Deterministic and Stochastic Model in the Structuring of Batch Within an Arc Furnace for Multi Objective Optimization

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Keywords: technical preparation of steel, multi objective optimization, electric arc furnace, preparation of materials, charge composition, intelligent support, interactive builder.

Abstract. The traditional technology of preparation of charge materials does not include an intellectual component and is conducted only on the basis of an evaluation of the results of an industrial experiment. This study has the following purpose: increasing the efficiency of the steelmaking process in large capacity arc furnace on the basis of implementation a new decision-making system about the composition of charge materials. Authors proposed a diagram of an interactive intelligent builder which is capable to solve problems of optimizing the composition of charge materials in the presence of several different targets.

1. Introduction

Currently, there is an increase in the production of steel in electric arc furnaces (EAF). As of 2015, the world steel production volume is up to 1621 million tons of steel per year. At PJSC "Magnitogorsk Iron and Steel Works" 2 million tons of steel are melted in the EAF annually. Thus, the quality of the semi-finished product depends on the quality of raw materials, wherein there are a number of harmful impurities, such as sulfur, phosphorus, and copper.

Now there is a stable technology for preparing information for making decisions on the formation of the structure of the metal charge for steel melting in the electric arc furnace. Traditional technology does not include an intellectual component and is conducted only on the basis of an evaluation of the results of an industrial experiment based on the results of the work of an expert technologist [1-3].

In order to increase the efficiency of making decisions on the composition of charge materials for an arc furnace, it is necessary to introduce a new intellectual system for collecting and preparing information, as well as the basis for automated decision making using an interactive builder.

The interactive designer makes it possible to solve problems of optimization of the composition of charge materials in the determination of various goals, including minimization of electric power, minimization of steel production costs when melting in EAF, rational use of raw materials and alternative materials, achievement of a given chemical composition in finished steel, etc. The list of goals and limitations can be expanded depending on the customer's requirements and production conditions.

The basis of optimization problem is a mathematical model. Models of processes occurring in conditions in which their analytical description is difficult, contain two components: the deterministic component and the empirical component. As a result, a deterministic and statistical model is formed.

2. Components of the deterministic and stochastic model of the structure of charge materials

Considering that the process of steel melting in an arc furnace is highly expensive for energy resources, and the initial composition of the charge materials determines the duration of the arc under
the current and the amount of chemical impurities in the steel, it is necessary to perform predictive modeling of the result of the arc melting. In [4-6], the authors considered mathematical models for the selection of the structure of charge materials:

- for a single-objective problem of mass search for components of four elements, leading to a minimum cost of charge materials;

- or a problem with three criteria for minimizing energy costs while limiting the content of chemical impurities in steel, in particular chromium, nickel and copper.

The disadvantages of the mathematical models given in [4-6] are:

1) the model is limited by the conditions of steel melting for one type of EAF: EAF-180;

2) the limited number of constituents of charge materials with basic raw materials (scrap metal, liquid and solid cast iron, hot briquetted iron);

3) no restrictions on reserves of raw materials.

To eliminate these shortcomings, an extended deterministic and statistical model is proposed to predict the results of arc melting.

The mathematical model includes two components: deterministic and statistical.

The set of deterministic components of model $D$ includes known dependencies, assumptions, conditions and constraints. Such components are:

$D_1$: dependence $R = f(t_1, t_2)$, where $R$ – specific electricity consumption per ton of finished steel, [kW]; $t_1$ – arc time under the current, [min]; $t_2$ – duration of melting, [min];

$D_2$: system of constraints $[E_i^{\text{min}}] \leq [E_i] \leq [E_i^{\text{max}}]$, $l = 1, k$, where $k$ – the number of chemical elements requiring strict limitations on their content for obtaining the designated steel grade; $[E_i]$ – proportion of the $i$-th chemical element in finished steel, %; $[E_i^{\text{min}}]$, $[E_i^{\text{max}}]$ – allowable proportion of the $i$-th chemical element in the finished steel according to the technological handbook, %;

$D_3$: system of constraints $[P_j^{\text{min}}] \leq [P_j] \leq [P_j^{\text{max}}]$, $j = 1, m$, where $m$ – the number of components of the charge materials, %; $[P_j]$ – proportion of the $j$-th component of the charge materials in electric arc furnace, %; $[P_j^{\text{min}}]$ and $[P_j^{\text{max}}]$ – allowable proportion of the $j$-th component of the charge materials in electric arc furnace according to normative documents, %;

$D_4$: dependence $R = f([P_j])$, $j = 1, m$, where $R$ – bulk density of charge materials in the working area of an electric arc furnace, [kg/m$^3$];

$D_5$: dependence $C = f([c_j], [P_j], t_1, t_2, c_t)$, $j = 1, m$, where $C$ – prime cost of one ton of finished steel, RUB, in thousands; $c_t$ – cost of 1 [kW] of electric energy consumed by EAF, [RUB];

$D_6$: system of constraints $0 \leq [M_j] \leq [M_j^{\text{max}}]$, $j = 1, m$, where $[M_j]$ – mass of the $j$-th component of the charge materials, [t]; $[M_j^{\text{max}}]$ – mass of $j$-th component of charge materials in production reserves, [t].

The set of stochastic components of the model $S$ assumes a description of the regularities for which analytical forms of recording based on the fundamental laws of physics, chemistry, and mathematics have not been known so far.

It is impossible to study such processes on operating aggregates and it is connected with the absence of methods for direct measurement of values, studied quantities, in real time, the presence of many known and unknown factors that influence the course of the process, the presence of high temperatures and enclosed space that restricts access to the object. The set of stochastic components of the mathematical model contains empirical dependences of the linear and nonlinear forms, which are constructed from the results of passive observation of the smelting process and are recorded in the melting report. The set of stochastic components includes empirical dependencies (Eq. 1- Eq. 5):

$S_1$: $t_1 = f([P_j])$, $j = 1, m$;  

$S_2$: $t_2 = f([P_j])$, $j = 1, m$;  

$S_3$: $[E_i] = f([P_j])$, $j = 1, m$, $i = 1, k$;  

$S_4$: $[P_j] = f([M_j])$, $j = 1, m$;  

$S_5$: $[M_j] = f([P_j])$, $j = 1, m$.
Learning of the empirical data accumulated in the study of the melting of steel in the EAF showed that the set of stochastic model components includes interdependent quantities, which subsequently form a system of interdependent equations. Determining the parameters of empirical dependencies requires a stage of identification of the system type. As an example, Fig. 1 shows the visualization of one of the equations for the component $S_4$ for the conditions of EAF-180.

The sets of deterministic and stochastic components can be expanded depending on the customer's requirements for the quality of the finished product, taking into account the technological conditions of the subsequent redistribution.

\[ S_4: \{E_i\} = f(\{[E_i]\}), \quad f = \begin{cases} \frac{1}{1+m} \quad &t = \frac{t_1}{1+m} \\ \frac{t_1}{1+m} \quad &t = \frac{1}{1+m} \end{cases} \]

\[ S_4: \{E_i\} = f(\{[E_i]\}, \{\varepsilon_i\}), \quad f = \frac{1}{1+m} \]

Figure 1. Visualization of the $S_4$ component for EAF-180 conditions.

3. **Structure of the interactive builder of the multicriteria optimization problem**

The model forms the basis of the intellectual support system in the system of management of the technical preparation of production for the electric arc furnace. Paper [8] propose one of the classification of the of decision-making tasks, according to the available information on the variety of alternatives $X$ and the optimality principle $opt$, the tasks are divided as follows:

– common decision-making problem – $X$ and $opt$ are unknown;
– the choice problem – $X$ is known, $opt$ is unknown;
– the problem of optimization or the problem of ordering the alternatives – $X$ and $opt$ are known.

The presence of a deterministic and stochastic model makes it possible to determine the structure of an interactive builder for setting the problem of making decisions in the system for managing the technical preparation of production for an electric arc furnace, in particular, the choice of the structure of charge materials.

In the structure of a new system for collecting and preparing information for the formation of charge materials [7], the interactive builder forms the basis of the task formulation module. Fig. 2 shows the structure of the interactive builder.
4. Summary

1. A deterministic and stochastic model for the interactive designer of a multicriteria optimization problem for the composition of charge materials for an electric arc furnace is proposed.

2. The introduction of new intellectual support for the management system of the technical preparation of production for the arc steelmaking furnace makes it possible to introduce changes in the traditional technology of making decisions on the structure of charge materials.

3. The solutions synthesized by the intellectual support system of the technical production management system allow obtaining recommendations on the structure of the charge materials taking into account the customer's requirements with minimal material and energy costs for steel production.

References


