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# Sustainable technological process as an element of the sustainable development strategy realisation

**R. Nowosielski, M. Spilka***
Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
* Corresponding author: E-mail address: monika.spilka@polsl.pl

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**Cleaner production and biotechnology**

## ABSTRACT

**Purpose:** The aim of this work is a presentation of the possibility of the sustainable development conception realisation through the sustainable technological processes designing and implementation.
**Design/methodology/approach:** The article includes analysis and estimation of the nickel and chromium coated on the metal elements. In order to modernization of the real process in direction to the sustainable process, the technical solutions which minimise influence on the environment of galvanic treatment process were presented.
**Findings:** The sustainable technological process reduces the achievement of the sustainable development to small area analysis which is the technological process, what makes possible the quantitative estimation (in the internal area of technology).
**Research limitations/implications:** The definition, the model of the sustainable technology and the sustainable development conception are relative and they have not clear character. It means there is no possibility of absolutely the best technology or technological process determination. Because of that we can only design the better process in the comparison with another with regard to adequate criteria.
**Practical implications:** The solution presented in the paper can apply in the industry to estimation and selection of a group of technological processes which characterise different environmental influences.
**Originality/value:** The paper presents search for the sustainable technological processes according to proposed procedure of the sustainable technology design and implementation. Application of the sustainable technological processes in the local scale can leads to the sustainable development conception realisation in the global scale.
**Keywords:** Industrial application; Cleaner production methods; Sustainable development; Sustainable technological process; Galvanic treatment

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## 1. Introduction

Global results connected with sustainable consumption and production and closely connected with effective productive assets using invite to the opinion modification connected with applying the sustainable development postulates [1-3]. The sustainable development problems should be analysed and controlled in suitably small areas of economic processes in this productive [4]. To the several tools making possible such actions belong: life cycle assessment of a product procedure, cleaner production, ecoefficiency, and environmental management systems [5-7]. In the principle, these tools relate to the area of the enterprise, but they can be usage in fragments at least, applied to the smaller elements of the system analysis. It seems that the technological process should be the smallest area, the most suitable to the analysis, hence the sustainable technology conception. However, it is difficult talk about the sustainable technology but more easily about the sustainable technological processes in which we can make quantitative measurements [8]. Therefore search and implementation of the best available technological solutions [9,10], causing decrease of the waste quantity and the economic effects obtained are the basis of the sustainable technology conception. Using this conception in the local scale, it can leads to the sustainable development conception realisation in the global scale (Fig. 1).

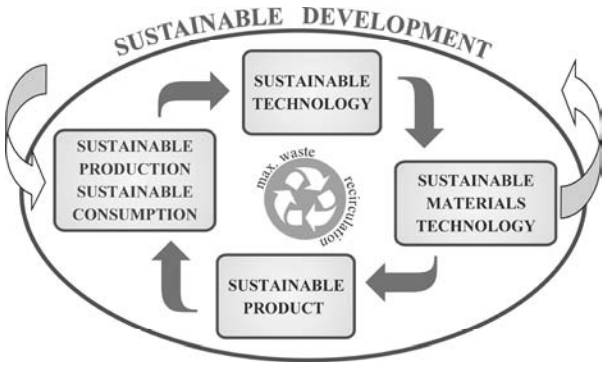


Fig. 1. Schema of sustainable development achievement

## 2. The idea of the sustainable development

The world is in the sustainable development stage which essence is programming of the development in direction to conservation and renewal of the particular resources and whole ecosystems.

In the theoretical foundations at least two approach of the sustainable development perception function as the ecological and the civilisation [11].

The sustainable development in the ecological aspect is perceived as the process of limiting the pressure on the environment and the improvements of its condition through the economic ecological processes and the integrated environment protection systems implementation.

The sustainable development in the civilisation aspect means the process of search, check and implementation of the new economic development forms (not duplication actually existing), the new technologies, the new energy and social communication forms and the new extraeconomic forms of the society activity also.

The sustainable development conception founds [12]:

- renewable energy resources (water, in this geothermal water, solar radiation and wind) used together with energy reduction implementation through efficiency enlargement in the production processes and economic energy using, what make possible the inexhaustible energy resources preservation for the future generations;
- promotion of the minimum and no waste technology and safe for the natural environment products;
- material cycles closing including the production cycle, the product exploitation and utilization; it lets on decrease of energy consumption, materials used and qualitative product improvement assurance.

The result of above is the universal sustainable development conception. It constitutes the social - economic development philosophy, taking into consideration both the economy and the current society and the future generations [13].

The sustainable development ideas and their basic rules relatively can be easily described in the total scale. In the total scale materials used, quantity of waste generated and energy consumption minimisation easy are postulate.

In fact, all results in the total scale are a sum of all local economic processes and productive processes in the world. So the basic problem of present economic processes is the elaboration of method of the integrated influence on local, individual (elementary) productive events. These local productive events can relate to the level of technological processes and particularly to the materials technological processes [14]. Because of that the materials and materials processes in productive processes and their influence on the environment (and especially for the possibility of the recirculation of a product life cycle in the final stage) are important.

## 3. The conception of the sustainable technology

The technological process was recognised as one of smallest local, elementary areas which has influence on realisation of the sustainable development principles in the global scale. To get intentional results according to the sustainable development principles, technology which consists of the technological processes has to be sustainable [14].

Every technological process in general way can be described to mutual account of three basic streams: stream input (raw materials and energy), stream output that is the stream of products and the stream of waste which make growing environmentally threat.

An alternative for presented process is the process which has no waste - sustainable. This means that the technology and especially important in the production processes the materials technology is sustainable when it is in full symbiosis with the environment (environment understood as a nature and a society). Hence made an attempt of the sustainable technology model elaboration which makes possible the sustainable development requirements realisation [15].

The essential is that the model of the sustainable technology is based on three main aspects: ecological, social and economic, what is agreed with the principles of the sustainable development (Fig. 2). The full integration of the sustainable technological process operations leads not only to the natural resources protection, but it causes also increase of the process productiveness and its economic profitability.

However the premise of the model is the endeavour to the entirely zero waste process which in the reality does not exist. The perfect process does not also exist. The ideal solution, in which the sum of materials mass on input is equal to the sum of products on output is impossible, because do not allow to this the thermodynamics principles. In practice always appear some streams of waste and we can only minimise them. Hence the basic activity in the sustainable development direction should be analyse, technical and ecological estimation and searching for proper (better) technological processes which limit: resources used, energy consumption, and first of all quantity of waste. Take into account such approach, the realisation of the sustainable development principles on the level of the technological process, should be the optimisation process, based on search for better solutions (with regard to criterion or criteria), minimising the negative influence on the environment.

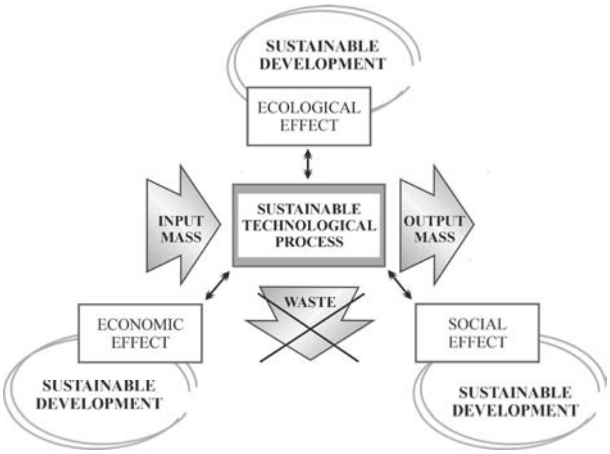


Fig. 2. The simplified model of the sustainable technology

To achievement the sustainable technology model, the simple tool making possible its implementation proposed. It is the sustainable technology procedure [16], elaborated on the basis of the well known waste minimisation procedure. In this procedure the estimation phase and the phase of analysis of realisability conditions developed and subordinate to the sustainable technology model requirements. The difference is that the waste minimisation procedure leads to the environmental management system creation, the sustainable technology procedure leads to designing of the sustainable technological process.

Therefore a basic part of the sustainable technology procedure is the analysis of the realistic (existing) technological process relating to identification of reasons causing “unbalancing” of the technological process, and then to search for solutions having the distinct influence on its improvement (modernisation) or designing of the new better technological process [16,17].

The essence of this is the opinion that there is no absolutely perfect technological process and we search for the best process (optimum) because of many related with each other environmental, economic, technological, market criteria and maybe many different [18,19,20].

Procedure of the sustainable technology design and implementation consists of seven phases [16]:
1. preparation,
2. identification,
3. collection of solutions,
4. analysis of solutions,
5. project of the technological process modernisation,
6. implementation and,
7. reaching of the established production capacity.

Purpose of the preparation phase for the possible modernisation or a change of the technological process is checked up of its necessity. Thereby a first stage of this procedure is analyse of the technological process in respect of technical, ecological and economic. It can be achieved by the general review of practical devices, issues of hazardous substances to the environment and the costs of the technological exploitation process. Obtained results from the review, mostly ecological and technical should be comparing with present obligatory legal (laws, permissions) concerning requirements of analysed technological process. In the case of the disagreement should be making a decision about the modernisation of the technological line or change the technological process for sustainable. At this stage of the procedure is important to appoint the team of persons whose an assignment would be the organization of the procedure.

The identification phase consists on the qualification, in the first stage, the aim of the modernisation or the technological process changes. The aim should define the direction for further activities. The modification or the possible technological process changes has to make eliminations of the usage of hazardous substances and changes of materials on the input of the technological process. The main aim of the modernisation of the technological process is the decrease of costs by the diminution of the quantity forming losses in consequence of carry off the excessive quantity of waste by the introduction of technical solutions. At this stage of the area identification analysis should be define limits of the technological process. Accordingly the specification and the discussion of operations input into analysed technological process are necessary.

A following stage is the identification of problems for solution occurrent in the area of each operations. So prepared of the technological process is necessity. At this should be prepared the schema of flows in the technological process names the balance of materials, energy, waste and costs. The balance is the method comparing all elements input of the technological process (materials, water and energy) with elements which must output the process in the form of the useful product or waste (solid, liquid, gas). Obtained results from analysis can be presented on circular graphs, histograms, diagrams, etc. On this stage of the procedure it is necessary to identify connected costs with each position of the input and the output also. From the balance should be defined problems which generates analysed technological process, so following phase of the procedure is proposing of alternative solutions eliminating negative results of each operations.

The phase of collection of solutions consists of the search, and then collecting of the wide group of alternative solutions variants. During collection of optimum solutions exists the possibility of the adaptation of well-known solutions, obtained from the specialist technical literature, from specialists, producers of devices or creation methods.

The analysis of solutions phase indicated which from proposed solutions are possible for implementation. In the stage of the initial solutions selection should be defined set border of proposed solutions. The solutions collection of possibly for implementation should contain the manners of waste elimination at the source of their formation, what causes the decrease of technological process costs in consequence of the removal of problems connected with waste. In case when do not exist such solutions should be concentrate on methods basing on the recirculation which permit to use waste by reuse the substitute of the raw materials in the original technological process (or added materials to other technological process). Collected alternative solutions variants are subject then for the estimation to which the main criterion is the cost of introduced changes. From here at the decision about the solutions choice for the further analysis making should be turn into direction to variants of concerning modifications. These variants can be cheap implemented in the short time period, and which also promise the main chances on minimisation of the negative influence on the environment. The implementation of solutions variants can carry out using techniques of the decision making. One of many especially useful methods is the method of the weighted sum, making possible the analysis and the variants estimation.

An effect of the initial selection is the choice of optimum solutions which become created of the segregation on thematic groups. In this stage should be realised the technical, ecological and economic analysis of sorted variants. The aim of the technical analysis is defined if proposed variant is possible to work in the concrete technological process. Finally, the best solutions to implementation are chosen.

The aim of the project of the technological process modernisation phase is the preparation of the final report, in which will be presented the possible implementation of proposed solutions. The final report is the base for the collection of investment decisions and elaborations the business plan.

A first stage of the implementation phase is the preparation of the business plan for get money on project completion or the change of the technological process. Next stage of the procedure is preparation of the technical draft which will make possible the decision making about the implementation. The plan of time limits of the realisation of the project will be indicated in the schedule of implementation.

The aim of the reaching of the established production capacity phase is the estimation of obtained results with assumptions. In case when results are not compatible with a project, the variants which not realizing initial expectations must be subject to the renewed elaboration or to the modification.

The generality of the sustainable technology methodology and its simplicity contributes to continuous analysing and improving of every technology, especially the materials technology [17].

## 4. Proposal of the sustainable technological process: case of the galvanic treatment process

According to the procedure of the sustainable technology design and implementation, it is necessary the full ecological (taking into consideration added materials, energy consumption and waste quantities), technical and cost analysis of the selected technological process performed.

For illustration of elaborated procedure realistic nickel and chromium coated technological process was chosen. In the formal consideration the procedure was used without I, VI, VII phases.

### 4.1. The identification phase

The aim of the modernisation stage of the galvanic treatment is the costs reduction of the technological process realisation. It can be done by the implementations of technological solutions allowing to minimisation of the resources and energy consumption and the same the difficulties waste quantity limitation. This indicates minimisation of threats for the natural environment and health of workers.

The product subject to the galvanic treatment shows Fig. 3. Schema of analysed process is presented in Fig. 4.

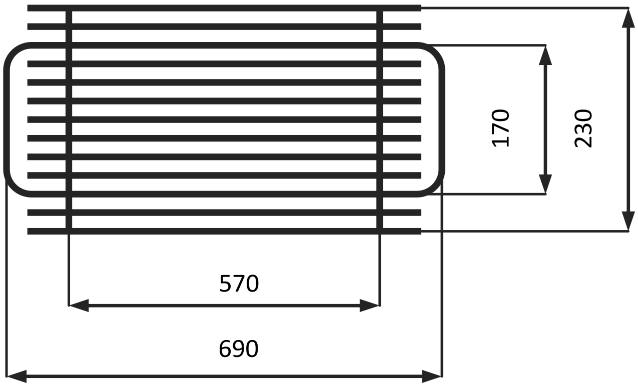


Fig. 3. The metal element subjected to the galvanic treatment (dimension mm)

Table 1.
The technological data comparison concerning the analysed nickel and chromium plating technological process

| Operations | Bath compositions | Temperature, °C |
|---|---|---|
| Defatting | NaOH, $Na_2CO_3$, $Na_3PO_4$ | 45 |
| Rinsing | $H_2O$ | 15 |
| Pickling | HCl | 15 |
| Rinsing | $H_2O$ | 15 |
| Nickel plating | $NiSO_4 \cdot 7\ H_2O$, $NiCl_2 \cdot 6\ H_2O$, $MgSO_4 \cdot 7\ H_2O$, $H_3BO_3$ | 42 |
| Rinsing | $H_2O$ | 15 |
| Chromium plating | $CrO_3$, $H_2SO_4$ | 50 |
| Rinsing | $H_2O$ | 15, 40 |

The nickel and chromium technological process is characterised with the following production parameters (Table 1):

- the average production - elements surface treatment - 9500 $m^2$/year (galvanizing plant worked - 10 months production, 2 months production line regeneration),
- production line - working time - 3 changes - 24 h,
- electroplating bath - nickelous and chromic,
- tanks capacity - 2100 l (nickel and chromium plating, pickling), 1500 l (defatting and rinsing).

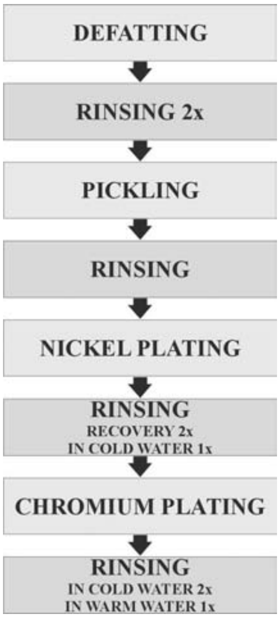


Fig. 4. Sequences of the operations carry out in the analysed process

In the aim of the problems identification which occur in the analysed process the materials, energy, waste and costs balance was prepared - separately for every operation of the process (Tables 2-6 and Figs. 5-7).

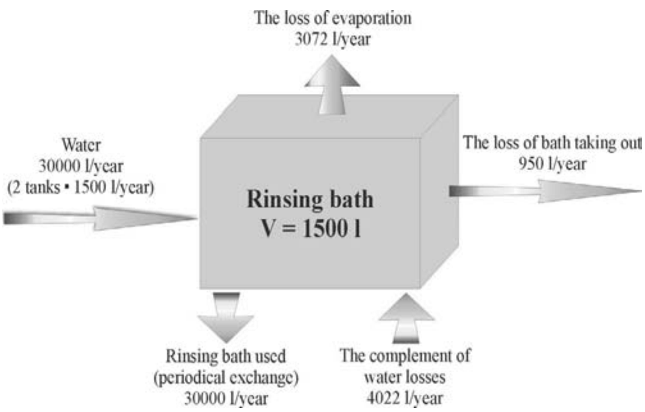


Fig. 5. The material balance of the rinsing operation after defatting operation

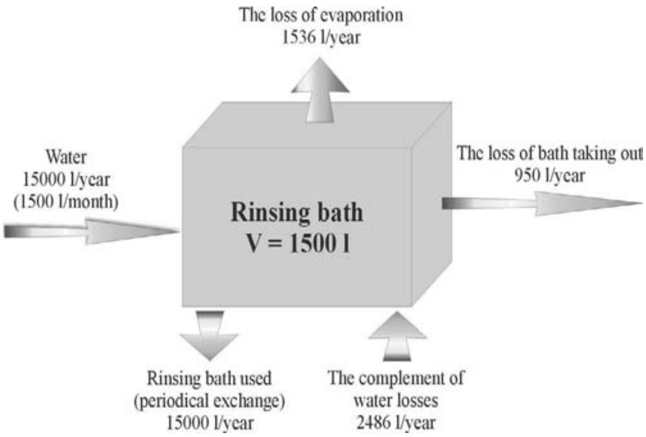


Fig. 6. The material balance of the rinsing operation after pickling operation

Table 2.
Comparison of the materials used and losses, energy consumption and waste quantity of the defatting operation (two times bath exchange in the year)

| Materials used | kg/year |
|---|---|
| sodium hydroxide | 150 |
| sodium carbonate | 90 |
| trisodium ortophosphate | 120 |
| water | 2640 |
| **Materials completing the losses** | **kg/year** |
| water completing the losses of evaporation | 11520 |
| water completing the losses from bath taking out | 836 |
| NaOH completing the losses from bath taking out | 47.5 |
| $Na_2CO_3$ completing the losses from bath taking out | 28.5 |
| $Na_3PO_4$ completing the losses from bath taking out | 38 |
| **Waste quantity** | **kg/year** |
| $H_2SO_4$ to sewage neutralisation | 20 |
| sludge after neutralisation | 380 |
| liquid after neutralisation | 2620 |
| **Energy consumption** | **kWh/year** |
| Energy necessary to warming of the bath from the ambient temperature to the temperature of the bath work - $Q_o$ | 104.7 |
| Energy necessary to the complement of the warm losses through the tank - $Q_s$ | 806.4 |
| Energy necessary to the complement of the warm losses through the surface of the tank - $Q_p$ | 1843.2 |
| Energy necessary to the compensation of the warm losses connected with the heat transfer of bath by the treatment metal elements - $Q_w$ | 182.4 |
| Energy necessary to the heating up the bath completing loss of element taking out and evaporation - $Q_u$ | 435.4 |

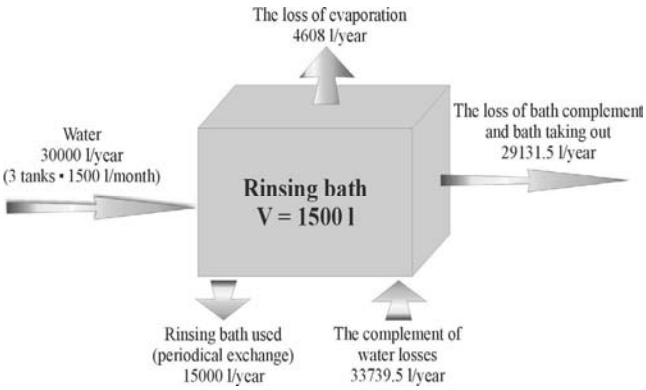


Fig. 7. The material balance of the rinsing operation after nickel plating operation

Table 3.
Comparison of the materials used and losses and waste quantity of the pickling operation (two times bath exchange in the year)

| **Materials used** | **kg/year** |
|---|---|
| hydrochloric acid | 126 |
| water | 4074 |
| **Materials completing the losses** | **kg/year** |
| water completing the losses of evaporation | 2112 |
| water completing the losses from bath taking out | 921.5 |
| HCl completing the losses from bath taking out | 28.5 |
| **Waste quantity** | **kg/year** |
| deposits after pickling | 428.2 |
| $Ca(OH)_2$ to sewage neutralisation | 127.3 |
| sludge after neutralisation | 253.3 |
| liquid after neutralisation | 3946.7 |

Table 4.
Comparison of the materials used and losses, energy consumption and waste quantity of the nickel plating operation

| **Materials used** | **1 tank** | **2 tanks** |
|---|---|---|
| | **kg/year** | **kg/year** |
| nickel sulfate | 735 | 1470 |
| nickel chloride | 105 | 210 |
| magnesium sulfate | 84 | 168 |
| boracic acid | 84 | 168 |
| demineralised water | 1092 | 2180 |
| **Materials completing the losses** | **kg/year** | **kg/year** |
| water completing the losses of evaporation | 12672 | 25344 |
| water completing the losses from bath taking out | 650.8 | 650.8 |
| $NiSO_4 \cdot 7\,H_2O$ completing the losses from bath taking out | 237.5 | 237.5 |
| $NiCl_2 \cdot 6\,H_2O$ completing the losses from bath taking out | 23.8 | 23.8 |
| $MgSO_4 \cdot 7\,H_2O$ completing the losses from bath taking out | 19 | 19 |
| $H_3BO_3$ completing the losses from bath taking out | 19 | 19 |
| nickelic anode | 1150 | 2300 |
| **Energy consumption** | **kWh/year** | **kWh/year** |
| $Q_o$ | 15.7 | 31.5 |
| $Q_s$ | 801.6 | 1603.2 |
| $Q_p$ | 2280 | 4560 |
| $Q_w$ | 168 | 336 |
| $Q_u$ | 102.1 | 204.1 |
| Energy necessary to the bath filtration | 8224 | 8224 |

Table 5.
Comparison of the materials used and losses, energy consumption and waste quantity of the chromium plating operation

| **Materials used** | **kg/year** |
|---|---|
| chromic anhydride | 525 |
| sulfuric acid | 3.3 |
| demineralised water | 1571.8 |
| **Materials completing the losses** | **kg/year** |
| water completing the losses of evaporation | 20064 |
| water completing the losses from bath taking out | 1861 |
| $CrO_3$ completing the losses from bath taking out | 237.5 |
| $H_2SO_4$ completing the losses from bath taking out | 1.5 |
| **Waste quantity** | **kg/year** |
| deposits after chromium plating | 729.8 |
| neutralisation | 2467.5 |
| sludge after neutralisation | 2992.5 |
| **Energy consumption** | **kWh/year** |
| $Q_o$ | 20.4 |
| $Q_s$ | 1041.6 |
| $Q_p$ | 2956.8 |
| $Q_w$ | 216 |
| $Q_u$ | 204.1 |

Table 6.
Comparison of the materials used and losses, energy consumption and waste quantity of the rinsing operation after chromium plating operation

| Materials used | kg/year |
|---|---|
| water | 45000 |
| **Materials completing the losses** | **kg/year** |
| water completing the losses of evaporation | 10752 |
| water completing the losses from bath taking out | 950 |
| **Waste quantity** | **kg/year** |
| rinsing bath used | 45000 |
| **Energy consumption** | **kWh/year** |
| $Q_o$ | 436.5 |
| $Q_s$ | 672 |
| $Q_p$ | 1536 |
| $Q_w$ | 153.6 |
| $Q_u$ | 223.8 |

Comparison of the total waste quantity in the nickel and chromium plating technological process presented in Fig. 8, the total costs of the analysed process shows Fig. 9.

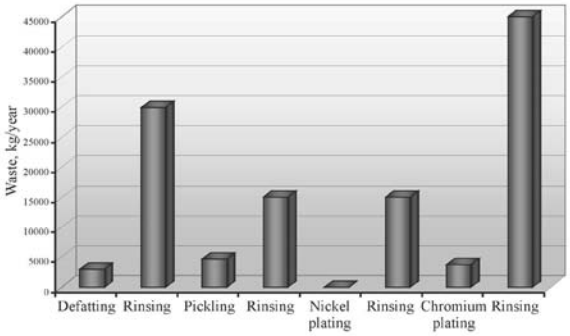


Fig. 8. Comparison of total waste quantity in the nickel and chromium plating technological process

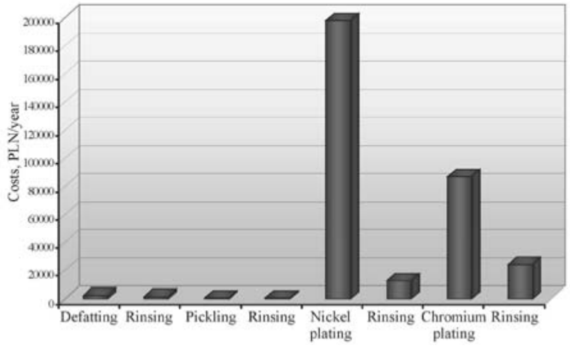


Fig. 9. Comparison of total costs in the nickel and chromium plating technological process

Considering this that the nickel and chromium electroplating technological process does not sustainable, several areas separated which should be subject to the modernisation.

To the basic problems - threats can be accepted:

- using of harmful defatting substances,
- using of electroplating high concentration baths,
- high water consumption in the rinsing operation,
- high water losses (e.g. evaporation etc.),
- dangerous waste (sewage, sludge) disposal to the environment which have high metals, acid concentration.

To eliminate these problems it is necessity solutions implementation, which eliminate the threats for people and environment, minimise the materials and energy losses, and the costs of the process realisation [21].

## 4.2. The collection of solutions phase

- Using of harmful defatting substances - proposal solutions: defatting using water substances, elongation of the defatting standing, possibility of the defatting minimise or reduction, ultrasonic defatting.
- Using of electroplating high concentration baths - proposal solutions: chromium plating in low concentration baths, cascade rinsing, showerly rinsing and rinsing in water fog, without flow static rinsing, using the same water again, improvement of the rinsing efficiency, rinsing recycle.
- High water losses (e.g. evaporation, etc.) - proposal solutions: elongation of the drip time, drip plate installation, drip bath installation, evaporation limitation, aerosol limitation.
- Used up technologic baths to the environment disposal - proposal solutions: elongation of electrolyte function time, filtration and ultrafiltration, ion exchange resin used, direct technologic baths recovery, direct baths recovery in LAFT system.
- Dangerous waste (sewage, sludge) disposal to the environment - proposal solutions: possibility of the electro-deposit used, elongation of the pickling bath life, ion exchange, electrochemical recovery, reverse osmosis.

## 4.3. The analysis of solutions phase

In this phase the best solutions selected and proposed several solutions which cause considerable ecological and economic effects. These solutions which are simple, cheap and easy to the use will be the most profitable.

The following variants of solutions were chosen to the more far analysis: baths covers used, defatting with water substances used, elongation of the pickling bath life, recycle of pickling bath, elongation of chromic bath with ion exchange resin used, chromium plating in low concentration baths used, three-stage cascade recovery rinsing used.

## 4.4. The project of the technological process modernization phase

Proposed solutions allowed waste reduction and they minimise costs of the technological process used. In connection with above the solutions lead to the sustainable process achieved.

The comparison of ecological and economic effects presented Figs. 10 and 11.

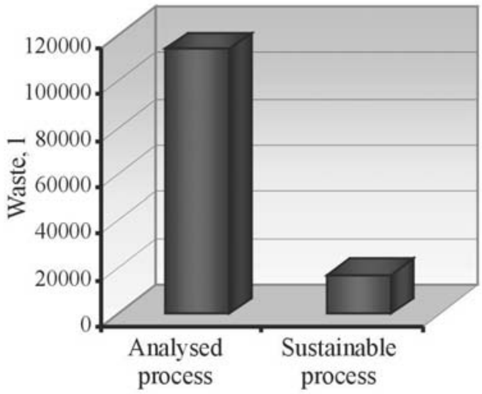


Fig. 10. Ecological effects which can be obtained after the sustainable technological process applied

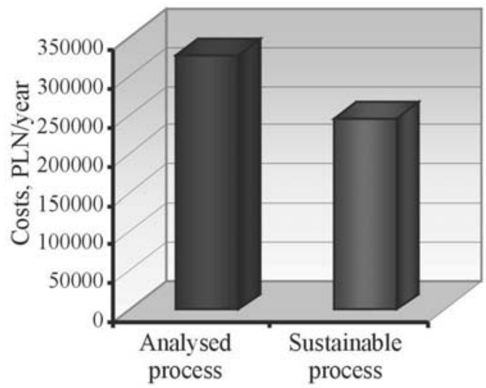


Fig. 11. Economic effects which can be obtained after the sustainable technological process applied

## 5. Conclusions

The definition and the model of the sustainable technology, and more closely - the sustainable technological process reduce of the sustainable development achievement to small area analysis which is the technological process, what makes possible the quantitative estimation (in the internal area of technology). It also facilitates, depending on possibility and needs, the analysis in the larger area taking into account external environment. However, the definition, the model of the sustainable technology and the sustainable development conception are relative and they have not clear character. It means there is no possibility of determination of absolutely the best technology or technological process. Because of that we can only design the better process in the comparison with another with regard to adequate criteria.

In order to modernisation of the real process in direction of the sustainable process presented technical solutions which minimise influence of galvanic treatment process on the environment.

It was estimated, that the proposed solutions implementation to the analysed process of the nickel and chromium plating should let on:

- decrease of the losses evaporation of water about 70% and energy consumption about 60% thanks to the tank covers used,
- minimisation of waste toxicity in the cleaning process through the change of the chemical constitution of the technological baths,
- reduction of the harmful substances emission to the atmosphere,
- prolongation of a period of technological baths used till four years for the systems of the internal recycling,
- decrease of the exploitation costs connected with the process,
- improvement of the workers conditions and cleaner environment for inhabitants.

Suggested solutions will ensure the obtainment of ecological, economic and social effects and they are compatible with the sustainable technology model principles.

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