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EFFICIENCY ENHANCEMENT OF THE METHODS INTENDED FOR MODELING OF THERMAL ENGINEERING FACILITIES

The paper considers problems dealing with modeling of thermal engineering facilities with distributed parameters, methods of their efficiency enhancement as a results of unification of finite – difference and fuzzy models are suggested. Problems of modeling are considered in the context problems of production quality control.

Key words: *thermal engineering facilities, finite – difference methods, fuzzy models, production quality control.*

Introduction

Processes of thermal treatment are the important component of numerous industrial enterprises in power engineering branch, metallurgy, chemical industry, where different thermal facilities and installations are used. Thermal engineering objects with distributed parameters (TEDP) can be considered as separate class of such facilities. These objects are characterized by the following features: continuous thermal process, distributed of temperature field along the length of objects with distributed parameters (ODD), division of TEDP into zones with the possibility of separate temperature control over each zone, longtidudional movement of processed material, constant time of its location in certain position of TEDD and considerable influence of thermal processing stage on its characteristics.

Problems of modeling of thermal objects with distributed parameters

Mathematical model of thermal engineering objects with distributed parameters is functional dependence of $\mathbf{T} = F(\mathbf{X}, \mathbf{U}, L, t)$ type and allows to define the value of temperature field $\mathbf{T}$ of thermal engineering object (or material) at the moment of time t in the point L at corresponding set of values of thermal engineering object $\mathbf{X}$ parameters and control impacts $\mathbf{U}$. The problem of thermal engineering ODP lies in maintaining of corresponding temperature curve i.e. as a result of modeling such values of control vector $\mathbf{U}$ is defined, at which vector $\mathbf{T}$ values are maximally approached to corresponding reference values of temperature curve.

Analysis of mathematical models of TEDP [1-3] showed that their usage is quite justified and proved in practice. However existing models do not allow to provide maximum of efficiency of thermal treatment processes, that is defined by the ratio of fuel expenditures and quality of end product, for instance, ,manufacturing of law quality goods at high energy expenditures . Thus can be explained by the fact that existing models do not take into account all factors of technological process, starting from product formation and finishing by product indices, that is why they do not allow to modify rapidly the parameters of technological process.

The aim of the given research is to improve the method of TODP modeling by means of intelligence component of object model and algorithm of ODP model optimum parameters determination, that enables to increase its operation speed.

Improvement of TODP modeling efficiency is considered on the example of tunnel oven for bricks burning, temperature field of the oven is shown in Fig. 1.

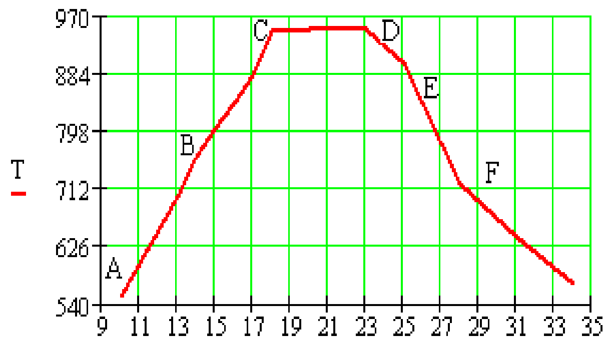

Fig.1. Curve of temperature mode of thermal technological ODP

In most cases for obtaining temperatures vector **T** from equation in quiotient derivatives, which describes functioning of thermal technological ODP, we pass to the system of finite-difference equations and use numerical method of finite differences. Accuracy and adequacy of the results of the given method, depend on stability of differencial scheme, influenced by steps ratio, by time and spatial variable, number of variables, type of diffrencial scheme.

Since the maintenance of differencial scheme stability defines labour-consumption of the solution, then, for analysis of finite diffrencial method efficiency the study of 1D, 2D and 3D models of DPO was performed. The study was carried out by means of variation of grid parameters, usage of explicit and implicit schemes, computation of maximum relative error between real and numerical values, labour consumptional oprerations

Table 1

Results of thermal technological DPO modeling

Number of Model parameters	Scheme	Time step, τ	Computation time, (sec.)	Degree of labour consumption,	Maximum relative error, (%)
1D	explicit	0,001	2,4	10^{4}	0,708
	inexplicit	0,01	2,15	10^{4}	0,798
	inexplicit	0,001	42,172	10^{5}	0,759
	inexplicit	0,0001	1024,21	10^{6}	0,638
2D	explicit	0,01	17,8458	10^{4}	1,618
	inexplicit	0,001	8267,22	10^{6}	2,996
3D	inexplicit	0,001	48672,2	10^{11}	14,21

Analysis of modeling results, suggested in the Table , showed, that the efficiency of finite-differencial methods considerably depends on dimensionality of thermal technological DPO model and modeling parameters value – time sampling and special variables. Decrease of these parameters in order to provide preset accuracy of the solution and coincidence of differencial scheme results in considerable computational resources expenditures and complicates the models usage procedure in existing control systems, oprerating in real time.

Taking into account the existing inverse relationship of finite differences method labour coefficient on digitization step, in our opinion, its usage at the sections of temperature curve, where the value of temperature can be considered as constant (Fig. 1, section CD) is not expedient. That is why, authors suggested combined method of modeling of thermal technological DPO, its application allows to increase modeling rate. We will consider the peculiarities of the suggested method on the example of tunnel oven for bricks burning.

Algorithm of thermal technological DPO modeling

The essence of the given method is that for modeling of DPO temperature field various types of models are used. The choice of the model is determined by the gradient of temperature field on certain position of DPO. Algorithm of the method includes:

1. Determination of the temperature at the beginning – T^0 and at the end – T^k of corresponding position of tunnel oven.

2. If $\left|T^k - T^0\right| > \xi$, (where ξ – preset admissible deviation of the temperature from specified values), then for distribution of temperature for the given position conditions $\begin{cases} \frac{\partial T}{\partial t} \geq G_T; \frac{\partial T}{\partial l} \leq G_L \end{cases}$ (where G_T, G_L – are specified limits of the temperature change in time and length). In this case the following steps are performed:

2.1) mathematical model of temperature field distribution using theory of thermal conductivity is constructed;

2.2) mixed problem with corresponding initial and boundary conditions T^k, T^0 is formulated.

2.3) mixed problem is solved using the method of finite diffrences .

3. If $\left|T^k - T^0\right| \leq \xi$, then for modeling of temperature field of corresponding position (for instance, Fig. 1, section CD) the following steps are performed:

3.1) tunnel oven for burning is considered as the object with concentrated parameters;

3.2) fuzzy mathematical model of the given position in the form of DPO with its further solution relatively $\mathbf{U}$ is constructed.

Fuzzy model of burning out process

As the model of thermal object with concentrated parameters, the author suggested fuzzy models, since models of the given class [4-5] are not complex and are suitable for usage in existing ACS of technological process, operating in real-time. For elaboration of fuzzy model of tunnel oven for burning out the analysis of factor, influencing the temperature of each position of the oven was performed. These parameters characterize the conditions of thermal and previous position and take into account motion of air along the oven:

x_1 – absolute deviation of the temperature T from the set one T_3 at current position of the oven; x_2 – rate of temperature change; x_3 –calorific power of fuel; x_4 – temperature of the air in the previous zone; x_5 – amount of air, remove to the next position; x_6 – fuel rate at the current position ; x_7 – temperature of the material in current zone. Hierarchial tree of material in the mode structure, that enables to reduce the amount of rules in database.

Adequacy of fuzzy model is proved by the results of experimental research, which showed that mean square error of the model is 9.64.

Results model accuracy study are shown in Fig. 2, where T_{mod} – value of the temperature, obtained by means of fuzzy model, T_{real} – experimental value of the temperature, $T_z \pm d$ – admissible deviations of the temperature according to technological regulation Calculation time of control parameters V for obtaining specified value of the temperature 1,5 c.

Results of modeling showed that the method, of thermal technological DPO modeling, suggested in the research, allows us compared with the data of the Table 1, to increase considerably modeling rate due to application of fuzzy model at positions, for temperature distribution of which, relation $\left|T^k - T^0\right| \leq \xi$ is performed.

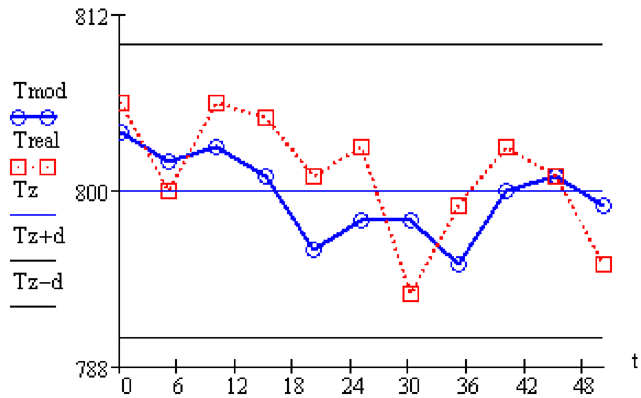

Fig. 2. Investigation of fuzzy model accuracy

Optimization algorithm of TDPO model parameters

To account peculiarities of the whole technological process the paper suggested the method of determination of optimal parameters of TDPO model (Fig. 1). The importance of the method is that the existing models do not take into account the factors of the complete technological process, disturbances, connected with temperature and air humidity changes, characteristics of raw material. deviation of semifinished products preparation, that is why these method do not allow to describe adequatly DPO in various conditions. The idea of the method [6] is the following. Using value of technological process parameters we can forecast maximum possible class of production quality and find optimal, in the sense of energy expenditures, values of temperature field, at which the specified class of quality is achieved.

Method of determination of thermal technologies DPO optimal parameters includes the following steps:

1. Forecast of maximum possible class of products quality, performed using logic-probabilistic model (block LV-model of products class determination, Fig. 3) that allows to define the quality class taking into account decision-making risk, predetermined by complexity and failure rate of the object, considerable lag of control channels, distribution of gas environment temperature

2. Low limit is defined for forecast maximum possible quality is solved using the model of the complete technological process (block “model of quality forecast”) optimization model (block “Optimization model”) and constrains of technological specifications relatively temperature field values T:

$$f(\mathbf{T}(\mathbf{U})) \to min, \tag{1}$$

$$\begin{cases} MM\_Class(\mathbf{H},\mathbf{T}) = Class_{max}; \\ MM\_Mitsnist(\mathbf{H},\mathbf{T}) = M_{min}\big|_{CLASS\,max}; \\ \mathbf{W}_{min} \le \mathbf{W} \le \mathbf{W}_{max}, \end{cases} \tag{2}$$

where $f(\mathbf{T}(\mathbf{U}))$ – is efficiency factor, that takes into account relation between the temperature and energy expenditures needed to maintain it; MM_Class – is mathematical model of products quality classification; $MM\_Mitsnist$ – is mathematical model of TP products quality; $\mathbf{H}$ – is vector of parameters, which precede the stage of DPO usage; $\mathbf{W}_{min}$, $\mathbf{W}_{max}$ – are limits control system technical parameters.

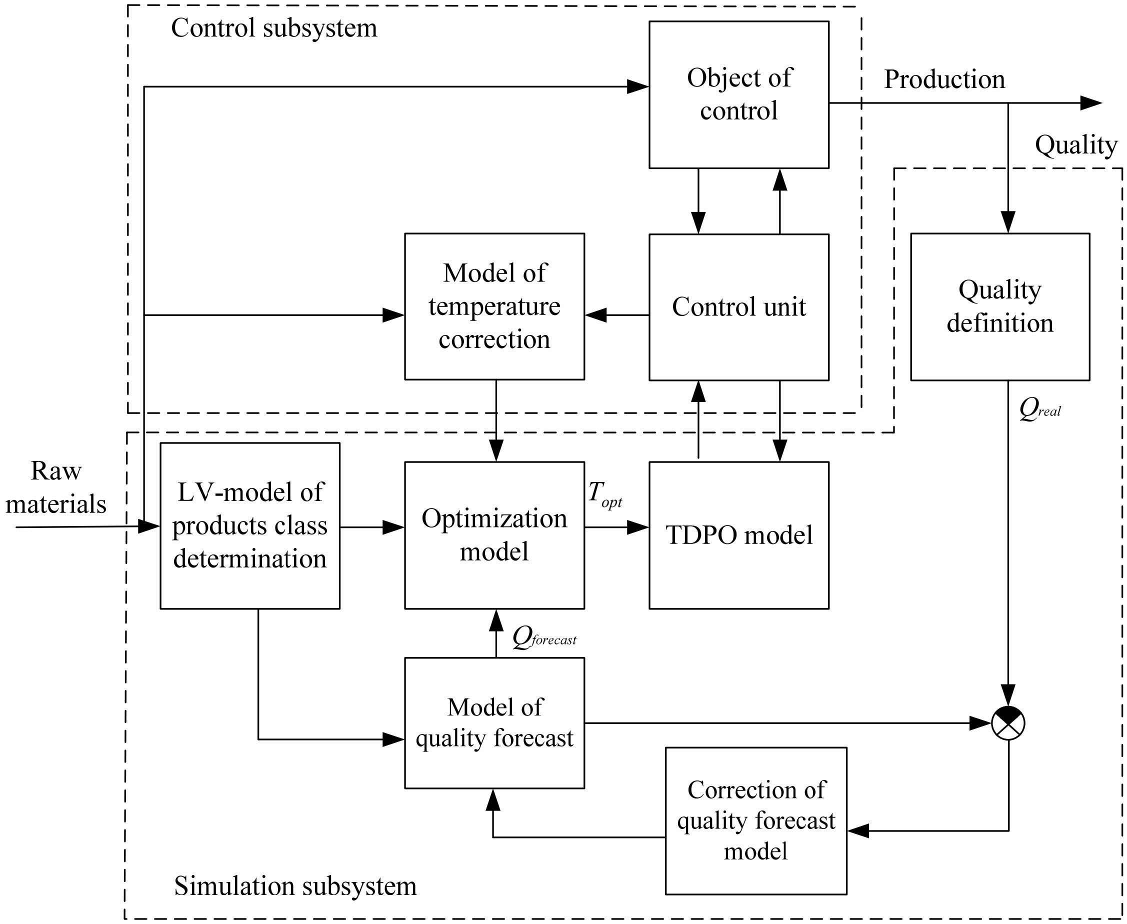

Fig. 3. Block-diagram of the method of DPO optimal parameters

1. Corrected parameters of thermal technological DPO-T_{opt}, obtained at previous step, are used in the model of thermal technological DPO (block "Model of TTDPO") for modeling of temperature field of control object.

2. If it is impossible to maintain calculated temperature curve due to technical reasons (for instance, change of items pushing mode, failure of burners in separate positions) the method provides the possibility of immediate correction of temperature field by means of temperature field correctional model (block "Model of temperature correction"), at the input of which, besides the parameters of previous stages of TP, values of temperature field, obtained prior to the given position, arrive.

3. After completion of TP real quality of production $Q_{реал}$ (block "Quality determination"), is defined and compared with forecast quality $Q\ forecast$. In case if $\left|Q_{real} - Q_{forecast}\right| > \Delta Q_{\lim}$ (where ΔQ_{lim} – is maximum allowable deviation of quality value), then correction procedure of neuronetwork model of quality forecast (block "Correction of quality forecast", fig. 3) using teaching algorithm.

Efficiency factor of optimization problem is presented in the form of standard deviation between heat, brought in and removed for i-th position of DPO:

$$F(T,V) = \begin{pmatrix} V_i Q_н^p + V_i R_s (1+X) E_{пов} + V_{i+1} E_{п.г.}(T_{i+1}) - \\ -(V_{i+1} + V_i) E_{п.г.}(T_i) - \alpha S \cdot \left(T_i - T_z\right) \end{pmatrix}^2, \tag{3}$$

where V_i – fuel expenditures at current position; $Q_н^p$ – least calorific power of the fuel; R_s –

stoichiometric ratio air/fuel; X – excess air factor at oven position; $Ecom$ – enthalpy of air, supplied for burning ; V_{i+1} – volume of the fuel, spent at the next position; T_{i+1} – temperature at the next position; $E_{п.г.}$ – enthalpy of combustion products, formed while burning of 1 m^3 of fuel ; α – convective heat exchange factor; S – area of heating surface; T_z – temperature of material.

We should note that criterion (3) is non-linear relatively temperature field $\mathbf{T}$, that is why for its investigation the method of quadratic programming was applied. As a result of optimization problem solution optimum temperature curves were defined, these curves allow to obtain maximum usage of energy resources. Graphs of temperature curves: references $T_{\max}$ and optimum T_{dosl} for I yh set of TP factors are shown in Fig. 4

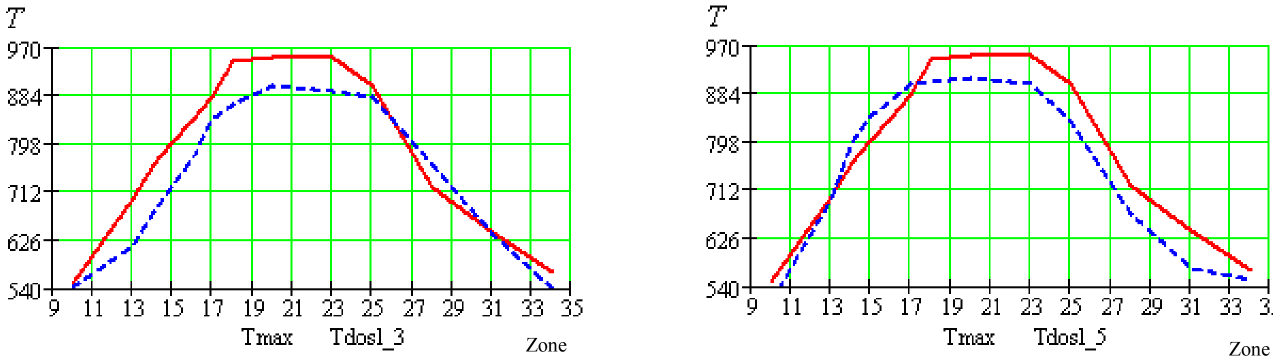

Fig. 4. Temperature curves of tunnel burning oven

Analysis of fuel consumption for maintaining of references $T_{\max}$ and optimum T_{dosl} temperature curve showed that the suggested method allows on average for one lot of products to save $\approx 428.3м^3$ of fuel (7,14%).

Conclusions

Thus, efficiency increase of TDPO modeling methods can be realized at the expense of combination of classic and intelligent technologies, aimed at creation of rapid models for minimization of temperature field deviation. This will enable to take into account risk indices while control of thermal objects and reduce energy consumption.

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