Statistical methods of evaluating quality of technological process control of trends of main parameters dependence

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Abstract. The approach to the study of metallurgical processes with the help of analysis of the trends of dependencies of the main parameters on the technological process is considered. The adopted technique for experimental data processing makes it possible to interpret the results obtained for their further practical application. The way of definition of probabilistic dependences between variables of the research object, checking the efficiency of ACS control using the basic material flows, and quality of a target product is presented. The influence of individual factors on the composition of the desired product is analyzed.

1. Introduction
One of the important tasks for technology and control of Vanyukov’s process during the processing of sulfide copper-nickel raw materials of the Norilsk industrial region is monitoring of regularities and revealing positive trends of technical, technological, economic and organizational factors aimed at increasing the efficiency of production and the quality of products. The identification and study of these patterns are also a necessary condition for the automation of technological processes.

The aim of the work is to solve the above mentioned tasks, as well as to check the effectiveness of the ACS control by the main material flows and the quality of the target product in relation to the conditions of the Copper Plant of the Polar Division of PJSC MMC Norilsk Nickel.

2. Initial data
The solution of this problem with reference to PV is considered by the example of processing operational control data for one calendar year. For analysis, a representative sample of 150 points was formed. The sample included every second day. Days before and after downtime or processing of atypical types of metal-containing raw materials were not included.

The following parameters are selected as the main investigated parameters of the technological process: consumption of metal-containing materials (the composition of materials entering the furnace is conditionally assumed constant), t/h; consumption of flux materials, t/h; consumption of technical oxygen, m³/h; air consumption, m³/h; consumption of natural gas, m³/h; total consumption of oxygen-air mixture (CMC), m³/h; oxygen content in the oxygen-air mixture, %; content of copper in matte, %.

The choice of such factor space is determined by the purpose of the study, the main direction of which is to find ways to stabilize the copper content in a matte.

To process the results, a daily data representation basis has been adopted. The choice of this level of discretization is connected with a number of objective reasons: a day is the minimum level of discretization of reporting documents of the technical department of the plant, as well as the clearly expressed individuality of shifts work in the process behaviour, which is leveled by averaging. The
A methodological basis for the processing of primary data is the correlation and regression analyses, taking into account the specific features of pyrometallurgical processes.

3. Evaluation of the relationships between the main control variables

Let us estimate the mutual influences between the main process variables with respect to correlation coefficients $r$. The values of the correlation coefficients between the main technological parameters of PV are given in Table 1.

Table 1. Values of correlation coefficients of the PV basic parameters (the coefficients that are significant by Student's criterion are shown in bold type)

|                              | Consumption of metal-containing materials | Consumption of fluxes | $O_2$ content in oxygen-air mixture | Total consumption of the oxygen-air mixture | Natural gas consumption | Air consumption | Technical oxygen consumption | Copper content in matte |
|------------------------------|-------------------------------------------|-----------------------|-------------------------------------|---------------------------------------------|------------------------|----------------|-------------------------------|------------------------|
| Consumption of metal-containing materials | 1                                          |                       |                                    |                                             |                        |                |                               |                        |
| Consumption of fluxes        | -0.156                                    | 1                     |                                    |                                             |                        |                |                               |                        |
| $O_2$ content in oxygen-air mixture | 0.618                                      | 0.427                 | 1                                  |                                             |                        |                |                               |                        |
| Total consumption of the oxygen-air mixture | 0.224                                      | 0.391                 | 0.584                              | 1                                           |                        |                |                               |                        |
| Natural gas consumption      | -0.406                                    | -0.339                | -0.665                             | -0.562                                      | 1                      |                |                               |                        |
| Air consumption              | -0.537                                    | -0.336                | -0.837                             | -0.494                                      | 0.836                  | 1               |                               |                        |
| Technical oxygen consumption | 0.501                                      | 0.463                 | 0.864                              | 0.549                                       | -0.675                 | -0.774          | 1                             |                        |
| Copper content in matte      | 0.420                                      | 0.204                 | 0.306                              | 0.004                                       | -0.403                 | -0.343          | 0.301                         | 1                      |

The analysis of the correlation coefficients shows that a stable relationship that does not contradict the theory of metallurgical processes is observed between the supply of sulphide materials and all parameters characterizing the blast. The only exception is the insignificant relationship between the consumption of metal-containing materials and fluxes (correlation coefficient). This means that the supply of fluxes is inconsistent with the supply of metal-containing materials and, with other things being equal, indicates insufficient attention to compliance with the ratio of the charge components regulated by the Technological Instruction. The insignificant coefficient of regression (Table 1) between the variables under consideration and the correlation field of the points (Fig. 1, a), in which charge of fluxes fluctuates in the range of 20-60 t/h at practically any rate of loading of metal-containing materials,
testifies to this conclusion. In this case, from the statistical point of view, there is no sense to talk about the dependence, and the flux consumption is appropriate to characterize using only the arithmetic mean.

![Figure 1. Interaction between the main PV process parameters](image)

The main relationship "the rate of loading of metal-containing materials - oxygen content in the oxygen-air mixture" (Fig. 1, b), which determines the depth of physicochemical transformations to achieve the required matte quality, is expressed quite strongly (correlation coefficient). However, there is a clear tendency not to correlate the required oxygen percentage in the oxygen-air mixture at low charging rates of charge materials. Here, the fear of regulating the feeding of the oxygen-air mixture into the reaction zone of the furnace, which is confirmed by the absence of a relationship between the loading of metal-containing materials and the total consumption of the oxygen-air mixture, affects the shifts personnel (Fig. 1c). Thus, the entire dependence is within the limits of 26-32·10³ m³/h at a load range of 20 to 100 t/h.

This indicates the insufficiently rigid control of the process: either the operator performs a change in the loading of sulphide materials almost independently from the oxygen supply changes, or there is lack of appropriate software for real time data linking over these information channels. Rather, both these trends take place, which does not allow one to stabilize the quality of the target products with the required reliability (Figure 1, d).
Fig. 1, c, shows that the degree of the connection tightness of the trend line is high for the field of interest, but there is practically no correlation between the charge of metal-containing materials and the oxygen-air mixture consumption (correlation coefficient). The significance of the regression coefficient (18.768) is in the same range that, with the values of the total consumption of the oxygen-air mixture of the order of 20-40·10³, allows one to consider the trend line to be practically absent, and in such conditions the average arithmetical consumption of the oxygen-air mixture for the period under study (about 28.5·10³ m³/h) seems to be the most affordable evaluation.

4. Analysis of the possibility of matte quality control
Let us estimate the possibilities of solving the problem of quality control of finished products while maintaining the production technology, based on the results of statistical analysis of the same sample, by isolating the regime parameters of loading with a stable matte composition. To do this, all the initial data were divided into three groups depending on the copper concentration in matte: 50-55 %, 56-60 %, and 61-65 %, and the same dependencies within each group were analyzed separately. The results of some dependencies are shown in Fig. 2.

The analysis of Fig. 2 shows that the correlation fields of the points completely overlap in all the considered dependences for different concentrations of copper in matte. Thus, it can be stated that an attempt to separate at least some zones of variation of the control variables to obtain a matte of stable composition with the given technology of control of the Vanyukov furnace is not possible.

5. Conclusions
1. The analysis of the correlation coefficients between the main control variables of the Vanyukov process for a long period of time (1 year) made it possible to state that the relationship between the feed of the charge and all parameters of blasting differs significantly from zero and does not contradict the theory of pyrometallurgical processes. However, their value for effective control of the process is clearly insufficient, since the random component in the scatter of points along the correlation fields is too large.
2. The absence of statistically proven dependences (insignificance of regression coefficients) between the main control variables does not allow using in most cases even paired linear connections for local calculations in the SCADA system.
3. The dependence between the control variables and the quality of matte (copper content) is too weak due to the high volatility of the input mass flows (the "human factor") and the lack of coordination of the amount of supplied technical oxygen with the furnace load (disadvantage of SCADA systems).
4. The improvement of the quality of the target smelting products (matte and slag) is possible by stabilizing and tight enough tying of input mass flows and blowing regimes through the introduction of an intelligent SCADA system that minimizes the impact of the "human factor".

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