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MODELING AND MANAGEMENT OF SINTERING PROCESSES USING FUZZY LOGIC

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ABSTRACT

This work presents the mathematic models of the basic processes from an iron ore processing plant. Based on the mathematic models, using the Matlab/Simulink platform, are achieved the block diagrams for calculation of the parameters from the sintering process.

For the last two phases of the agglomerate's manufacturing process are presented the diagrams of some expert systems based on Fuzzy logic, by means of which is achieved the management of these processes.

These expert systems based on Fuzzy logic allow the automatic management optimization of non-linear processes of agglomerating charge elaboration.

1. INTRODUCTION

Restructuring of steel industry is strongly influenced by the modernization of manufacturing processes from the sintering plants.

Sintering, as phisycal-chemical process of iron ores preparation and obtaining of a controled situation, is of maximum importance because the resulted agglomerate allows the obtaining of quality cast-irons as they are required currently on the market. The current technology of cast-iron making imposes more and more rigorous conditions to the quality of the charge, that should allow the optimization of the entire process, increasing the productivity and reducing the coke consumption.

In this respect, the major cast-iron producing countries use iron ores which are previously prepared as agglomerate, ment to ensure the achievement of some charges with high iron content and homogeneous from chemical and granulometric viewpoint.

From the processes with special influnece on preparation, in this work are analyzed: dosing, sintering and cooling (fig.1).

Dosing flow includes the quantitative dosing of the charge components, their pre-homogenization into the primary mixing drum (TAP) and the conveying flow of the mixture/blend from the dosing station into the main body to the charge bunker of the sintering machine.

Sintering flow includes the following steps: mixing/blending, humectation and forming of micro-pellets in the secondary mixing drum (TAS); loading the mixture on the sintering machine's carriers; burnig-up the charge; sintering of the mixture/blend; sizing of the agglomerate and recirculation of the return.

Cooling flow includes the following steps: cooling of the agglomerate after the hot screening; conveying in cold condition to the screening station; conveying to the furnaces silos and to the agglomerate's shippment station.

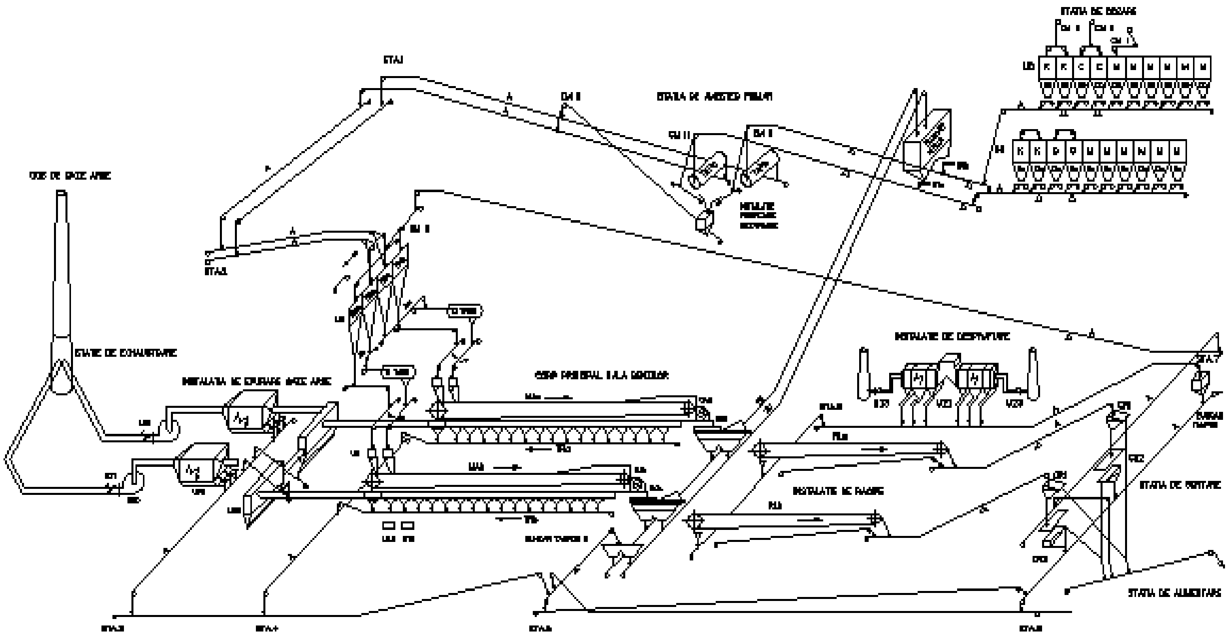

FIG.1. TECHNOLOGICAL DIAGRAM OF THE SINTERING PROCESS

2. MODELING OF DOSING SUB-PROCESS

The mathematic model of the dosing sub-process is described by the following equations:

$$M = S \cdot \frac{1}{1 + c_0 + r_0 + \frac{\left[\sum_{i=1}^{n} m_i \cdot (Is_i - k_i) + c_0 \cdot Ce \cdot (Is_{Ce} - k_{Ce}) + r_0 \cdot (Is_r - k_r)\right]}{(k_k - Is_k)}} \tag{1}$$

$$K = S \cdot \frac{\frac{\left[\sum_{i=1}^{n} m_i \cdot (Is_i - k_i) + c_0 \cdot Ce \cdot (Is_{Ce} - k_{Ce}) + r_0 \cdot (Is_r - k_r)\right]}{(k_k - Is_k)}}{1 + c_0 + r_0 + \frac{\left[\sum_{i=1}^{n} m_i \cdot (Is_i - k_i) + c_0 \cdot Ce \cdot (Is_{Ce} - k_{Ce}) + r_0 \cdot (Is_r - k_r)\right]}{(k_k - Is_k)}} \tag{2}$$

$$R = S \cdot \frac{r_0}{1 + r_0 + c_0 + \frac{\left[\sum_{i=1}^{n} m_i \cdot (Is_i - k_i) + c_0 \cdot Ce \cdot (Is_{Ce} - k_{Ce}) + r_0 \cdot (Is_r - k_r)\right]}{(k_k - Is_k)}} \tag{3}$$

$$C = S \cdot \frac{c_0}{1 + r_0 + c_0 + \frac{\left[\sum_{i=1}^{n} m_i \cdot (Is_i - k_i) + c_0 \cdot Ce \cdot (Is_{Ce} - k_{Ce}) + r_0 \cdot (Is_r - k_r)\right]}{(k_k - Is_k)}} \quad (4)$$

In the above equations intervene the following measures: M – iron ore flow ; K – limestone flow ; R – return flow ; C – coke flow ; S – charge flow ; I – basicity index ; s_i , k_i – lime and silica from the iron ores ; s_k , k_k – lime and silica from the limestone ; s_{Ce} , k_{Ce} – lime and silica from the coke ashes; s_r , k_r – lime and silica from the return ; r_0 – return participation against the total iron ore ; c_0 – coke participation against the total iron ore

This mathematic model allows the calculation of the material flows from the charge, either at variation of their chemical composition, or at variation of reference values S, I, r_0, c_0.

The S value varies as result of the machine's speed adjusting transitory regime, and the values r_0 and c_0 are established by independent criteria, such as : balancing of the fine-grained circulation – respectively to ensure the optimal compromise between the agglomerate's production on one hand and the specific coke consumption on the other hand – between the agglomerate's reducibility and strength.

The reference value I is constant, depending on the installation's needs, and the chemical and mineralogic compositions of the iron ore, limestone, coke and return are introduced either manually (lab analysis), or automatic (spectral in-flow continuous analysis in the bunkers, to the dozers or on the belt conveyors).

Further it's been achieved the block diagram for calculation of the material flows that comes into the sintering charge componency (fig.2) using the Simulink program from the Matlab environment.

From the figure we can note that the time-variable input measures for the calculation of the material flows from the charge are: charge flow S, which is modifying following the modification of the sintering machine's speed, and the return's lime and silica which are modifying because they depend on the flows of iron ore, limestone, coke, return and on the charge flow.

The rest of input measures are parameters with constant values which are prescribed or determined by chemical analysis of the sintering charge components.

$$s_r = \frac{M \cdot \sum m_i \cdot s_i + C \cdot Ce \cdot s_{Ce} + K \cdot s_k}{S - R} \quad (5)$$

$$k_r = s_r \cdot I \quad (6)$$

and M(m^3/h) = f(S, s_r, k_r); K(m^3/h) = f(S, s_r, k_r); C(m^3/h) = f(S, s_r, k_r); R(m^3/h) = f(S, s_r, k_r) (7)

Further will be calculated the iron ore flow, limestone flow, coke flow and the return flow considering that in the agglomerate's manufacturing recipe enter four types of iron ore: autochtonous iron ore (iron ore 1), Krivoi-Rog iron ore (iron ore 2), Brasilian iron ore (iron ore 3) and scale (iron ore 4), each with its own chemical composition, i.e. with different lime and silica.

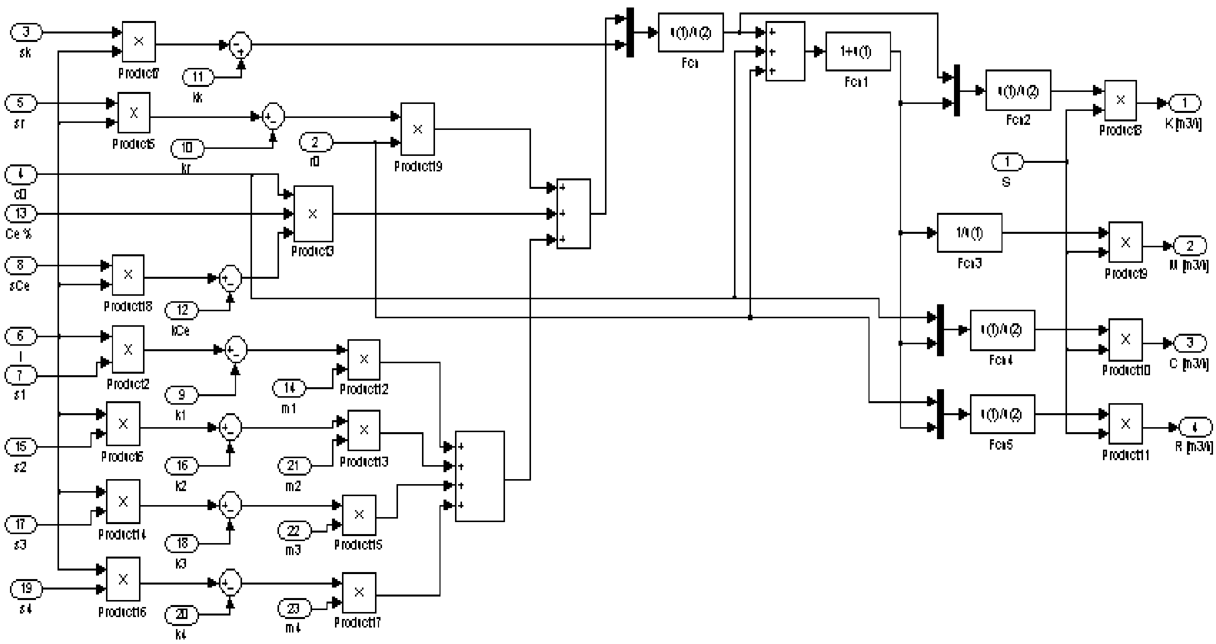

FIG.2. BLOCK DIAGRAM FOR CALCULATION OF THE MATERIAL FLOWS FROM THE CHARGE

3. MODELING OF THE SINTERING SUB-PROCESS

The mathematic model of the sintering sub-process is described by the following equations:

$$v_{m\,opt} = v_m \cdot \frac{L_u}{L_{n-1} + 0{,}5 \cdot p_c \cdot \dfrac{T_{n-2} - T_n}{T_{n-2} - 2T_{n-1} + T_n}} \tag{8}$$

$$\Delta C = 1{,}25 \cdot \Delta c \cdot M \tag{9}$$

$$\Delta c = (a - b \cdot r_0) - (a - b \cdot r) \tag{10}$$

$$S = k \cdot v_{m\,opt} \cdot H_s \cdot B \tag{11}$$

In the above equations intervene the following measures : v_m – the sintering machine's prescribed speed; H_s – height of the layer; k – proportionality factor; B – sintering machine's width; T_n,T_{n-1},T_{n-2} – temperatures in the last three suction chambers; $r = \frac{R}{M}$ - proportion of the return against the total iron ore; $r_0 = \frac{R_{mp}}{M}$ - proportion of the fine-grained produced against the total iron ore; a, b – constants which are determined statistically for each installation in part.

Further have been achieved the block diagrams for calculation of the sintering machine's optimal speed and the variation of the coke content from the charge (fig.3 and fig.4) using the Simulink program from the Matlab environment.

For the calculation of the sintering machine's optimal speed, the time-variable input measures are the temperatures measured by the three thermocouples mounted in the last three suction chambers on the sintering machine, because the vertical burning of the sintering layer depends on a multitude of factors which are changing in time and along the sintering line.

The rest of the measures on which depends the machine's optimal speed are either presribed measures (v_m), or technological construction measures of the sintering machine (L_{n-1}, p_c, L_u).

$$v_{m\,opt} = f\left[T_{n-2}, T_{n-1}, T_n\right] \tag{12}$$

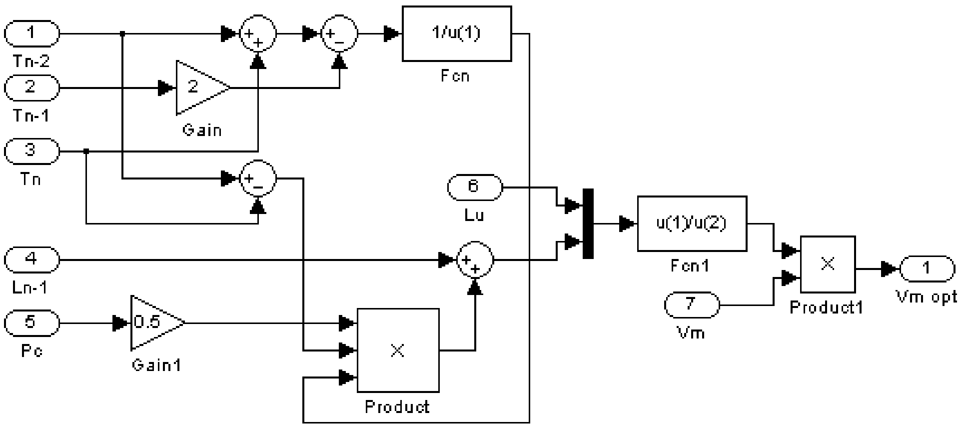

FIG.3 BLOC DIAGRAM FOR CALCULATION OF THE SINTERING LINE'S OPTIMAL SPEED

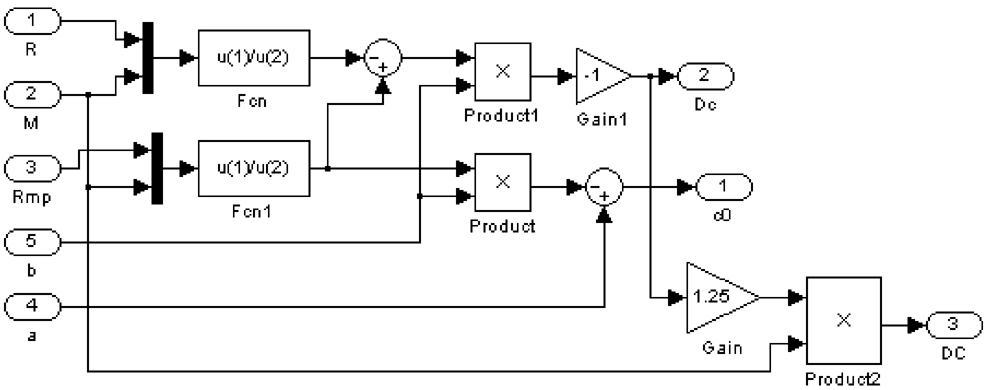

FIG.4. BLOC DIAGRAM FOR CALCULATION OF THE COKE CONTENT'S VARIATION FROM THE CHARGE

Balancing of the fine-grained (return) circulation is a basic condition for ensuring of a stationary regime as stable as possible and consists of the following relation:

$$R_{mp} = R_{opt} \tag{13}$$

$$R_{opt} = r_0 \cdot M \tag{14}$$

The calculation relation of the charge's carbon content for balancing of the fine-grained circulation is:

$$\Delta C = 1,25 \cdot \Delta c \cdot M \tag{15}$$

$$\Delta C = f(R, R_{mp}, M) \tag{16}$$

4. FUZZY MODELS FOR PROCESS MANAGEMENT

A decision problem can not be always formulated in classic mathematic language right from the start. The most often, in expressing of such problems, there are interferences between the natural language and an artificial language. Using the simplifying terminology of the mathematic programming, not all the restrictions and objectives of a given problem can be precisely expressed. The Fuzzy sets theory brings an advantage in this direction, allowing a formalization of imprecision, by means of a non-adequate treating of linguistic variables. A linguistic variable is different from a numerical variable by the fact that its values are not numerical, but words or propositions in a natural or artificial language. A linguistic variable is not obligatory a fuzzy variable, but, often times, is a variable that takes fuzzy variables (sets) as values.

The expert systems become useful and efficient not only for solving of some high complexity problems, but also for simpler management problems (decisional), that contain a high grade of uncertainty. Such expert systems can be implemented on conventional computers. The expert system represents a calculation algorithm that solves a certain type of problems by modelling of human expert judgements. The expert system ensures consulting facilities for the users, being an interactive system between the user and the knowledge base. In order to be able to design an expert system, it should exist a human expert who can solve the problem. Nowadays, the iron ores sintering process and the agglomerate's cooling process are conducted through analogic adjustment loops without taking into account a serial of factors that influence these processes, such as:

- Technical endowment with modern sensors and transducers;
- Technical endowment with modern processing equipment (microcontrollers, PLC, industrial micro-computers);
- Conceiving of a hierarchical automation strategy;

- Completion of the automation strategy with an expert system and/or in fuzzy logic.

Improving of the current situation can be achieved by using of expert systems. Their need is imposed by the fact that the processes can not be modelled mathematically with precision and a lot of parameters (charge humidity, materials' physical-chemical properties, sintering vertical speed, cooling speed, agglomerate's temperature on the cooling belt) are changing in
time in a way that can not be previously acknowledged.

There are proposed two expert systems based on Fuzzy logic: one for the process management on the sintering machine and the other for process management on the agglomerate's cooling machine (fig.5 and fig.6).

5. THE GENERAL MODEL OF THE SINTERING FLOW

The general mathematic model consists of the following general equations:

$$M = S \cdot \frac{1}{1 + c_0 + r_0 + \frac{\left[\sum_{i=1}^{n} m_i \cdot (Is_i - k_i) + c_0 \cdot Ce \cdot (Is_{Ce} - k_{Ce}) + r_0 \cdot (Is_r - k_r)\right]}{(k_k - Is_k)}} \quad (17)$$

$$K = S \cdot \frac{\frac{\left[\sum_{i=1}^{n} m_i \cdot (Is_i - k_i) + c_0 \cdot Ce \cdot (Is_{Ce} - k_{Ce}) + r_0 \cdot (Is_r - k_r)\right]}{(k_k - Is_k)}}{1 + c_0 + r_0 + \frac{\left[\sum_{i=1}^{n} m_i \cdot (Is_i - k_i) + c_0 \cdot Ce \cdot (Is_{Ce} - k_{Ce}) + r_0 \cdot (Is_r - k_r)\right]}{(k_k - Is_k)}} \quad (18)$$

$$R = S \cdot \frac{r_0}{1 + r_0 + c_0 + \frac{\left[\sum_{i=1}^{n} m_i \cdot (Is_i - k_i) + c_0 \cdot Ce \cdot (Is_{Ce} - k_{Ce}) + r_0 \cdot (Is_r - k_r)\right]}{(k_k - Is_k)}} \quad (19)$$

$$C = S \cdot \frac{c_0}{1 + r_0 + c_0 + \frac{\left[\sum_{i=1}^{n} m_i \cdot (Is_i - k_i) + c_0 \cdot Ce \cdot (Is_{Ce} - k_{Ce}) + r_0 \cdot (Is_r - k_r)\right]}{(k_k - Is_k)}} \quad (20)$$

$$v_{m\,opt} = v_m \cdot \frac{L_u}{L_{n-1} + 0{,}5 \cdot p_c \cdot \frac{T_{n-2} - T_n}{T_{n-2} - 2T_{n-1} + T_n}} \quad (21)$$

$$S = k \cdot v_{m\,opt} \cdot H_s \cdot B \quad (22)$$

$$s_r = \frac{M \cdot \sum m_i \cdot s_i + C \cdot Ce \cdot s_{Ce} + K \cdot s_k}{S - R} \tag{23}$$

$$k_r = s_r \cdot I \tag{24}$$

$$R_{mp} = R_{opt} \tag{25}$$

$$r_0 = \frac{R_{opt}}{M} \quad ; r = \frac{R}{M} \tag{26}$$

$c = c_0 - b \cdot (r_0 - r)$ and the necessary correction: $\Delta c = -b \cdot (r_0 - r)$ (27)

$$\Delta C = 1{,}25 \cdot \Delta c \cdot M \tag{28}$$

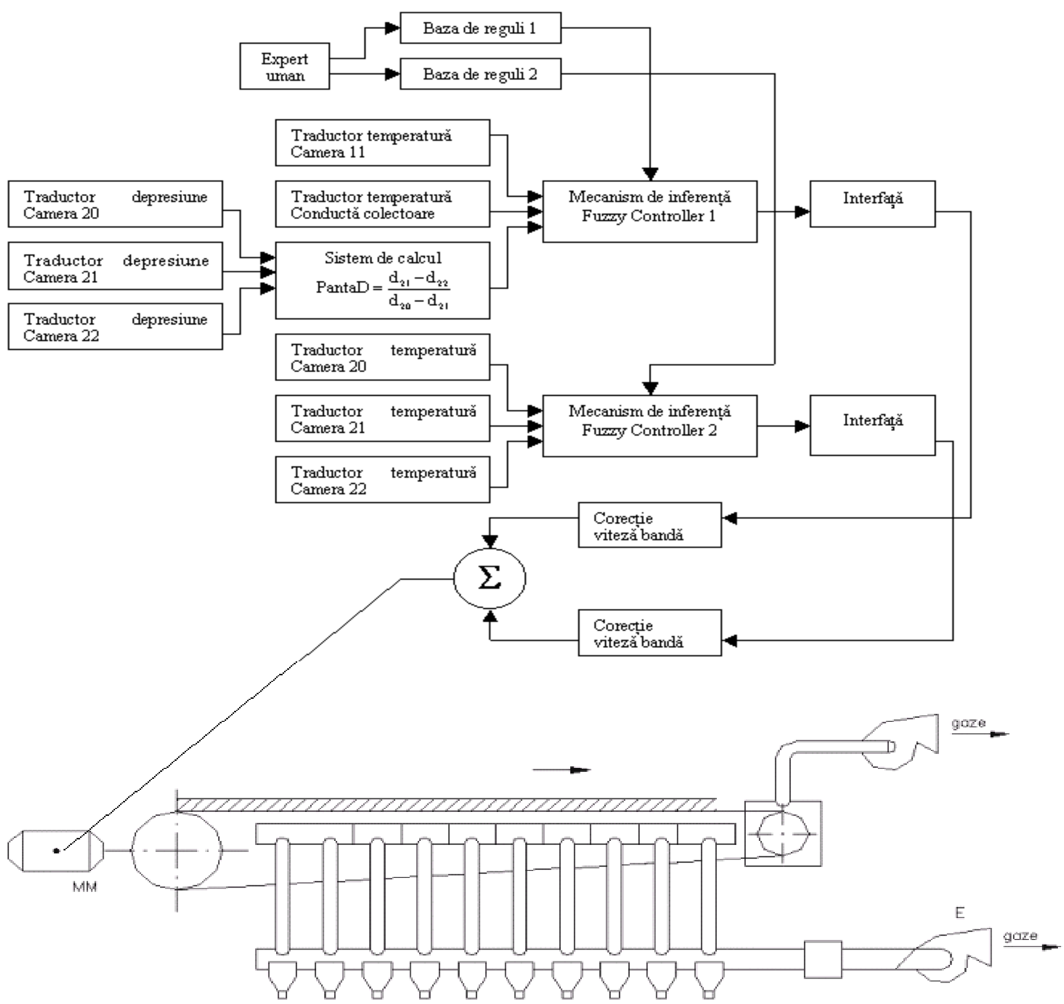

FIG.5. EXPERT SYSTEM FOR CORRECTION
OF THE SINTERING BELT'S SPEED BASED ON FUZZY LOGIC

$$C_0 = C \pm \Delta C \quad (29)$$

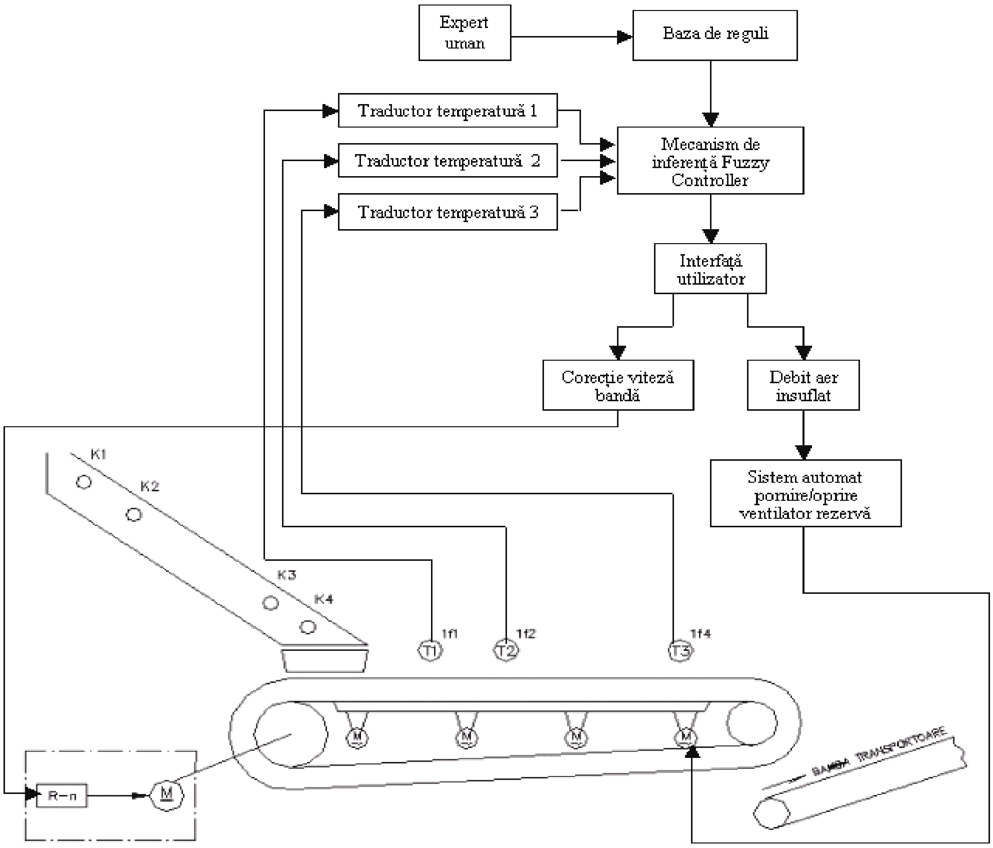

FIG.6. EXPERT SYSTEM FOR THE COOLING PROCESS MANAGEMENT BASED ON FUZZY LOGIC

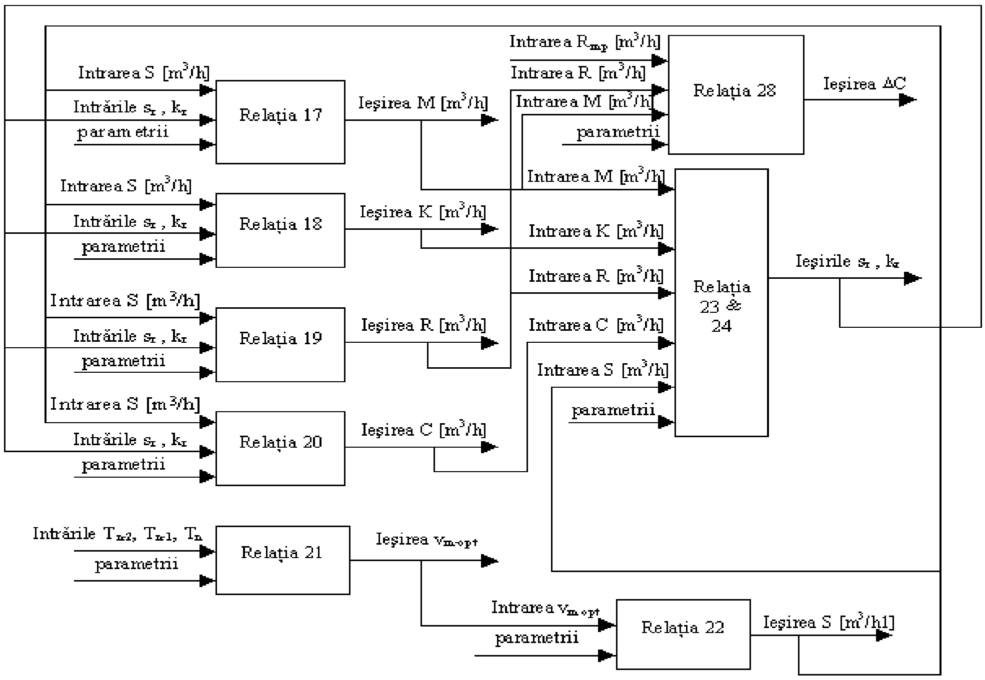

FIG.7. BLOCK DIAGRAM OF THE SINTERING FLOW'S GENERAL MATHEMATIC MODEL

6. EXPERIMENTAL RESULTS

For the process management on the cooling machine is used a Fuzzy regulator which makes the speed correction of the cooling belt and start/stop of the spare ventilator by opening of the damper plate depending on the parameters read along the cooling belt. Out of the 4 temperature thermocouples mounted over the cooling belt and used for the process management with PLC, for the fuzzy management will be used the first 2 from the beginning of the cooling belt and the last one mounted towards the belt's end.

The designed Fuzzy regulator has as input measurs: temperature T_1 measured by thermocouple 1f1, temperature T_2 measured by thermocouple 1f2, temperature T_3 measured by thermocouple f4 (see fig.6) and as output measures: speed correction of the cooling belt and the air flow blown by the ventilators. In fig. 8 is presented the block diagram of the Fuzzy regulator that was designed using the Fuzzy set from the Matlab environment and in fig. 9 is presented the rules basis of this Fuzzy regulator.

At this regulator, the implication is of Mamdani type, the rules aggregation is made with the max-min connectives, and de-fuzification is made by gravity center method.

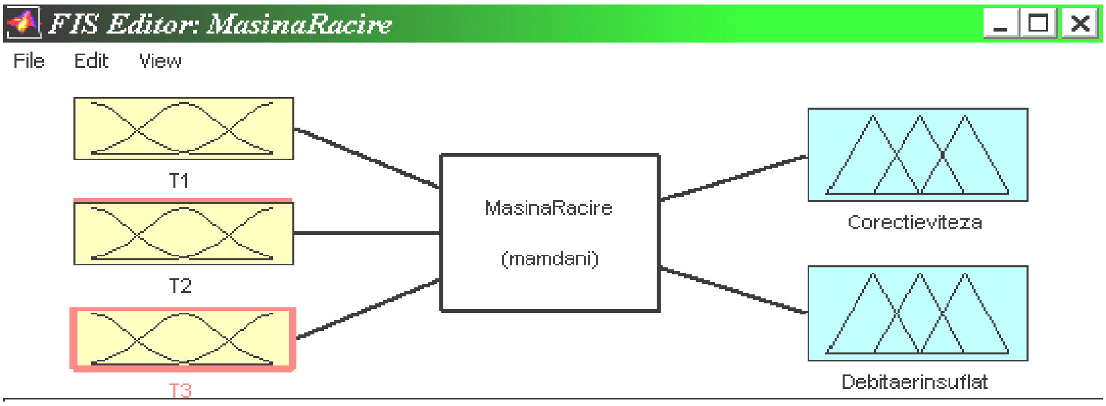

FIG.8. BLOCK DIAGRAM OF THE FUZZY REGULATOR

In fig. 10 is presented one of the adjusting surfaces obtained following the simulation of the designed Fuzzy regulator's operation.

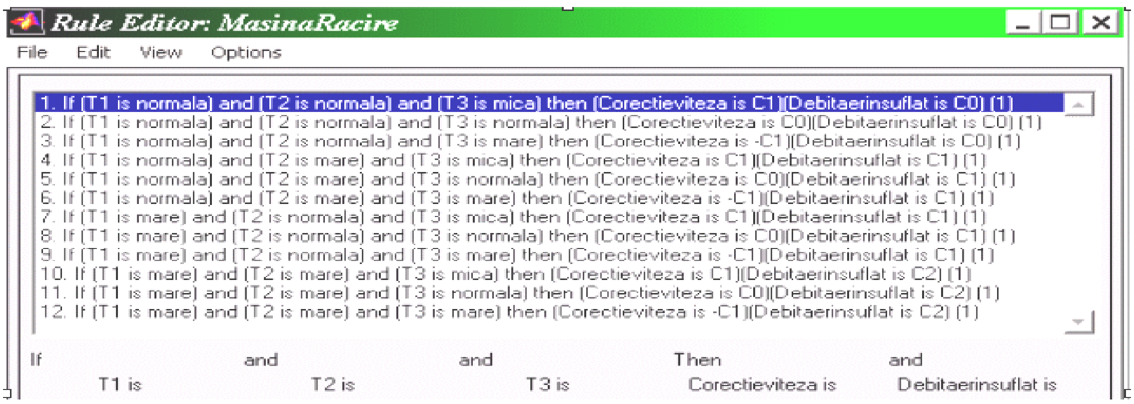

FIG.9. RULES BASIS OF THE FUZZY REGULATOR

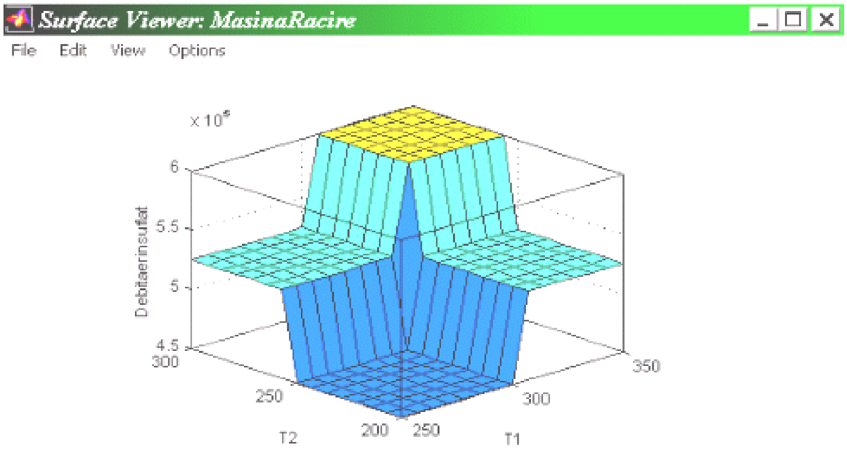

FIG.10 ADJUSTING SURFACE FOR THE AIR FLOW BLOWN AT $T_3=50^0C$

7. CONCLUSIONS

In the last period are used more and more expert systems, which are capable to simulate the judgements and the behavior of a human expert. Researches upon the behavior of the "human expert" have emphasized the fact that specific to him is a strongly non-linear behavior, accompanied by anticipation, delay, integration and prediction effects and even adapting to the concrete operation conditions. Specification of the linguistic characterization for process' undergoing, as well as the experience-based interpretation of the process from the cooling machine, represents "the parameters" by which the regulator's properties can be modified.

As consequence, the designed fuzzy algorithm has lead to a non-linear regulator which, taking into account a great number of variables for the adjusted parameter, will obtain a presision clearly superior to the current situation.

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