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Charge Melting Materials Selection Procedure for Eaf to Work in Power Saving Mode

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Abstract: The work presents the need for a scientific justification of charge melting materials selection procedure for EAF to work in power saving mode. The studies were conducted at the large integrated steel factory producing steel in 180-ton AC-EAFs. The procedure comprises six steps, including the collection and structuring of technological information, the design of logical diagrams, the description of electricity consumption process using multiobjective optimization task, containing a system of restrictions with empirical coefficients.

Key words: Power-saving mode · Electric arc steel-smelting furnace · Charge materials ratio · Multi-criteria optimization problem · Structured information.

INTRODUCTION

The steel production using AC-EAFs is one of the most expensive ones in steel industry if we take into account electricity consumption. Since 2006 "Magnitogorsk steel mill" OJSC ("MSM" OJSC) has been operating two electric arc furnaces with a total production capacity up to 4.0 million tons of steel per year. The energy consumption for these units makes 235 - 365 kW/h per ton depending on the proportion of cast iron in metal stock.

The study of electricity prices dynamics used at "MSM" OJSC for electric arc furnaces, showed a steady upward trend at an average rate of 0.0087 rubles per month, starting since 2010 till the present time (Fig. 1).

The following designations are presented on Fig. 1: AV - average voltage of electric current; HV - high voltage of electrical current; D - the price difference between the electric power of medium and high voltage.

According to the resulting growth rate of electricity prices the price of 1 kW will make 2.5273 rubles by the end of 2014 and 2.6317 rubles per 1 kW the end of 2015, which will make 11% increase in December 2014 and 16% increase in December 2015 compared to the electricity prices in January 2013. The higher prices for electricity proportionally increases the cost of 1 ton of steel obtained in electric arc steel smelting furnaces as an account cost for electricity makes about 40% of steel production cost [1].

Procedure: The steelmaking technology in "MSM" OJSC arc furnaces provides three modes of operation depending on charge material structure listed in the Table 1 [2]. According to technological instruction [2] the steelmaking by AC-EAFs uses scrap metal and steel-making iron as charge materials.

Automatic control systems have been developed for each of abovementioned modes. The electric arc in alternating current electric arc furnaces is the primary source of thermal energy and the control circuit of a furnace electric mode is the primary one in the control system of an electric arc furnace. The following actions are used as control ones during the regulation of electric arc furnace electric mode:

- Switching of furnace transformer voltage levels;
- Electrode transition at the selected voltage level.

When transformer voltage levels are switched electrode power voltage varies. This effect leads to an abrupt changes of voltage supplied to electrodes and to an arc current change at the same electrode position.

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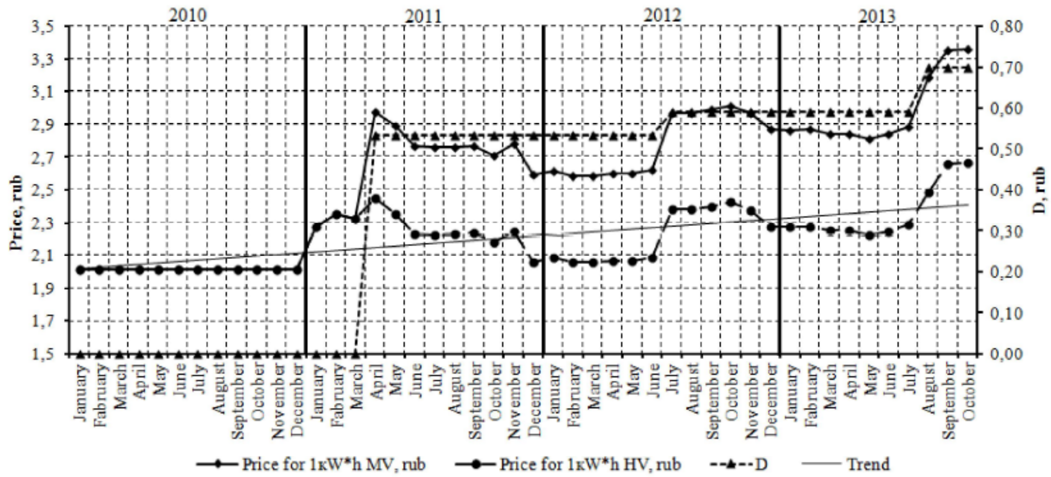

Fig. 1: Electricity price dynamics during stable operation of production since 2010 till 2013

Table 1: Standard values of electric power consumption per 1 ton of steel

Mode	Blend ratio, % Scrap	Cast iron	Electric energy specific consumption, kWt·h/t
I	100	0	365
II	75	25	290
III	60	40	235

The arc length varies at electrode transition and it leads to an arc voltage drop and thus to the changes of current in furnace phases [3].

However, the shortage of scrap in the regions of its active processing results to the use of charge alternative components such as cold pig iron (PI), hot briquetted iron (HBI) or use only liquid iron (LI) or metal scrap (Sc) during smelting.

If you change the composition of charge new terms of smelting appear: the change of charge bulk density when HBI or pig iron is used; an increase (or decrease) of heat amount when a larger (or smaller) mass of liquid iron is used during smelting. The appearance of impurities in charge materials composition leads to the internal defects formation in the half-finished and finished products. The elimination of such impurities requires the development of additional guidance on technological processes conducting at the stage of steel processing without furnace and the subsequent continuous casting [4-6].

Taking into account the existing problems and experience in the development of charge composition optimization methods and models [7-10], the authors of this article aimed to develop recommendations to perform smelting in electric arc furnaces with the power saving mode when the composition of charge materials is changed. The following purposes were solved in order to achieve this aim: monitoring implementation concerning technological parameters of electric arc steel-smelting furnace using alternative materials in metallic charge at a steel mill for AC furnaces; processing the monitoring and identification results of empirical regularities that allow to substantiate scientifically specific electricity consumption by using alternative materials in a furnace charge.

Main Part: In order to monitor and control the production of steel in steel-smelting electric arc furnace (EAF) at "MSM" OJSC the continuous monitoring of smelting process parameters is performed on the basis of corporate database. The data illustrated by Fig. 2 are located in database to estimate EAF energy consumption.

Fig.2 introduced the following designations: m_{ml}, m_{HBI}, m_{LI}, m_{SI} - the mass of the constituent charge materials: metal scrap, HBI, LI and SI respectively, t; t_1 - smelting cycle time, min; t_2 - time of arc under current, min; R - specific electric power consumption, kWt/t; [Cr], [Ni], [Cu] - percentage of residual elements in finished steel, %; T_{out} - finished steel temperature at the outlet of steel-smelting EAF, °C.

The total mass of charge in the furnace charge, t, the proportion of each charge component in the total mass, the concentration of solid phase in the furnace charge are calculated additionally on the basis of provided data.

The values of all parameters are recorded in real time, transferred to the corporate ERP base and uploaded by control and diagnostic services during local database development for the statistical study of steelmaking process.

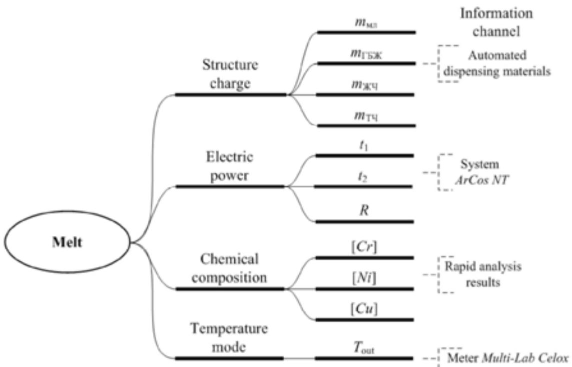

Fig. 2: Data structure fragment to estimate steel-smelting EAF energy consumption

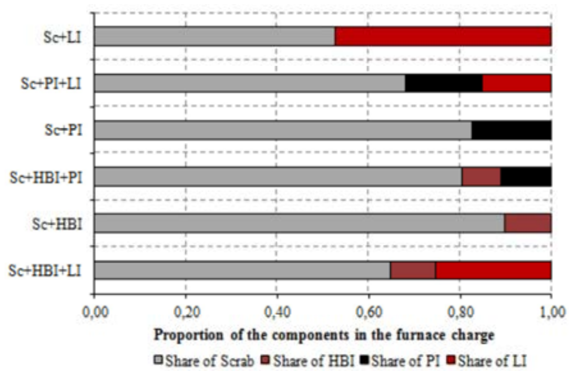

Fig. 3: Combinations and proportions of metallic charge components to perform EAF smelting

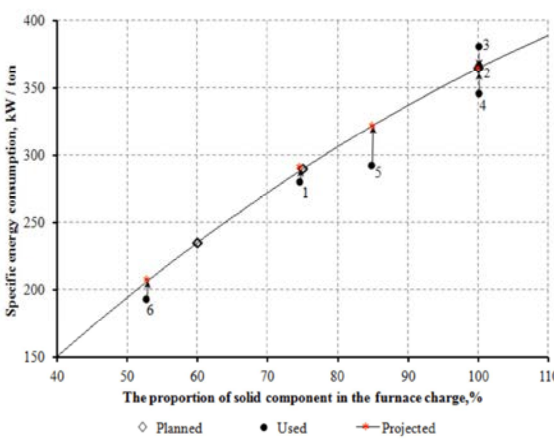

Fig. 4: Dependence of the average specific energy consumption and the average proportion of solids in metallic charge

In 2013, because of the shortage of scrap metal at electric-furnace melting shop of "MSM" OJSC such materials as HBI, SI were used in furnace charge besides traditional LI and ML.

Combinations were made in the ratio of specified components of furnace charge. These combinations are presented by Fig. 3.

The variation of share for each component of metallic charge did not exceed 5% within each smelting for each combination (Fig. 3). The observations for smelting technology compliance were processed concerning 230 planned heats. Thus, the requirements [2] meet the combinations of ML+SI+ML+HBI+SI and ML+HBI, which may correspond to the mode I (Table 1) and the combination of ML+HBI+LI is closed to the mode II (Table 1). The combinations of ML+LI and ML+SI+LI do not withstand the requirements [2] and the justification of specific energy consumption choice shall be performed for them.

The dependence of the average specific energy consumption and the average proportion of solids in the metal charge (Fig.4) was drawn up to estimate the dependence of the specific energy consumption and the composition of components in furnace charge. The following designations are specified by Fig.4: 1 - ML+HBI+LI; 2 - ML+HBI 3 - ML+HBI+SI; 4 - ML+SI; 5 - ML+SI+LI; 6 - ML+LI. The points 2, 3 and 4 corresponding to the mode I of Table 1 demonstrated significant differences on the average specific energy consumption, as for minimum rate so as for maximum rate, respectively, which constitute Δ_2 = -6.84 kWt/t; Δ_3 = -21.1 kWt/t; Δ_4 = 13,73 kWt/t. The combinations of ML+SI+LI and ML+LI do not match any of the recommended modes for Table 1. When the forecast for the quadratic trend with the determination coefficient is equal to 1 for the recommended modes an understated specific electricity consumption Δ_5 = -28.66 kWt/t and Δ_6 = -12.35 kWt/t is observed. The combination of ML+HBI+LI is performed at economic energy mode corresponding to Table 1 recommendations according to mode II.

The correlation analysis results showed the presence of complex correlation and multicollinearity between the indicators selected for the study and allowed to reveal causal effects between them (Fig. 5).

According to the article [4] the authors propose the strategy of setting multiobjective optimization problem to select steel-smelting arc furnace operation modes based on the number of residual elements in steel, such as chromium, nickel and copper. The procedure described here may be extended by an additional criterion of energy efficiency and the composition of alternative materials in metallic charge.

Fig. 5a shows a causal diagram for specific energy consumption, showing the multi-level of empirical relationships with other values and requiring the development of criteria system to achieve the minimum energy consumption values:

$$t_1 = a_1 \cdot m_{HBI} + a_2 \cdot m_{LI} + a_3 \rightarrow min, \quad (1)$$

$$t_2 = b_1 \cdot m_{SI} + b_2 \cdot m_{ML} + b_3 \cdot t_1(m_{HBI}, m_{LI}) + b_4 \rightarrow min, \quad (2)$$

$$R = c_1 \cdot t_2(m_{SI}, m_{ML}, t_1(m_{HBI}, m_{LI})) + c_2 \rightarrow min, \quad (3)$$

where a_i, b_j, c_k are empirical coefficients, i = (1,3); j = (1,4); k = (1,2).

The causal diagrams pictured by fig. 5b-5d allow determine the limits of charge composition optimization problem at power saving mode of EAF operation:

$$\begin{cases} [Cr]_{min} \le [Cr] \le [Cr]_{max}, \\ [Ni]_{min} \le [Ni] \le [Ni]_{max}, \\ [Cu]_{min} \le [Cu] \le [Cu]_{max}. \end{cases} \quad (4)$$

where the minimum and maximum percentage of residual elements and steel temperature at the EAF outlet are determined for each grade of steel and the values for the selected charge composition are determined by empirical relations:

$$\begin{aligned} [Cr] &= d_{11} \cdot m_{ML} + d_{12} \cdot m_{LI} + d_{13} \cdot m_{HBI} + d_{14} \cdot m_{SI} + d_{15}, \\ [Ni] &= d_{21} \cdot m_{ML} + d_{22} \cdot m_{LI} + d_{24} \cdot m_{SI} + d_{25}, \\ [Cu] &= d_{31} \cdot m_{ML} + d_{32} \cdot m_{LI} + d_{34} \cdot m_{SI} + d_{35}, \\ T_{out} &= d_{41} \cdot m_{ML} + d_{42} \cdot m_{LI} + d_{43} \cdot m_{HBI} + d_{45}, \end{aligned} \quad (5)$$

where d_{ij} are empirical coefficients, i = 1,4; j = 1,5.

Also the restrictions are imposed on the stocks of resources constituting metallic charge:

$$\begin{cases} 0 \le m_{ML} \le S_1, 0 \le m_{LI} \le S_2, \\ 0 \le m_{HBI} \le S_3, 0 \le m_{SI} \le S_4 \\ M_{min} \le m_{ML} + m_{LI} + m_{HBI} + m_{SI} \le M_{max}. \end{cases} \quad (6)$$

where S_l is the restrictions concerning the stocks of resources by type of components in metallic charge, t; M_{min} and M_{max} are the restrictions for the total EAF load weight, etc.

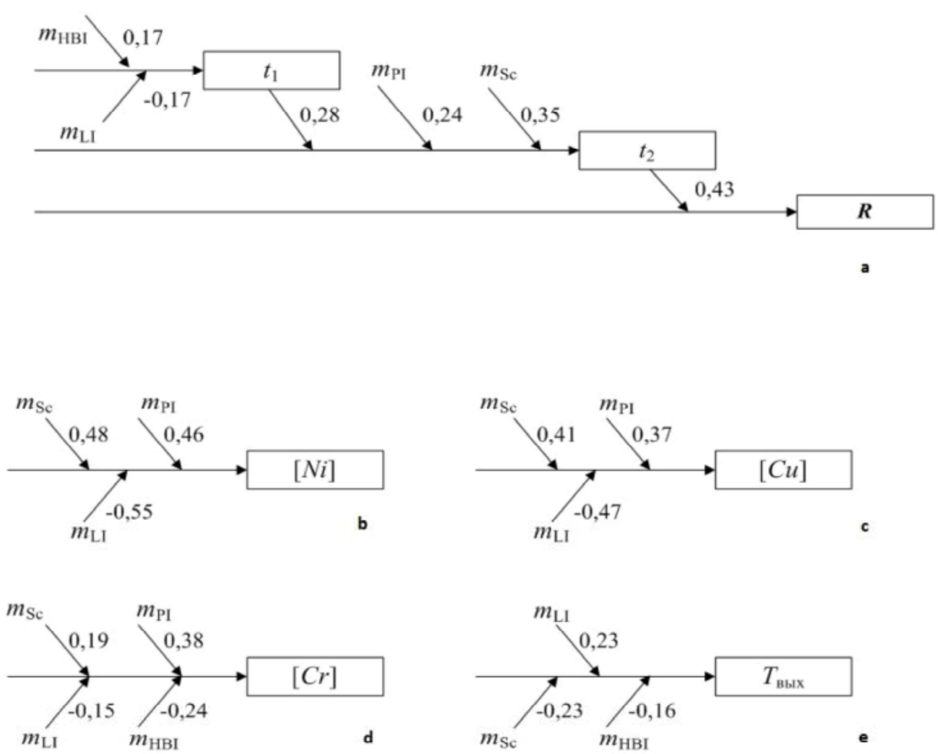

Fig. 5: Causal diagrams of indicators specifying the process of steelmaking in EAF

The use of linear empirical equations with the significance pair correlation coefficients used in drawing up of causal diagrams (Fig. 5) is sufficient for the tasks (1)-(7).

RESULTS

Thus, the selection of charge material components ratio can be formulated as a procedure shown by Fig. 6.

The technique consists of six basic steps. The selection of information is performed during stage 1 concerning technological indicators of smelting conducted with the use of alternative materials and its structuring according to the diagram shown by Fig.2. The filters are used provided by the user dialogue of technologist workplace to select the initial data. The choice of information results are placed in the table for further processing. The development of causal diagrams for the data selected during stage 2 based on the results of the correlation analysis which allow determine target functions at the performance of stage 3. According to the identification of empirical parameters the stage 4 of the model is performed based on the methodology described in [4] and developed on the theory of empirical equations identification. The solution of multicriteria problem optimization is performed during stage 5 by concession method. The result of such solution is the vector of quantitative estimates for the ratio of metallic charge components with the use of alternative materials. The obtained results are used to estimate the arc time under current, the cycle length and the specific energy consumption at obtained ratios according to equations (1)-(3).

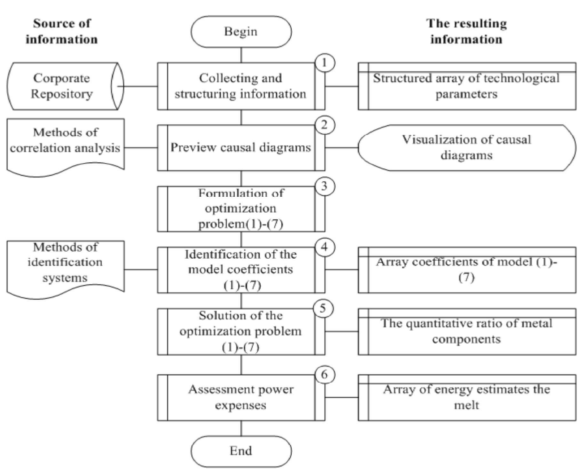

Fig. 6: Selection procedure of components ratio in metallic charge of arc steel-smeltering furnace using alternative materials

CONCLUSION

Thus, by using alternative materials in EAF metallic charge the conditions of specific energy consumption selection is changed. It is necessary solve the problem of multicriteria optimization that identifies and adapts during EAF industrial operation in order to search for energy saving modes.

Summary: It was determined during the current monitoring of technological parameter values for electric arc furnace that the addition of alternative materials to metallic charge led to the appearance of "new" modes of ArCos NT operation. New charge contents add two modes, 5 and 6, which are not provided by current technological instruction.

The addition and expansion of current technological instruction is executed to solve the problem of multicriteria optimization according to the proposed procedure, which combines analytical and empirical research methods while preserving the physical meaning of processes conduction when smelting is performed in an steel-smelting electric arc furnace.

When you use the optimal ratio of alternative charge materials the provision of specific energy consumption reduction by 1.25 % may be performed which makes about 2.94 - 4.56 kWt x h/t, reducing the cost of steel and providing energy savings.

REFERENCES

1. Pavlov, V.V., U.A. Ivin, S.V. Pekhterev, O.S. Logunova and I.I. Matsko, 2011. Effect of scrap metal fractional composition on the performance of the steel-smeltering electric arc furnace. Electrometallurgy, 11: 2-7.
2. TI 101-ST-ESPTS-64-2007. Smelting of steel in electric furnaces, 2007.
3. Parsunkin, B.N., S.M. Andreev and O.S. Logunova, 2012. Automation and optimization of steel smelting process control in electric furnaces. Publishing company: Magnitogorsky state technical university named after G.I. Nosov, pp: 304.
4. Logunova, O.S., 2008 Internal-defect formation and the thermal state of continuous-cast billet. Steel in Translation, 38(10): 849-852.
5. Matsko, I.I., Y.V. Snegirev and O.S. Logunova, 2012. Data acquisition and preparation methods for continuously cast billets quality analysis software. Applied Mechanics and Materials, 110-116: 3557-3562.

6. Vdovin, K.N., S.V. Gorostkin and V.D. Kiselev, 1996. Effect of the secondary cooling zone of a continuous-casting machine on the quality of slabs. Steel in Translation, 26(12): 28-30.
7. Logunova, O.S., E.G. Filippov I.V. Pavlov and V.V. Pavlov, 2013. Multicriterial optimization of the batch composition for steel-smalting arc furnace. Steel in Translation, 43(1): 34-38.
8. Semin, A.E. and N.A. Smirnov, 2008. From scrap to stainless steel. Electric metallurgy, 5: 44-46.
9. Ivin, U.A., A.B. Veliky, N.V. Saranchouk, A.Valiahmetov, Kh. and L.V. Alekseev, 2008. Features of arc furnaces using liquid iron. Steel, 7: 49 - 52.
10. Guojun Zhang, Zhen Zhang, Wuyi Ming, Jianwen Guo, Yu Huang and Xinyu Shao, 2014. The multi-objective optimization of medium-speed WEDM process parameters for machining SKD11 steel by the hybrid method of RSM and NSGA-II. The International Journal of Advanced Manufacturing Technology, 70(9-12): 2097-2109.