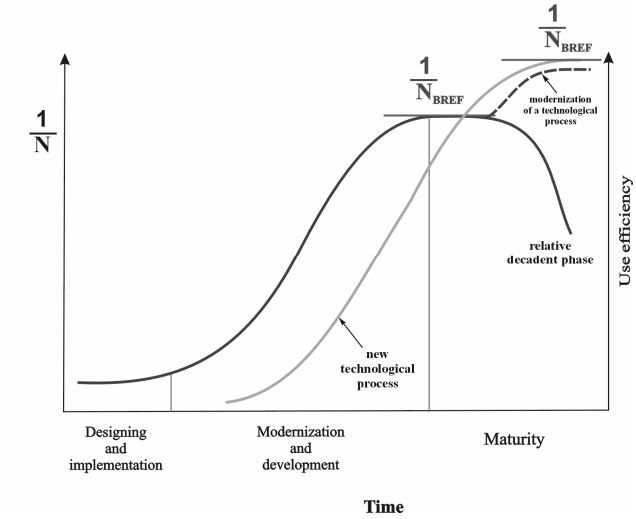
The knowledge of the environmental life cycle of the technological process makes possible the optimal technological process designing based on the sustainable (ideal) model. This method can be used for the new technological processes designing and for the existing technological processes modernizations which do not realize waited ecological, technical and economic criteria.

The methodology of the optimal technological processes search, based on the analogy with the Nadler's model [4], shows the figure 2.

The top of the triangle (pyramids) relate to *the sustainable technological process – ideal,* which is characterized with the lack of waste (waste=0), using of exclusively renewable energy sources and the renewable raw materials. Thanks to the rule - the zero of the negative influence on the environment - it does not demand the incurrence of additional costs. But the ideal technological process does not exist because in every technological process appears waste.

More profitable is the level of *the scientifically optimal technological process*, which is possible to use considering the intensive advance in science and techniques. This technological process is characterized with the greatest use of renewable energy sources and renewable resources. In this reason we can minimize the energy consumption and the waste quantity. The level of the scientifically-optimal technological process based on the entire utilization of the knowledge and also based on experiences. This is surely the standard – technological process but the high implementation costs let on it use only in the future.

Below the scientifically-optimal technological process is found *ecologically, economically and technically optimal technological process* which is technically realizable and it is received by the optimization from the technological processes group about different environmental weights, costs and technical parameters, most often very diverse. In this instance the optimization takes into account simultaneously environmental criteria, i.e. the raw materials used, energy consumption, the waste quantity.



N – negative environmental influences,
N_{BREF} – negative environmental influences according to BREF

Fig. 2. Method of optimal technological process [3]

At the base of the pyramid is found *the greatest environmentally* weights technological process with costs of its use. This technological process is very expensive and also pollutes the environment. After the ecologically, technically and economically analysis and the estimation it is subject to the modernization or change.

The methodology of the optimal technological process founds the full analysis and the estimation (ecological, technical, economic and market) of the present technological process. In every case of its modernization or change shows the necessity of the qualification and designing of the sustainable technological process. On this stage, after the settlement of the technical possibilities, we can propose necessary limitations and at last after the optimization obtain best, most ecological solution of the optimal technological process.

3. The modified procedure of the sustainable technology design and the implementation

In fact that a foundation of the sustainable technology model [5,6,7] is the technological process which has not streams of waste, it is necessary to search technically, ecologically and economically optimal technological process. The modification of the sustainable technological procedure can lead to create of quantitative estimation methods of the technological processes (Fig. 3).

A part of principle of the procedure is the analysis of the technological process relying in the large reduction on identifying of reasons causing „unbalancing" of the technological process, and then to search of solutions having the distinct influence on its improvement [5].

On purpose phases of the PREPARATION to the possible modernization or change of the technological process is the performance of the recognized whether in fact exists the necessity of the interference into the technological process at present practical. Thereby a first stage of this procedure is analysing of the technological process in respect of technical, ecological and economic criteria. To the estimation of the environmental influences analysed technological process can be include: the minimal added materials used (Z_Z), the minimal energy consumption (Z_E), the minimal waste quantity (solid, gas and liquid) (O), the minimal technological process costs (K).

The phase of the IDENTIFICATION consists on the qualification, in the first stage, the aim of the modernization or the change of the technological process.

The phase of the COLLECTION OF SOLUTIONS consists of searching, and then collecting of the wide group of alternative solutions variants. In the creation of the collection of optimal solutions exists the possibility of the adaptation optimal materials technological process POMPT procedure using the computer.

The phase of the ANALYSIS OF SOLUTIONS indicated which from proposed solutions are possible to implementation.

The aim of the phase of the PROJECT OF THE MODERNIZATION OF THE TECHNOLOGICAL PROCESS is the concoction of the final report, in which will be presented the possible implementation of proposed solutions.

A first stage of the IMPLEMENTATION phase is the concoction the business plan for get money on project finalizes or the technological process change. Next stage of the procedure is preparing the technical draft which will make possible the decision making about the implementation. The plan of time limits of the realization of the project will be tight in the implementation schedule.

The aim of the REACHING TO THE ESTABLISHED PRODUCTION CAPACITY phase is the estimation of obtained results with establishes.

A helpful tool in the choice of the technological process of the least environmental weights and simultaneously efficiency is the multiobjective optimization. We can use it in the moment, when possible is the choice among at least two technological processes about which environmental influences are different in respect of the intensity.

The polyoptimization we can use in the case when several different criteria existence. At the estimation of environmental technological processes influences the part of such criteria can realize [2]:

- the minimal use of added materials (Z_Z),
- the minimal energy consumption (Z_E),
- the minimal waste quantity (solid, gas and liquid) (O),
- the minimal technological process costs (K).

Considering above the estimation criteria we can qualify the objective function (f) in the form [2,8]:

$$f(x) = w_1 \cdot \frac{Z_Z}{B_Z}(x) + w_2 \cdot \frac{Z_E}{B_E}(x) + w_3 \cdot \frac{O}{B_O}(x) + w_4 \cdot \frac{K}{B_K}(x) \qquad (1)$$
$$f \rightarrow \min$$

where:

x – decision variables (following environmental data, concerning use of natural resources, energy consumption, waste quantities and using costs of each technological process subject to the optimization),

Z_Z - total use of resources and added materials in the technological process,

Z_E - total energy consumption in the technological process,

O - total waste quantity (solid, liquid, gas) in the technological process,

K - costs of the technological process,

B_Z - use of resources in the technological process regarding to conventionally accepted values; accept of BREF,

B_E - energy consumption in the technological process regarding to conventionally accepted values; accept of BREF,

B_O - waste quantity in technological process regarding to conventionally accepted values; accept of BREF,

B_K - agreed costs of the technological process, e.g. regard to BREF,

and w_i - such weights that [2,8]:

$$\sum_{l=1}^{k} w_i = 1 \qquad w_i \in [0,1] \qquad (2)$$

Considering above factors, the modified procedure of the optimal technological process, containing elements of the estimation methodology of the environmental life cycle of the product, consists of six stages [6]:

- **Stage I** - qualification of the functional unit
- **Stage II** - inventory and the database creation
- **Stage III** - reference data to the limits in BREF
- **Stage IV and V** - the materials technological process optimization and verification of the optimal technological process

Stage I - The qualification of the functional unit

Under the optimization of the technological processes it is necessary to the functional unit defined. One of the primary purposes of a functional unit is to provide a reference to which the input and output data are normalized. Thereby the functional unit shall be clearly defined and measurable. It is also necessary that the technological processes compared have the same unit, because then they will be comparability.

The optimal materials technological process procedure is based on normative or arbitrarily accepted values. The functional unit can determine every single machine and the function realized by its or the electric etc. Comparisons between technological processes shall be made on the basis of the same function, quantified by the same functional unit in the form of their reference flows.

Stage II - The inventory and the database creation

This stage involves the quantitative and qualitative description of the inputs and outputs needed to determine where the process starts and ends and the function of the unit process. For this purpose it is helpful to do: the resources and added materials balance, the energy balance, the waste balance and the costs balance. Collected data, either measured, calculated or estimated are utilized to quantify the inputs and outputs of the technological processes. The major headings under which data can be classified include:

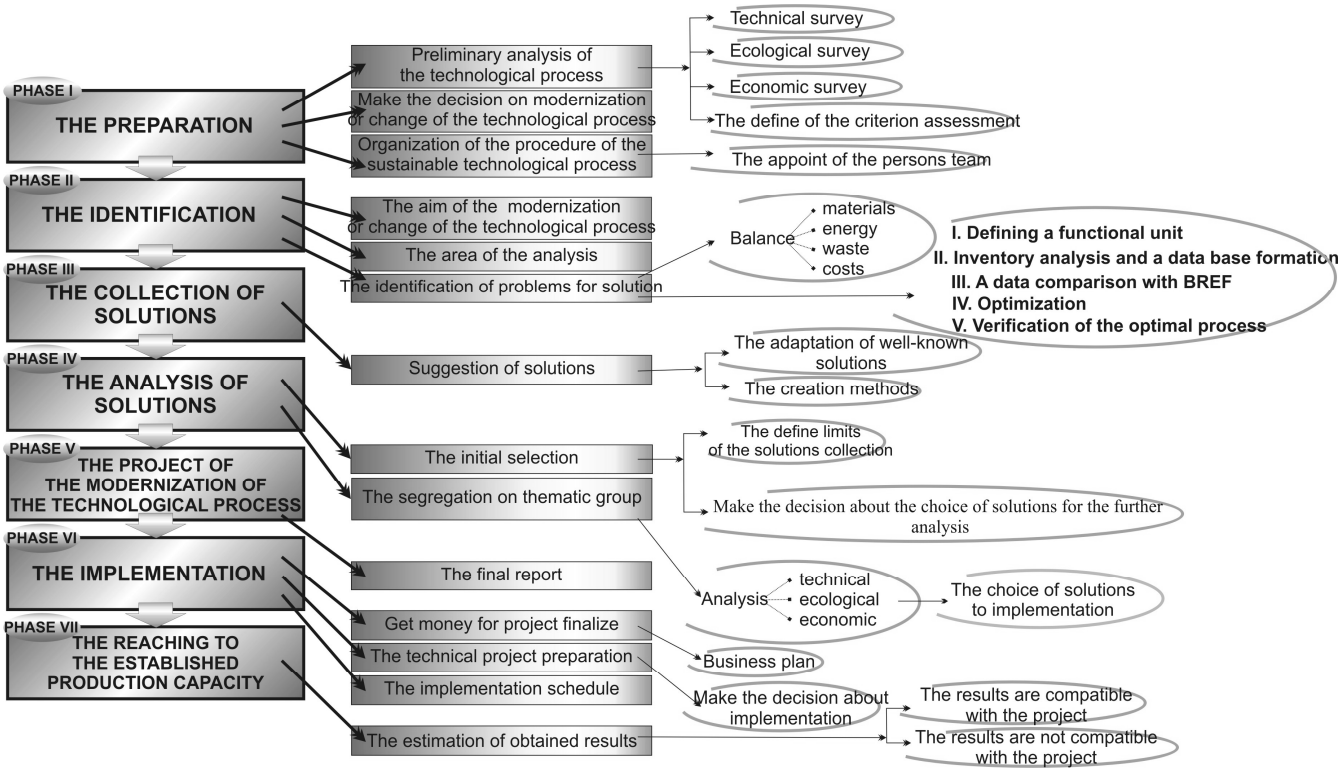


Fig. 3. The procedure of the designing and the initiation of the sustainable technology after modification (MSTP – Modified Sustainable Technology Procedure)

- resources inputs, ancillary inputs (total use of resources and added materials - ΣZ_Z),
- energy inputs (total energy consumption - ΣZ_E)
- outputs from the process: emissions to air, emissions to water, emissions to land and the solid waste (total waste quantity - ΣO),
- costs of the technological process used (total costs of the technological process used, so the resources and added materials costs, energy consumption costs, waste neutralization and utilization costs, etc. - ΣK).

Following the optimization data (ecological, economical) collection referring technological processes their single values shall be placed in the inventory table of the database. This activity permits on comparison of every operation results for all analysed technological processes.

Stage III - Reference data to the limits in BREF

The next step of the procedure is reference of the single values in all categories criteria to the conventionally accepted or to the standard limits. The data from the analysed technological processes (concerning raw materials used, energy consumption, waste quantities) shall be reference with the suitable values in BREF for the proper production technology [4]. Because the limits of BREF do not take into account costs of the technological processes used, these costs can be conventionally accepted using materials costs, energy consumption costs (so in the case of analysed technological processes) and average costs of the materials recycling, the waste neutralizations and the waste storages.

$$\sum \frac{Z_Z}{B_Z}, \sum \frac{Z_E}{B_E}, \sum \frac{O}{B_O}, \sum \frac{K}{B_K} \tag{3}$$

where:

B - limits (negotiated values, accepted arbitrarily from the techniques collection; the data shall be definited in BREF) as the reference level of the numerical values of the raw materials used, the energy consumption, the waste quantities, the costs of the technological processes used,

Z_Z - use of resources and added materials in the analysed technological process,

B_Z - conventionally accepted, negotiated value of resources used, practical as the limitation for the analysed technological process,

Z_E - energy consumption in the analyzed technological process,

B_E - conventionally accepted, negotiated value of energy consumption, practical as the limitation for analysed technological process,

O - waste quantity (solid, liquid, gas) in the analysed technological process,

B_O - the conventionally accepted, negotiated waste quantity, practical as the limitation for analysed technological process,

K - costs of the analysed technological process,

B_K - agreed costs of the technological process used, accepted as the reference value for the technological process.

For the optimization quantitative data, obtained according to BREF, concerning: resources use, energy consumption, waste quantities and also costs of the technological process used of the analyzed operations, shall be placed in the specially part of the database inventory table.

Stage IV and V - The materials technological process optimization and verification of the optimal technological process

After the database creation we can begin the optimization [10] of the materials technological processes group (e.g. with computer use).

After the selection (with regard to environmental and economic criteria) of the optimal materials technological process we must take into consideration its environmental verification. It has in view separating of all areas which do not fulfill the limits among other things in BREF. For this purpose shall be checked the conditions which make possible come to a decision about the earlier modernization. Using the establishments presented in the Stage IV, we can favour two main variants which be subject the optimal technological process:

- the technological process is subject to the modernization or change [9], when data concerning resources used, waste quantities in following operations of the optimal technological process and also data concerning energy consumption and costs of the technological process used of each optimal technological processes operations in comparison to the conventionally accepted or negotiated values e.g. limits of BREF will be greater than one.

$$\frac{Z_{Z_i}}{B_{Z_i}}, \frac{Z_{E_i}}{B_{E_i}}, \frac{O_i}{B_{O_i}}, \frac{K_i}{B_{K_i}} > 1 \qquad (4)$$

In every case of the disagreements the data from the technological process with the limits of BREF shall be carried out the modernization of the technological process operations.

- the technological process realizes accepted limitations, among other things conditions definited in IPPC (Integrated Pollution Prevention and Control) - when data concerning resources used, waste quantities in following operations of the optimal technological process and also data concerning energy consumption and costs of the technological process used of each optimal technological processes operations in comparison to the conventionally accepted or negotiated values e.g. limits of BREF will be less or equal one.

$$\frac{Z_{Z_i}}{B_{Z_i}}, \frac{Z_{E_i}}{B_{E_i}}, \frac{O_i}{B_{O_i}}, \frac{K_i}{B_{K_i}} > 1 \qquad (5)$$

4. Summary

The problem of make decisions (management) in the company in the large part refers of the technological processes. It is also connected with the accepted criteria. These criteria are often environmental criteria which are treated in common with other criteria, such as: costs, the quality, the effectivity.

Because of that it is necessary to the estimation of the materials technological process with the environmental criteria. It provides to make decision about the choice of the optimal technological process from the group of analysed technological processes. This approach provides to the better tools search of the technically, ecologically and economically optimal technological process and especially the materials technological process.

The multiobjective optimization can be used to estimation of the technological processes group and to select of the optimal technological process.

The methods of the polyoptimization have a self-evident use accomplishing the choice of the best technological process in respect of reduced negative environmental influences.

In the paper four main environmental criteria determined: minimal use of added materials (Z_Z), minimal energy consumption (Z_E), minimal waste quantity (solid, gas and liquid) (O), minimal technological process costs (K).

These criteria are dependent themselves and they give possible to choice of the solution realizing the sustainable development rule.

Presented MSTP procedure is based on two supplementary sustainable development elements: the sustainable technology model and the environmental life cycle of the product. The modification of both tools makes possible the designing of the optimal technological process regarding to the environmental life cycle of the technological process or the modernization of existing technological processes based on BAT. Thereby the research process for the optimal solution should be based on the continuous monitoring.

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