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Technological processes optimisation according to MSTP procedure

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Analysis and modelling

ABSTRACT

Purpose: The paper presents optimization of technological processes according to MSTP (Modified Sustainable Technology Procedure) procedure by general analysis and estimation (with regard to BREF-BAT Reference Documents) of three realistic zinc plating technological processes.

Design/methodology/approach: In this article one of the polyoptimization methods - genetic algorithms (GA) for technological processes optimization has been proposed. As well as the universal software Poli-Opt version 1.0 for technological processes optimization has been presented.

Findings: Polyoptimization using simple genetic algorithms makes possible negative environmental influences minimization. It also leading to ideal process obtaining that in reality does not exist.

Research limitations/implications: The optimum solution in polyoptimization process is not absolutely optimum. This solution is about the largest probability of optimum obtaining. This results from the fact of different criteria and different objective function values using.

Practical implications: The simple and universal Poli-Opt version 1.0 software using elementary, but quite sufficient in practice, genetic algorithm could be in every company applied.

Originality/value: The Modified Sustainable Technology Procedure with computer supported could be for every materials technological processes optimization used.

Keywords: Artificial intelligence methods; MSTP procedure; Genetic algorithms; Zinc plating technological process

1. Introduction

In the aim of optimum materials technological processes selection it is necessary a modern and simple tool creation [1, 2].

The MSTP (Modified Sustainable Technology Procedure) procedure is one of such tools of the optimum materials technological process searching. The MSTP procedure [3, 4] makes possible the efficient and easy analysis and estimation of every technological process operations. It is based on two supplementary sustainable development elements: the sustainable technology model and the environmental life cycle of the product [5]. The modification of both tools makes possible the designing of the optimum technological process regarding to the environmental life cycle of technological process or modernization of existing technological processes based on BAT [6, 7].

The detailed technological process analysis has a meaning, if identified technological processes about the different negative environmental influences. It requires the database creation which is necessary for optimizing the group of different parameters of technological processes with artificial intelligence methods used.

The MSTP procedure defines main conditions that must be realized for the technological processes optimization effect. The main aim of the universal MSTP procedure is the objective function defined. It is very important because from it form depends the correctness of the carried out optimization.

For the materials technological process optimization with regard to the accepted environmental criteria (minimum added

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materials used, minimum energy consumption, minimum waste, minimum costs) the Poli-Opt version 1.0 software can be used. This programme is based on the one of the polyoptimization methods - genetic algorithms (GA) [8-11].

2. MSTP testing for the zinc plating technological processes optimization

According to the elaborated procedure, it is necessary the full ecological (taking into consideration added materials, energy consumption and waste quantities), technical and costs analysis of the selected technological processes performed.

2.1. The identification phase

For illustration of MSTP procedure [3] using computer programme based on genetic algorithms, three realistic zinc plating technological processes were chosen (Fig. 1, Table 1).

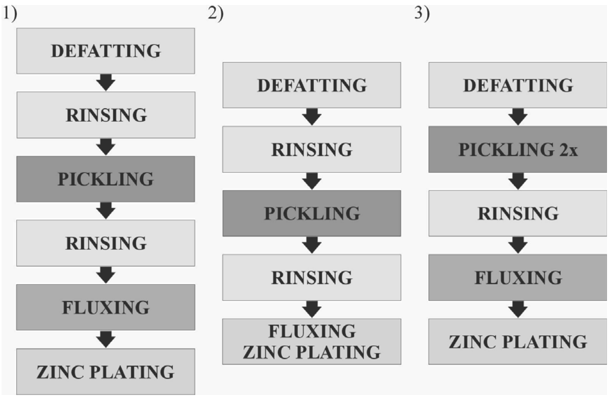

Fig. 1. Schema of tanks set in the production hall [12]; 1) zinc plating technological process 1, 2) zinc plating technological process 2, 3) zinc plating technological process 3

Stage I - defining of the functional unit

The analysed product of these processes is the zinc coated platform grid. In the elaboration, from the formal consideration, the II and III phase of the procedure were used [12, 13].

In the case of the zinc plating technological process (and the others processes coats too), the suitable functional unit is the surface subjected to zinc coated. Considering this, that BAT (Best Available Techniques) appointed of limits: raw materials used, energy consumption, waste quantities in the count over again for 1 Mg treatment details, the agreed surface of zinc coated details (the platform grid) equal 64.5m^2 applying to 1 Mg accepted.

For the estimation defined the optimum functional unit:

„Raw and added materials used, energy consumption to the technological process used and total raw materials costs, energy costs, quantities of waste in the counted over again on the zinc coated surface equal 64.5 m^2".

Stage II and III - inventory and database creation; data reference to BREF limits

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 aim, it is helpful to do: resources and added materials balance, energy balance, waste balance and costs balance. It is necessary that these balances for every analyzed zinc plating technological process operation separately performed.

The analysed zinc plating technological processes (subjected to estimation and polyoptimization) are characterized with the following production parameters [12]:

- platform grid dimension: 1000x500; mesh dimension: 34.3x25.4; flat (h = 20, g = 2); ribbed reinforcing bar (ø 5.8)
- the average production (the mass of zinc coated details):
  - zinc plating technological process 1–1200 Mg/year
  - zinc plating technological process 2–2160 Mg/year
  - zinc plating technological process 3–1920 Mg/year
- surface of zinc plating technological processes: 64.5 m^2/Mg
- the zinc coated details surface:
  - zinc plating technological process 1–77400 m^2/year
  - zinc plating technological process 2–139320 m^2/year
  - zinc plating technological process 3–23840 m^2/year
- working time - 3 changes–24 h
- tanks dimension:
  - zinc plating technological process 1–1000x1000x1500
  - zinc plating technological process 2–2600x1000x2000
  - zinc plating technological process 3–2600x1600x1200
- working days quantity–240 days/year

One of the main elements of materials technological processes optimization considering environmental criteria is the database creation. This database should be transparent and clear, because from it depends the final result of the optimization. It is significant, that the database creation stage allows to comparison of all results relating various technological processes for every estimation criterion (added materials used, energy consumption, quantity of waste and costs of technological processes realization).

According to the MSTP procedure, for analysis needs, the inventory table for every criterion separately created (the computer database). In this Table includes data of: raw and added materials used (Table 2), waste quantities (Table 3), energy consumption (Table 4) and costs (Table 5) for every separated operations of analysed zinc plating technological processes.

The last, fourth line of the database includes average limits of: raw and added materials used, energy consumption, waste quantities for every zinc plating technological processes operation which are defined for the zinc plating in BAT Reference Documents (unity zinc plating) [14, 15]. These data we can find on the internet page: http://eippcb.jrc.es.

For "Raw and added materials used" criterion distinguished following raw and added materials: water consumption (in the defatting operation, rinsing I operation, rinsing II operation, pickling operation and fluxing operation), defatting inhibitor used, hydrochloric acid used, flux and zinc and zinc ash used (Table 2).

Table 1.
Technological data (for every operation) of analysed zinc plating technological processes comparison [12]

operations	Zinc plating technological process 1	Zinc plating technological process 2	Zinc plating technological process 3
defatting	alkaline NaOH, Na_2CO_3 surface-active substance temperature 50°C	alkaline (on the base NaOH) surface-active substance temperature 50°C	acid HCl surface-active substance temperature 50°C
rinsing	H_2O temperature 15°C	H_2O temperature 15°C	–
pickling	HCl pickling inhibitor temperature 15°C	HCl pickling inhibitor temperature 15°C	HCl (2 tanks) pickling inhibitor temperature 30°C
rinsing	H_2O temperature 15°C	H_2O temperature 15°C	H_2O temperature 15°C
fluxing	dry fluxing $ZnCl_2$, NH_4Cl surface-active substance temperature 15°C	wet fluxing $ZnCl_2$, NH_4Cl glycerine surface-active substance temperature 450°C	dry fluxing $ZnCl_2$, NH_4Cl surface-active substance temperature 60°C
zinc plating	Z1 electrolytic zinc ZZA1 (Zn-Al) alloy temperature 450°C	Z5 zinc ZZA1 (Zn-Al) alloy temperature 450°C	Z5 zinc ZZA1 (Zn-Al) alloy temperature 450°C

Table 2.
Raw and added materials of analysed zinc plating technological processes used (with BREF limits) [g/Mg] [3, 8]

No of the process	water - defatting	water - rinsing I	water - pickling	water - rinsing II	water - fluxing	defatting medium	HCl acid	inhibitor	flux	zinc	zinc ash
1	21994	22410	12790	22410	960	1076	2095	28	24254	32630	7252
2	48010	36740	14830	36740	8600	2982	2570	64	5850	32630	0
3	31630	0	30250	40150	19970	571	4440	53	31356	32630	7252
4	12000	15000	17500	15000	10000	2000	9200	100	2500	73400	7500

Table 3.
Waste quantity of analysed zinc plating technological processes (with BREF limits) [g/Mg] [12, 14]

No of the process	defatting–sewage and sludge	defatting - oiled sludge	washings I	pickling – sewage and sludge	washings II	fluxing - sewage and sludge
1	7500	1000	15000	7501	15000	52590
2	28880	1000	28900	9600	28900	14400
3	9240	1000	0	20810	31200	35980
4	2700	160	15000	25000	15000	10000

Table 4.
Energy consumption of analysed zinc plating technological processes (with BREF limits) [kWh/Mg] [12, 14]

No of the process	defatting	pickling	fluxing	zinc plating
1	7.240	0	0	154.340
2	9.136	0	0	221.460
3	10.139	2.763	15.580	315.605
4	22.300	12.500	0	180.000

Table 5.
Costs of analysed zinc plating technological processes [PLN/Mg] [12, 14]

No of the process	defatting	rinsing I	pickling	rinsing II	fluxing	zinc plating
1	4.79	0.74	4.42	0.74	98.96	184.00
2	19.70	1.40	6.38	1.40	24.74	219.08
3	5.35	0	13.32	1.49	139.21	240.45
4	18.60	0.66	11.07	0.66	15.00	390.56

For "Waste quantity" criterion, for pollution areas identification accepted: sewage and sludge quantity and oiling up sludge in defatting operation, washings I (II) quantity, sewage and sludge quantity in defatting operation and also sewage and sludge quantity in fluxing operation (Table 3).

In case of "Energy consumption" criterion and "Costs" criterion, total energy consumption and total costs of every zinc plating technological processes were appointed (Tables 4 and 5). The tables above (for Poli-Opt version 1.0 software needs) in Excel programme known as „BazaDanych.xls" (every estimation criterion in individual sheet) were created.

After computer database creation the file known as „BazaDanych.xls" to Poli-Opt version 1.0 software was transferred.

Stage IV and V - materials technological processes optimization and verification of the optimum technological process

The optimization of analysed technological processes is the next stage of MSTP procedure. In this aim weights of individual estimation criteria were defined.

Weight values for accepted estimation criteria can suitably be modified. For zinc plating technological processes optimization the same weight values were established.

In case of GA [8-11] the following parameters of the genetic operators were defined [12]: mutation probability–0.35, crossing–0.01, generations number–100, person number–100.

Poli-Opt software counted modified objective function (f) (1-4) [12].

After calculations end the programme shows window about favourable or unfavourable end of optimization process.

The optimum solution (zinc plating technological process 1) with input data and limits of BREF represented in Table 6.

The optimum zinc plating technological process 1 does not realize all requirements of BREF for zinc plating (unity zinc plating). Because of that several areas separated (on restrictive conditions basis, which defined as added materials used values, energy consumption values, waste quantities and also costs values of each optimum zinc plating technological process operation with reference to suitable BREF limits; restrictive condition for modernization should be greater than 1) which should be modernization subjected.

In case of raw and added materials used should be reduced [12]:

- water consumption in defatting operation
  restrictive conditions: $Z_Z/B_Z = 1.83$
- water consumption in rinsing I operation
  restrictive conditions: $Z_Z/B_Z = 1.494$
- water consumption in rinsing II operation
  restrictive conditions: $Z_Z/B_Z = 1.494$
- flux used
  restrictive conditions: $Z_Z/B_Z = 9.7$

In case of waste should be minimized [12]:

- sewage and sludge quantity in defatting operation
  restrictive conditions: $O/B_O = 2.778$ (for sewage and sludge)
  restrictive conditions: $O/B_O = 6.25$ (for oiling sludge)
- sewage and sludge quantity in fluxing operation
  restrictive conditions: $O/B_O = 5.259$

Considering costs of each optimum zinc plating technological process operation, it is necessary total costs reduction [12]:

- rinsing I operation
  restrictive conditions: $K/B_K = 1.121$
- rinsing II operation
  restrictive conditions: $K/B_K = 1.121$
- fluxing operation
  restrictive conditions: $K/B_K = 6.597$

Energy consumption in the optimum zinc plating technological process suited the limits of BREF (Table 6).

Table 6.
Comparison of raw and added materials used, energy consumption, waste quantity and costs of optimum technological process and BREF limits [12, 14]

Raw and added materials used [g/Mg]											
	water - defatting	water - rinsing I	water - pickling	water - rinsing II	water - fluxing	defatting medium	HCl	inhibitor	flux	Zn	recovery Zn
optimum process	21994	22410	12790	22410	960	1076	2095	28	24254	32630	7252
BREF	12000	15000	17500	15000	10000	2000	9200	100	2500	73400	7500
Energy consumption [kWh/Mg]											
	defatting	pickling	fluxing	zinc plating							
optimum process	7.2400	0	0	154.340							
BREF	22.300	12.500	0	180.000							
Waste quantity [g/Mg]											
	defatting - sewage and sludge	defatting - oiled sludge	washings I	pickling - sewage and sludge	washings II	fluxing - sewage and sludge					
optimum process	7500	1000	15000	7501	15000	52590					
BREF	2700	160	15000	25000	15000	10000					
Costs [PLN/Mg]											
	defatting	rinsing I	pickling	rinsing II	fluxing	zinc plating					
optimum process	4.79	0.74	4.42	0.74	98.96	184.00					
BREF	18.60	0.66	11.07	0.66	15.00	390.56					

2.2. The collection of solutions phase

Considering that all areas of optimum zinc plating technological process 1 do not accomplish limits of BREF several improvements were proposed.

$$f^*(x) = w_1 \cdot w_1^* \cdot [f_{1\max} - f_1(x)] + w_2 \cdot w_2^* \cdot [f_{2\max} - f_2(x)] + \\ + w_3 \cdot w_3^* \cdot [f_{3\max} - f_3(x)] + w_4 \cdot w_4^* \cdot [f_{4\max} - f_4(x)] \quad (1)$$

$$f^*_{\max} = \max[f_{1\max} - f_{1\min}, f_{2\max} - f_{2\min}, \\ f_{3\max} - f_{3\min}, f_{4\max} - f_{4\min}] \quad (2)$$

$$w_1^* = \frac{f^*_{\max}}{f_{1\max} - f_{1\min}} \qquad w_2^* = \frac{f^*_{\max}}{f_{2\max} - f_{2\min}}$$

$$w_3^* = \frac{f^*_{\max}}{f_{3\max} - f_{3\min}} \qquad w_4^* = \frac{f^*_{\max}}{f_{4\max} - f_{4\min}} \quad (3)$$

In case, when:

$$w_i^* = 0 \qquad \text{then} \qquad i=1,2,3,4 \qquad f_{i\max} - f_{i\min} = 0 \quad (4)$$

where:
$f^*(x)$ - modified objective function,
x - following technological process,
$f_1(x)$, $f_2(x)$, $f_3(x)$, $f_4(x)$ - objective functions concerning of adequate criteria,
w_1, w_2, w_3, w_4 - weights value reference to technological processes criteria,
w_1^*, w_2^*, w_3^*, w_4^* - weights value reference to scaling objective function with regard to accepted criteria.

From a group of possible solutions chosen these, which a smallest restrictive condition values characterized. The proposed modernizations characterized simplicity and low realization costs. They provide also to total negative environmental influences improvement and cause increasing of company efficiency.

Collecting all information about possible modernization variants it is necessary the optimum solution selection (Table 7).

During solutions analysis affirmed that both biological defatting operation and micro and ultrafiltration defatting operation realized limits of BREF. For these modernizations, to select the optimum solution, simplified objective function value was counted [3,12] (Equation 5).

$$f(x) = w_1 \cdot \frac{Z_Z}{B_Z}(x) + w_2 \cdot \frac{Z_E}{B_E}(x) + w_3 \cdot \frac{O}{B_O}(x) + w_4 \cdot \frac{K}{B_K}(x) \quad (5)$$

$f \rightarrow \min$

where:
x - decision variables (following environmental data concerning: resources used, energy consumption, waste quantities and costs of each technological process subjected to optimization),
Z_Z - total resources and added materials used in technological process,
Z_E - total energy consumption in technological process,
O - total waste quantity in technological process,
K - costs of technological process realization,
B_Z - resources used in process regarding to conventionally accepted values; in paper BREF limits proposed,
B_E - energy consumption in the technological process regarding to conventionally accepted values; BREF limits proposed,
B_O - waste quantity in technological process regarding to conventionally accepted values; BREF limits proposed,
B_K - conventionally costs of technological process, e.g. considering BREF limits,
w_l - criteria weights.

The objective function (f) for biological defatting operation:

$$f = 0.25 \cdot (0.79 + 0.14) + 0.25 \cdot (0.62 + 0.3) + 0.25 \cdot 0.65 + 0.25 \cdot 0.32 = 0.705$$

After objective function values checked (for both variants), to real zinc plating technological process 1 modernization were selected following solutions [12]:

- defatting using micro and ultrafiltration (objective function value - 0.537) with tank cover using,
- cascade rinsing (using ionic exchange) for rinsing I and II operation,
- rinsing optimization and deiron washings cleaning for fluxing operation.

Table 7.
Comparison of restrictive conditions of proposed zinc plating technological process 1 modernizations [12]

defatting operation	water consumption	defatting medium	oils	sewage and sludge	energy consumption	total costs
biological defatting	0.79	0.14	0.62	0.3	0.65	0.32
micro and ultrafiltration defatting	0.82	0.29	0.19	0.42	0.26	0.17
rinsing operation	water used			rinsing I, II costs		
cascade rinsing	0.8			0.1		
fluxing operation	water consumption	flux used		sewage and sludge	total costs	
rinsing optimization and recovery	0.096	0.93		0.15	0.62	

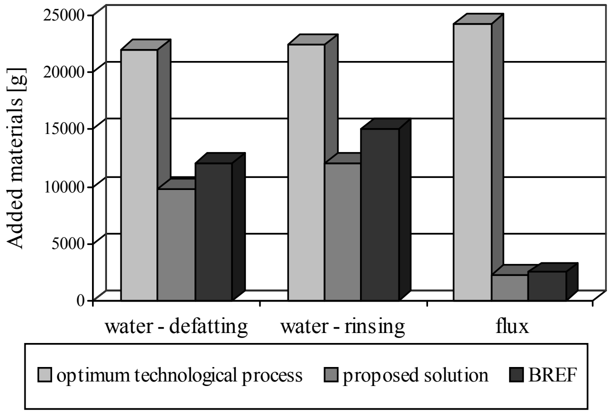

Fig. 2. Comparison of added materials used for proposed solution, optimum technological process and BREF [12]

The ecological effects concerning added materials used for proposed solution, the optimum technological process and BREF presented in Fig. 2.

3. Discussion

The problem of decision making (management) in the companies usually relates to technological processes.

The selection of the best technological (taking into consideration chosen criteria) process is connected with the optimization.

In this article multiobjective optimization methods [16, 17] with genetic algorithms (GA) was proposed. The GA was proposed because of the plurality of the estimation criteria (minimum added materials used, minimum energy consumption, minimum waste, minimum costs).

The universal MSTP procedure with Poli-Opt version 1.0 software for three realistic zinc plating technological processes optimization were presented. The main aim of this procedure is the proper objective function delimitation, because from its form depends correctness of the optimization realization. From this reason the universal Poli-Opt computer programme using elementary, but quite sufficient in practice, genetic algorithm elaborated.

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