EAF Environmental Impact Analysis through Mathematical Modeling and Fuzzy Logic

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Abstract: - The original optimizations mathematical model of the electric arc furnace's charge preheating process mainly takes into consider 2 thermo-technological aspects: the heat transfer between fluids and particles and the heat transfer between the fizz layer and an exchange surface. According the energetically balance at the gaseous environment level, the conductive transfer model is also analyzed through the finished elements method. The results of the mathematical model are presented as the analysis and quantification of the thermo gradients obtained during the charge preheating process. These thermo gradients are determined for various temporal moments and for different capacities of the electric arc furnace. The results of the mathematical model are presented as the analysis and quantification of the thermo gradients obtained during the charge preheating process. These thermo gradients are determined for various temporal moments and for different capacities of the electric arc furnace.

Key-Words: - Environmental Impact, Electric Arc Furnace (EAF), Modeling, Fuzzy Logic.

1 Introduction

The electric arc furnaces (EAFs), as powerful energy consumers, are also polluting emissions generators with an important environmental impact. The most significant polluting emissions of the EAF furnace are metallic and oxides powders driven by emergent gases [10-14], [23].

The powders are produced during the following technological operations: raw materials loading, steel melting, refining, alloying and evacuation.

Generally, the driven powders contain heavy metals (Cr, Ni, Zn, Cd, Pb, Cu etc) and some metal oxides (iron, manganese, aluminum and silicon oxides) and they can reach values of more than 15 kg/t steel [15-19], [1-3].

Fuzzy Logic (FL) is a powerful problem-solving methodology with wide applications in economical control and information processing, [4-9], [20-22]. It provides a simple way to draw definite conclusions from vague, ambiguous or imprecise information.

It resembles human decision making with its ability to work from approximate data and find precise solutions [24-26].

The neuro-fuzzy approach is to use neural networks and fuzzy set theory to model practical systems. A pattern match or recognition system is a black box constructed using multiple layers of neurons called neural networks.

Neurons have the ability of memory and self-learning by training. FL algorithms are implemented as an inference engine which can automatically infer from facts (data) [27-29].

Mathematical modeling of the electric arc furnace's processes (EAFP) for the optimization of the functional and technological performances of this complex unit is based on the next principles:

A. The principle of analogy – consists in observing and analyzing competently the modelated reality, using both analogy with other fields of research and logical homology. According to this principle, for mathematical models making were used the following steps:

• the modelated subject definition – represents the first phase of the modelation analysis. This step must satisfy both the purpose and the simultaneous system's aims, assuring their compatibility;

• the effiency criteria's definition – is a step imposed on the correct definition of the system's aims and allows the optimization of the modeling solutions;

• making the options – basing on accessing some realistically, original and efficient solutions;

• choices evaluating – related to the established efficiency criterials;

• choosing the final solution – based on the analysis between the different solutions of the modelling.

B. The principle of concepts is based on the sistems'theory, including the feedback concept.

C. The principle of hierarchisation consists of making a hierarchical models systems, for structuring the decision and coordinating the interactive subsystems.

Fuzzy Logic has been found to be very suitable for embedded control applications.

Several manufacturers in the automotive industry are using fuzzy technology to improve quality and reduce development time. In aerospace, fuzzy enables very complex real time problems to be tackled using a simple approach.

In consumer electronics, fuzzy improves time to market and helps reduce costs. In manufacturing, fuzzy is proven to be invaluable in increasing equipment efficiency and diagnosing malfunctions.

The gaseous phase (burnt gases) that comes out of the EAF mainly results from the melting and refining procedures and contains carbon monoxide, carbon dioxide together with nitrogen and sulfur oxides (NOx and SOx).

However, in practice it also contains very toxic other components, such as fluorides or volatile organic compounds (dioxine, chloride derivatives of benzene or phenol) resulted from burning of organic oils that are introduced as contaminants together with the raw materials.

2 Environmental Impact of EAF

From the total polluting emissions, over 90% are generated during the technological operations of melting and refining.

The chemical composition of these emissions is extremely variable and directly dependent on multiple factors, as followings:

- composition of the raw materials that make up the loading;
- the melting managing way;
- type of refining process that is used (with gaseous oxygen or ore);
- time duration of the melting and refining steps;
- desired quality degree of the elaborated steel.

Figure 1 presents the main scheme of the environment polluting system through the EAF.

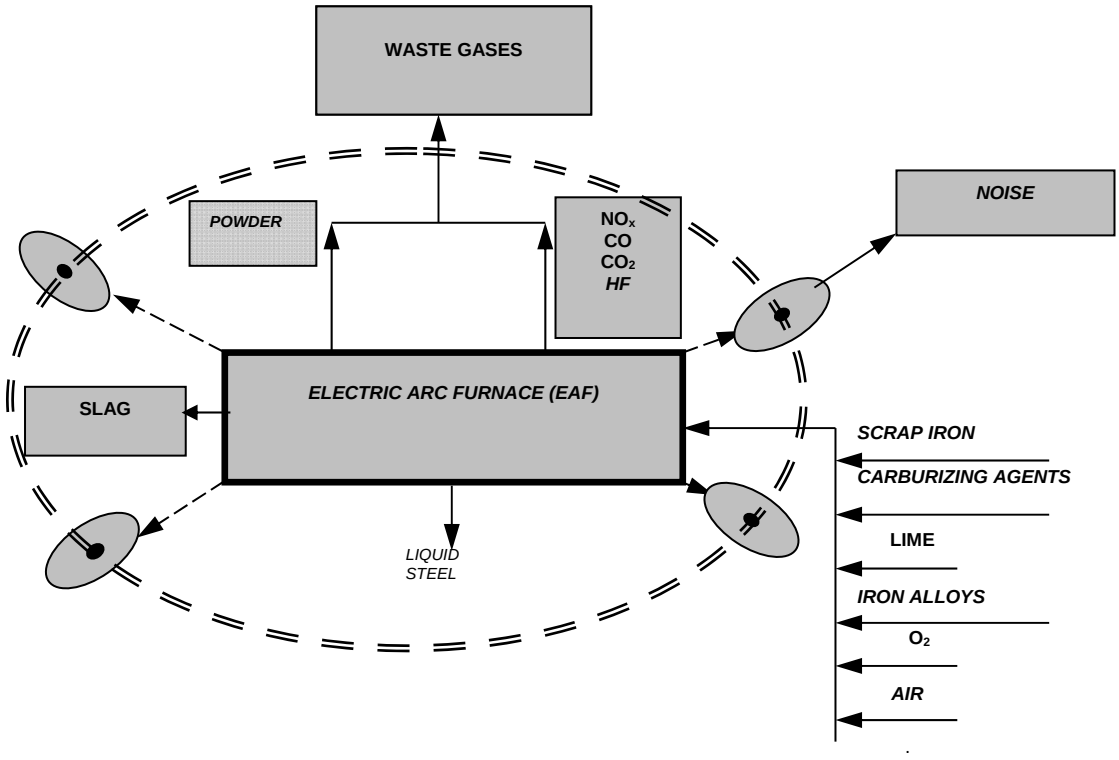


Fig. 1. Environment polluting system through the EA

Table 1 presents the variation limits of chemical composition for the powders generated during the steel elaboration in electric arc furnaces (EAF) in the USA and Germany, from loading that consists of scrap iron, only.

Table 1. Variation limits of chemical composition for the EAF powders

No.	Com-ponent	Variation limits, %		
		SUA	GERMANY	
			Plain Basic Steel	Alloy Steel
1	Fe_{total}	16.4 – 38.6	21.6 – 43.6	35.3
2	Si	0.9 – 4.2	0.9 – 1.7	17.0
3	Al	0.5 – 6.9	0.1 – 1.5	x)
4	Ca	2.6 – 15.7	6.6 – 14.5	0.4
5	Mg	1.2 – 9.0	1.0 – 4.5	1.2
6	Mn	2.3 – 9.3	0.9 – 4.8	2.0
7	P	0 – 1.0	0.1 – 0.5	x)
8	S	0– 1.0	0.3 – 1.1	0.1
9	Zn	0 – 35.3	5.8 – 26.2	1.4
10	Cr	0 – 8.2	0 – 0.1	13.4
11	Ni	0 – 2.4	x)	0.1
12	Pb	0 – 3.7	1.3 – 5.0	0.4

3 Environmental Modeling System of EAF

The modelling system's central element of the EAF processes conceived consists of the system's criteria function.

Knowing that the technological processes study for EAF is subordinated to high quality steel obtaining, the modelling system's criteria function (CF) is the ratio between quality and price:

$$CF = \left(\frac{QUALITY}{PRICE} \right)_{\max} \quad (1)$$

The maximum of the criteria function is assured by the mathematical model of prescribing the criteria function (M.P.C.F.)

The mathematical model of prescribing the criteria function concept consists of transforming the criteria function (CF) in a quality-economical matrice MQE, as in the scheme presented in fig. 2.

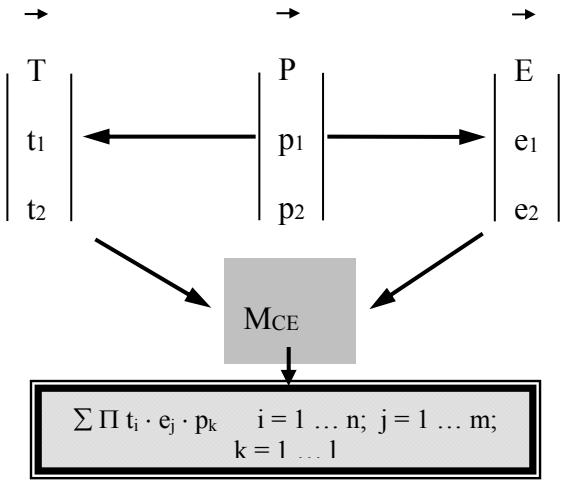


Fig. 2. The modelling system's criteria function's evaluation

The levels of prescribing the criteria function could be obtained by using a composition algorithm for three vectors:

- vector – technical parameters' vector (t_i);
- vector – economical parameters' vector (e_j);
- vector – weight vector (p_k).

4 Fuzzy Logic Modelling for Ecological Impact of EAF

Patterns reflect the behavioral characteristics of how a person or a system acts in a certain environment. A spending pattern may represent the way a consumer spends money on different goods, such as travels, cars, or food.

A defect pattern in a semiconductor equipment may indicate the way in which a part or assembly fails. By matching various patterns, a marketing specialist at a credit card company is able to better understand consumers spending habits, and therefore he can tailor his or her marketing strategies targeted to different consumer groups (Schneider, 2000).

By the same token, scientists study and match various patterns of machine faults in order to be able to predict and control the performance of equipment, including advanced warning.

The application of the fuzzy logic (FL) is based on 3 simple steps defined below (fig. 3).

In fig. 5 there is presented the general logical scheme used for the EAF'charge preheating.

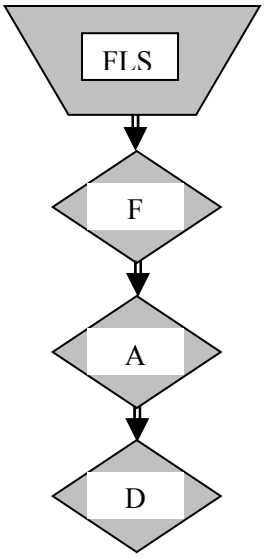


Fig. 3. The steps of the FL
FLS – Fuzzy Logic Steps; F – Fuzzification; A – Aggregation; D - Defuzzification

Neuro-fuzzy modeling is to use *neural networks* and *fuzzy set theory* to model practical systems. Neuro-fuzzy technology was developed that can automatically extract business rules from the neuro-fuzzy model. These rules can explain which and why people tend to fraud, or why a customer price increases.

Mathematically, the fuzzy utility function is a *more accurate measure on the consumption utility*. It can describe the relationships between: *spending* (S), *price* (P), *consumption composition* (CC), preference and subjective measure on *commodity* (C) or *service values* (SV). These relationships are described by the FUFC matrix concept (fig. 4).

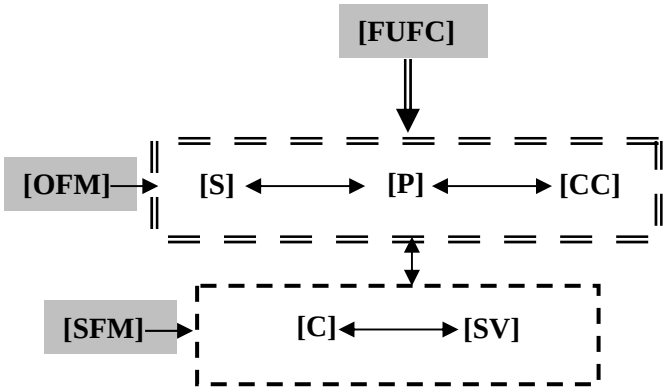


Fig. 4. FUCF Matrix concept
FUCF – Fuzzy Utility Function for Consumption; OFM – Objective Factors Matrix; SFM – Subjective Factors Matrix; S – Spending vector; P – Price vector; CC – Consumption Composition vector; C – Commodity vector; SV – Service Values vector.

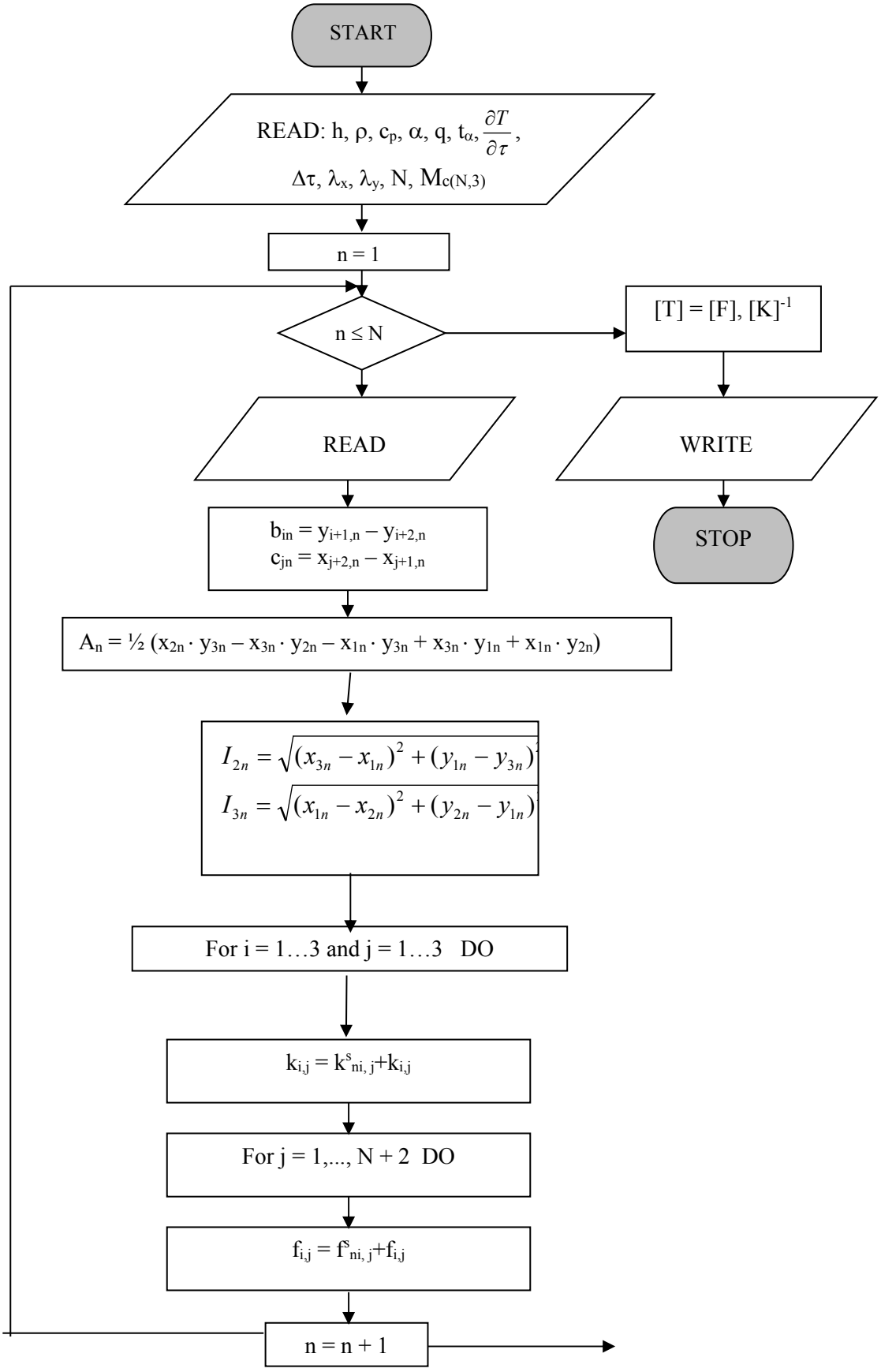


Fig. 5. General logical scheme

Fuzzy Consumption Utility Functions (FCUF) are based on Utility Theory (UT). Fuzzy Utility Function for Consumption (FUFC) is described by the FUFC matrix concept. This concept is based on the following vectors: S (spending vector); P (price vector); CC (consumption composition vector); C (commodity vector) and SV (service values vector).

5 Experimental Rezults

The scheme of the EAF environmental impact is presented in fig. 6.

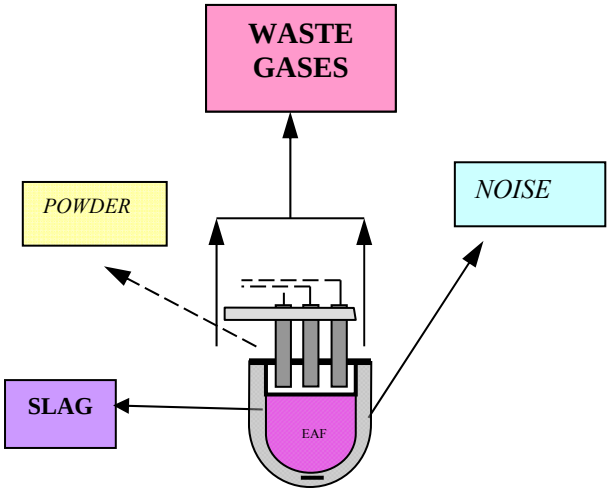


Fig. 6. Scheme of the EAF environmental impact

In fig. 7 is presented the CO concentration in the evacuated gas during the melting in the EAF.

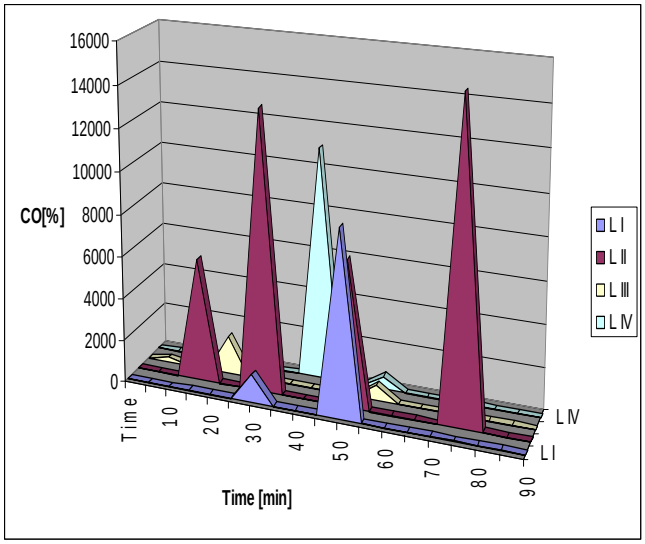


Fig. 7. CO concentration in the evacuated gas during the melting in the EAF

Fig. 8 presents the carbon dioxide impact of EAF [8].

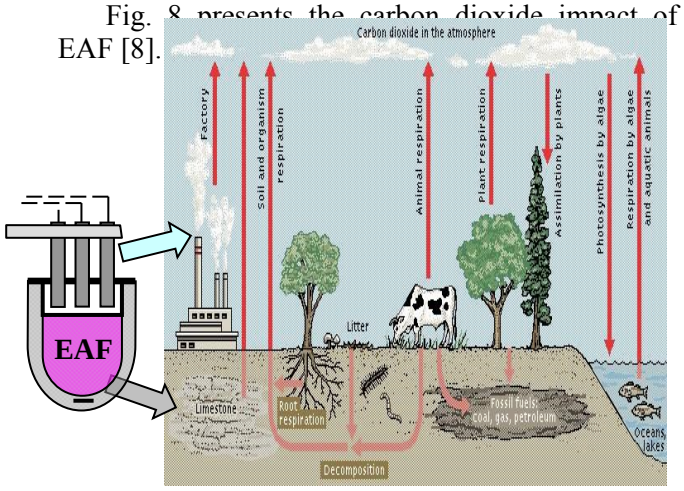
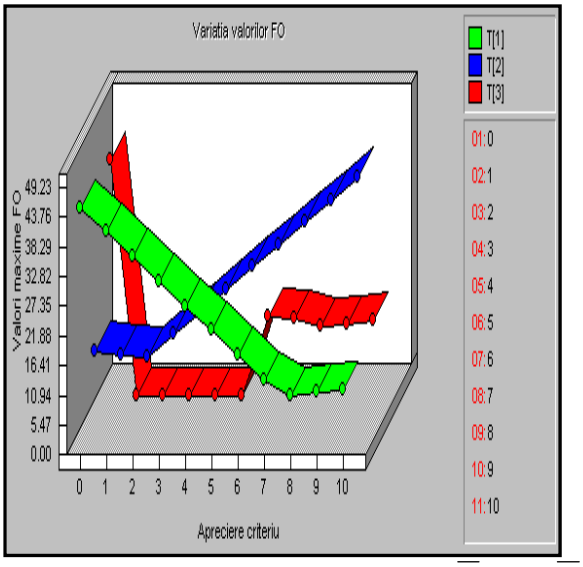


Fig. 8. Carbon dioxide impact of EAF

The correlation between the criteria function's (C.F.) prescribed levels and $\overline{T}$ vector's components' variation is presented in fig. 9.

The execution of the EAF's charge preheating modelling (CPM) was made both for a 10t EAF (fig.10a,b,c) and for a 50t EAF (fig. 10d). It was considered to be a load with medium permeability $\varepsilon = 0.45$.

The cumulated correlation between the criteria



function's (C.F.) prescribed levels and $\overline{T}$ and $\overline{E}$ vectors' variation are presented in fig. 11.

Fig. 9. The correlation between the criteria function 's (CF) prescribed levels and the $\overline{T}$

vector's components' variation $(\overline{T}_1, \overline{T}_2, \overline{T}_3)$

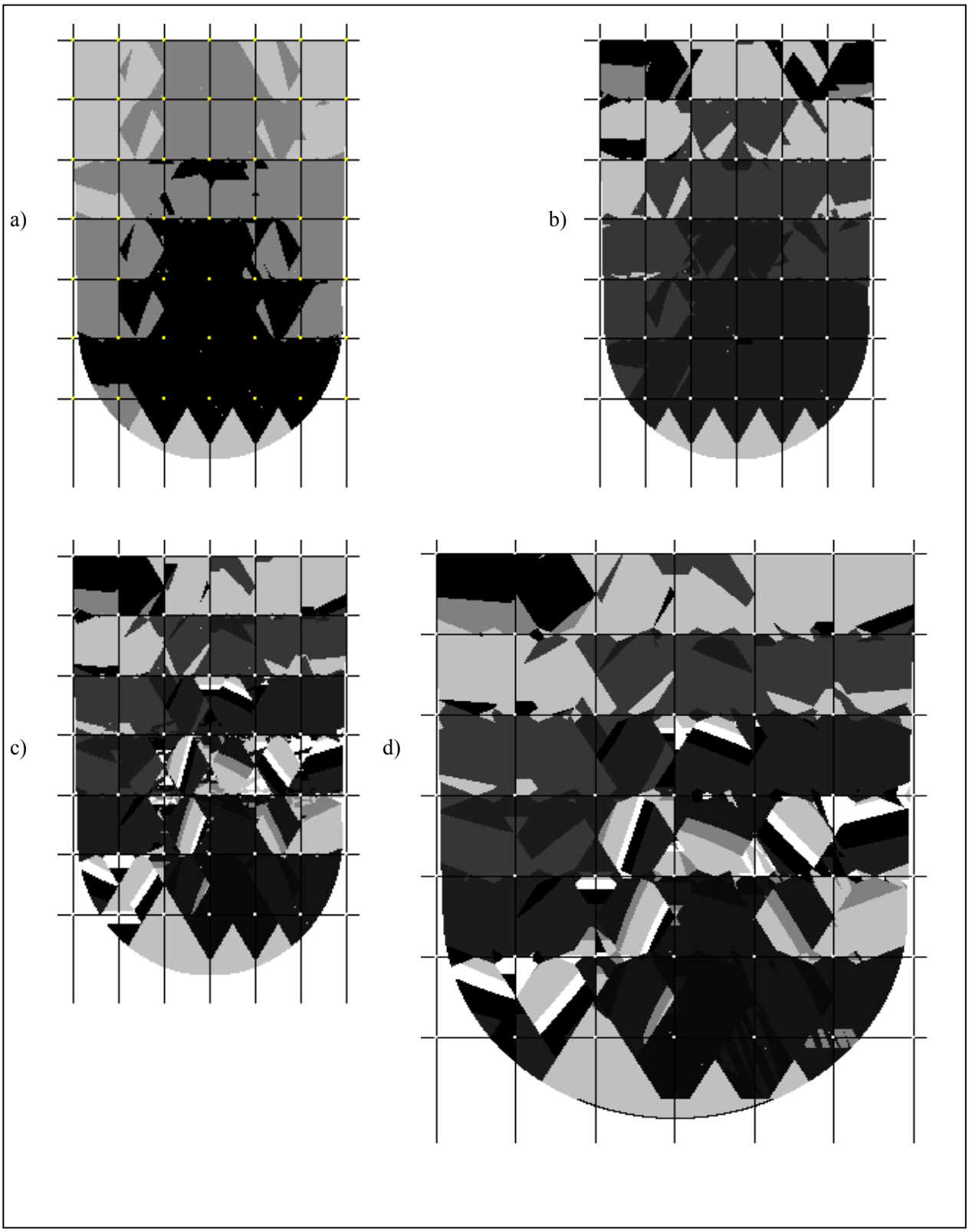


Fig. 10. The main CPM's result

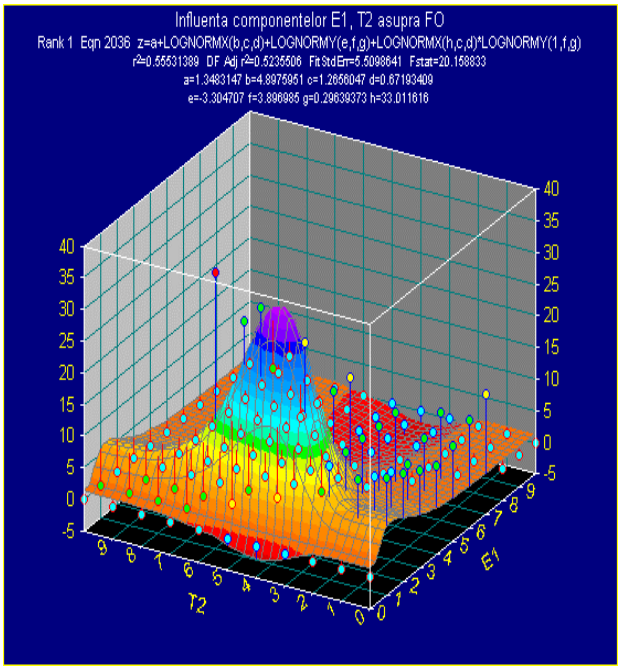


Fig. 11. The cumulated correlation between the criteria function's (CF) prescribed level and $\overline{T}$ and $\overline{E}$ vectors' variation.

The components of two vectors $\overline{T}$ and $\overline{E}$ which are considered to have important weight in the criteria function's evaluation are:

- t_1 – the steels chemical composition;
- t_2 – the steels purity (in gases);
- t_3 – the steels purity (inclusions);
- e_1 – the specific consumption of basic material and materials;
- e_2 – the specific consumption of energy;
- e_3 – the elaboration process's productivity in EAF.

The best level (NO) for each component of the 2 vectors is:

- for t_1 – the prescribed variation limits of the elaborated steel quality composition arithmetical mean.

The cumulated correlation between the criteria function's (C.F.) prescribed levels and $\overline{T}$ and $\overline{E}$ vectors' variation are presented in figure 11.

- for e_1 - the minimum content specific consumption prescribed of basic materials
- for e_2 - the minimum prescribed specific energy consumption.
- for e_3 - the maximum prescribed productivity of the elaboration process.

We can notice the obtaining of:

- the criteria function's maximum level $FO_{T,max} = 43,76$ for the $\overline{T}$ vector's variation (t_1 component - the prescribed variation limits of the elaborated steel quality composition arithmetical mean).
- the criteria function's maximum level $FO_{E,max} = 55,31$ for the $\overline{E}$ vectors' variation (e_3 component - the maximum prescribed productivity of the elaboration process).

And respective the criteria function's maximum level $FO_{CUM,max} = 19,85$ for the $\overline{T}$ and $\overline{E}$ vectors' cumulated variation.

6. Conclusions

From the total polluting emissions of EAF, over 90% are generated during the technological operations of melting and refining.

The gaseous phase (burnt gases) that comes out of the EAF mainly results from the melting and refining procedures and contains carbon monoxide, carbon dioxide together with nitrogen and sulfur oxides (NOx and SOx); however, in practice it also contains very toxic other components, such as fluorides or volatile organic compounds (dioxine, chloride derivatives of benzene or phenol) resulted from burning of organic oils that are introduced as contaminants together with the raw materials.

Fuzzy Logic has been found to be *very suitable for embedded control applications.* Every application can potentially realize some of the *benefits of FL*: *performance, productivity, simplicity and lower cost.*

FL algorithms are implemented as an inference engine which can automatically infer from facts. The application of the fuzzy logic is based on three steps: *fuzzification;* a*ggregation* and *defuzzification.*

Neuro-fuzzy modeling is to use *neural networks* and *fuzzy set theory* to model practical systems. Neuro-fuzzy technology was developed that can automatically extract business rules from the neuro-fuzzy model.

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The execution of the EAF's charge preheating modelling (CPM) was made both for a 10t EAF and for a 50t EAF.

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