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TASKS OF AUTOMATED CONTROL OF TECHNOLOGICAL PROCESSES IN A COPPER SMELTER

Abstract. This article examines the copper smelting complex as a control object, and provides a technological diagram of the relationship between the tasks of managing the complex. Substantial formulations of control problems for individual stages of the metallurgical complex have been formulated. As an example of a specific control problem, the mathematical formulation of the problem of optimal charge preparation and the method for solving it are considered.

In recent years, the development of copper metallurgy is characterized by an increase in the use of raw materials, the use of oxygen, and automated controlled processes for charging and smelting copper concentrates. The creation of automated process control systems is one of the important areas of development of non-ferrous metallurgy. Non-ferrous metallurgy is one of the major sectors of the national economy. Management in general and management of metallurgical production in particular is an informational process in nature that ensures the implementation of the material process, subject to the achievement of the pre-formulated goal of the functioning of the production management system.

Keywords. Copper concentrates, electric smelting, converting, matte, slag, technological complex, process.

Introduction.

The copper smelter processes copper concentrates using technological units such as ore-thermal electric furnaces, converters, and fire refining furnaces. The initial raw material of the workshop is a copper-containing charge, including granules, recycled materials and a pre-mixture mixture (limestone and pyrite concentrate). The charge enters parallel operating electric furnaces and is melted due to the heat generated in the slag bath. The melt, settling, is divided into matte and waste slag. As it accumulates, the slag is removed from the process to a dump, and the matte is sent for further processing in the converter stage.

During the conversion process, sulfur is removed from the matte and converted into gases in the form of SO₂, iron is slagged. To create the necessary slag regime, silicon ores (fluxes) are loaded into the converter [1].

The technological diagram and interrelation of tasks is presented in Fig. 1.

The conversion procedure belongs to the category of discrete-continuous, iterative, multi-stage operations, operating autogenously, generating heat. The latter allows for additional processing of cold materials (matte crusts, turns). The products of converter smelting are blister copper, converter slag, waste gases and dust. Converter slags are returned to electric furnaces for depuration; gases, after cleaning them from dust, are supplied to the production of sulfuric acid.

The copper smelting complex under consideration as a management object is characterized by a number of features.

1. Continuous-discrete nature of production. Thus, in the technological chain of copper smelting production, along with continuous processes (smelting furnaces), there are also discrete, periodic processes (converting and fire refining) [2-3].

2. A sequential - concurrent structure featuring technological intersections (among parallel streams) and feedback connections within the framework, which challenges the conditions for coordinating the work of adjacent departments and enhances the connections between them.

3. Significant-scale, energy-intensive facilities and significant length of technological “threads”, which ultimately determines substantial dynamic and transportation delays. Consequently, according to research data, the delay in the feed-to-matte pathway is approximately 6-7 hours while the charge-slag channel is 8-9 hours.

4. A wide spectrum and a significant range of external and internal disruptions, which determines the stochastic nature of the procedures and varying levels of variability across various time periods. This arises from substantial variations in the attributes of raw material flows and manufacturing outputs, as well as variations in the characteristics of units of the technological scheme, etc. [4].

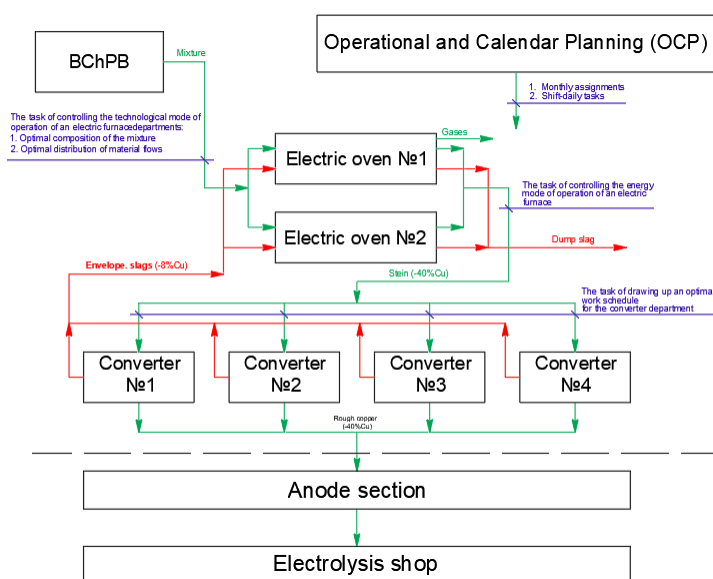


Figure 1 – Technological diagram and interrelation of control tasks of the copper smelting complex

When developing the structure of the control system for a copper plant shop, the principle of decomposition of the general mathematical model of the control problem into a number of models of subtasks was applied, taking into account a variety of units and the dynamic properties of control objects.

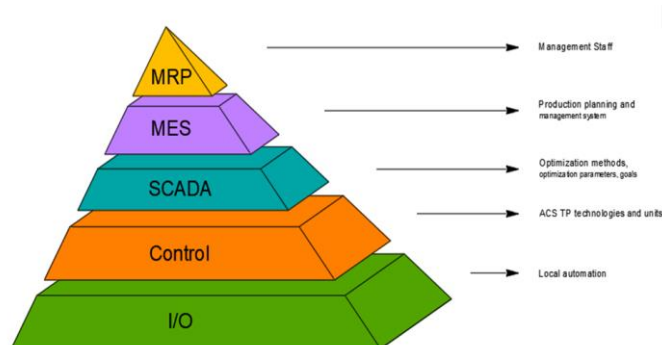


Figure 2 – Levels of enterprise management in a copper smelter

At the top level, the problem of operational management of the copper smelting complex of the metallurgical shop is solved as part of subtasks: load distribution between electric furnaces, drawing up schedules (schedules) for the operation of the envelope and anode departments.

The level at which MES technologies are used makes it possible to detail the daily plan down to shift-unit tasks, as well as to determine the requirements for managing technological limits (electric heating, metallurgical converting, anode treatment) [5].

The foundational tier of the control framework includes tasks focused on stabilizing the electrical mode during smelting and overseeing the conversion process through the purging phase

Materials and methods.

Technical and economic essence and formulation of management problems. Subsystem for operational management of a metallurgical workshop.

The organization of rhythmic and coordinated work of sections and units of a metallurgical workshop should be ensured by a system of operational control of technological processes, which carries out the formation and implementation of a plan - a workshop work schedule.

The daily work schedule of the metallurgical shop determines the distribution of loads between electric furnaces, the distribution of matte between the remaining converter melts, the start and end times of converter melt periods, the distribution of blister copper between individual anode melts, the start and end times of anode melt periods. The schedule must ensure the quantitative and qualitative implementation of the daily plan for the production of matte, rough and anode copper, determined by the production planning and management system (MES technology). The problem of creating an optimal schedule is reduced to a high-dimensional discrete programming problem. In this regard, there is a need to decompose this problem. As a result of decomposition, solving the problem of drawing up an optimal work schedule for a metallurgical workshop is reduced to solving the following subtasks:

- Drawing up an optimal work schedule for the anode department, ensuring the rhythmic operation of the processing unit.
- Drawing up an optimal schedule for the operation of the converter department, ensuring the rhythm of the processing unit and the implementation of the daily plan for the Generation of impure copper and the processing of cold materials;
- Efficient allocation of raw material streams between electric melting units and assessment of the elemental composition of the mixing mixture, limiting the copper losses within the electric furnace department.

Electric smelting process control subsystem.

The problem of controlling the technological regime of electric smelting, taking into account the peculiarities of the batch preparation stage (presence of a stack), is divided into two, which must be solved at different time intervals.

The elemental makeup of the charge is defined by the proportions and elemental structure of the material inputs entering the electric furnace (particulate matter, recycled materials, calcium carbonate, iron disulfide, and other related materials.). A significant role is played by the elemental composition of the particles (making up 70-80% of the total mass of the charge), which is achieved in a layered charge by blending Dzhezkazgan and pyrite concentrates, fluxing agents, and supplementary materials. During the production of a stack (4-6 days), random fluctuations in the composition of granules take place and at short control intervals (changes) the chemical composition of granules deviates significantly (2-4%) from the average optimal value for the stack.

In connection with the above, the problem of controlling the technological regime of electric smelting is divided into two, which must be solved at different time intervals:

- determination of the optimal composition of the stack for the interval of its laying (4-6 days);
- operational (per shift) distribution of flows across the furnaces, determining the current optimal consumption of granules, revolutions, pre-mixture mixture and chemical compositions of the latter [2].

Conversion process control subsystem.

The presence of technological feedback on converter slag significantly affects the technical and economic indicators of production as a whole. Thus, the total extraction of copper in a metallurgical workshop significantly depends on the amount of copper in the circulating product (converter slag).

The copper quantity in the slag mainly depends on the copper content within the converter mass, silica slag, and slag temperature.

The above formulated statements of problems for managing the metallurgical complex and individual technologies were included in the terms of reference for the creation of an integrated automated control system for copper at the Kazakhmys JSC plant.

As an example of the implementation of a control problem, let us consider the mathematical formulation of the problem of optimal charge preparation.

The charge preparation process involves mixing several types of concentrates, fluxes, and solid recycled materials in proportions that provide the final smelting product in quantity and composition.

A mathematical model of the technological regime of ore-thermal smelting of copper concentrates was obtained taking into account the balance ratios for individual substances and smelting products.

The solution to the problem of controlling the technological regime of the electric smelting process is carried out using a mathematical model of the “charge – blister copper” complex, taking into account the influence of envelope slag.

The mathematical formulation of the problem of determining the optimal composition of the charge is formalized in the form of a nonlinear programming problem.

Minimization of copper in the waste slag CaO, SiO and Fe was adopted as an optimization criterion

The formalized formulation of the issue is provided in the form of the following system of equations.

Optimization criterion – copper content in waste slag:

$$f(X_{16}) = f_{16}(G_0, G_3, G_{10}, X_{10}, X_{20}, X_{30}, X_{40}). \quad (1)$$

Accepted designations:

G_j – quantity of j -th material; ($j = 0, 3, 5, 6, 8, 9, 10$ – respectively denotes charge, converter slag, matte, dump slag, blister copper, oxidized ore, intra-shop circulation (crusts), electricity;

X_{ij} is the content of the i -th component in the j -th material; $i = 1, 2, 3, 4, 5$ – respectively denotes Cu, Fe, SiO₂, CaO, S.

Θ_1, Θ_2 are constant coefficients taking into account transport and production losses of materials;

$\gamma_{j-i}^{(i)}$ – extraction of the i -th component from the j -th material into the i -th material, where the same notations are adopted for j (extraction of copper from the charge into matte);

$\gamma_j^{(6)}$ – weight yield of j -th material into smelting products (taking into account waste and dust removal);

$\underline{\eta}_5, \overline{\eta}_5$ – respectively, the minimum and maximum values of the coefficient characterizing the specific yield of matte per ton of charge;

η_6 is a coefficient characterizing the specific yield of dump slag per ton of charge.

Equations for copper, iron and sulfur in matte, respectively. The model includes the following relationships. Model equations:

$$G_i X_{ij} = \gamma_{i-5}^{(2)} G_0 X_{ij} + \theta_i \gamma_{3-5}^i X_{ij}. \quad (2)$$

Equations for SiO₂, CaO and iron in waste slag

$$G_6 X_{ij} = \gamma_{0-6}^{(3)} G_0 X_{ij} + \theta_1 \gamma_{3-6}^3 G_3 X_{ij}. \quad (3)$$

Equations for blister copper

$$G_8 X_{18} = \theta_{5-8}^{(2)} G_5 X_{15} + \gamma_{2-8}^1 G_2 X_{1-2}. \quad (4)$$

Equations for iron and SiO₂, in converter slag

$$G_3 X_{ij} = \theta_2 \gamma_{5-3}^{(2)} G_5 X_{ij} + \gamma_{9-3}^{(2)} G_9 X_{ij} + \gamma_{2-3}^{(2)} G_2 X_{ij}. \quad (5)$$

Balances for electric furnace, converter stages, intra-shop cold circulation

$$G_5 + G_6 = \gamma_0^{(6)} G_0 + \gamma_3^{(6)} G_3; \quad G_3 + G_8 = \gamma_5^{(6)} G_9 + \gamma_{10}^{(6)} G_{10} + \gamma_5^{(6)} G_5. \quad (6)$$

When determining the optimal chemical composition, it is necessary to take into account the restrictions on the chemical composition of materials determined by technological standards.

System of restrictions on variables. Restrictions on the chemical composition of materials and the physical meaning of variables:

$$X_y \leq X_y \leq \bar{X}_y \leq X_{25} \leq X_{15} + X_{25} + X_{55} \leq \bar{X}_{25} \leq \bar{X}_{26} \leq X_{25} + X_{36} + X_{46} \leq \bar{X}_{26}. \quad (7)$$

Limitations on the specific yield of matte and slag per ton of charge:

$$G_6 \leq \eta_6 G_0; \quad \eta_5 G_0 \leq G_5 \leq \overline{\eta}_5 G_0. \quad (8)$$

The presented problem is an optimization problem for managing an object. change The variables in the task of determining the composition of the charge are the chemical compositions of the charge Xi0 ($i = 1.5$), matte Xi5 ($i = 1.2$), and waste slag Xi6 ($i = 1.3$).

Results and Discussions.

To solve the problem, a method was adopted based on the use of the penalty function method to transform the problem criterion and the Rosenbrock rotating coordinate method to solve the unconditional optimization problem, to which in this case the posed control problem is reduced.

That is, instead of the function $f(Xi6)$ a function $\Phi(Xi6)$ of the form is considered:

$$\Phi(X_{16}) = f(X_{16}) + \sum_i \mu_i \varphi_i(f_i(\bar{G}, \bar{X}) - a_i)^2 + \sum_i \lambda_i \Psi_i(f_i(\bar{G}, \bar{X}) - b_i)^2 - \sum_i \xi_i (Q(\bar{G}, \bar{X}) - G_i), \quad (9)$$

where μ, λ, ξ are penalty coefficients;
 $f(\bar{G}, \bar{X})$ – functions in constraints;
 $Q(\bar{G}, \bar{X})$ – functions in constraints;
 a, b – left and right inequality restrictions;
 c – values of equality type constraints;
 $\varphi, \psi, \xi = 0$, if the restrictions are met U , if the restrictions are not met.

Taking into account (4) and (6) for a sufficiently large value of the number U the solution of the transformed problem is quite close to the desired solution of the original problem of determining the composition of the charge.

Due to the fact that the Rosenbrock rotating coordinate method algorithm is a local search algorithm, when solving the problem taking into account (4) and (6), finding a global extremum is not guaranteed $F(X_{16})$.

However, given that the initial values

$$\sum_i \mu_i \varphi_i (f_i(\bar{G}, \bar{X}) - a_i)^2, \sum_i \lambda_i \psi_i (f_i(\bar{G}, \bar{X}) - b_i)^2 \text{ и } \sum_i \xi_i (Q(\bar{G}, \bar{X}) - G_i) \quad (10)$$

are given By data practices we can assume that a “good” initial approximation of the parameters of these expressions will provide the accuracy of solving the problem necessary for practical purposes [4, 6].

Conclusion.

As a result of the work done, the processes of electric smelting of sulfide copper concentrates into matte in ore-smelting electric furnaces and the conversion of copper matte in converters were considered. Calculations of the material and thermal balance of the process were made. An analytical review was carried out to determine the optimal composition of a stack of copper concentrates using electric smelting technological processes, a mathematical model was built for control systems for the processes of charging and melting of copper concentrates, which during smelting ensure a reduction in metal losses and energy costs.

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МЫС БАЛҚЫТУ ЗАУЫТЫНДАҒЫ ТЕХНОЛОГИЯЛЫҚ ПРОЦЕСТЕРДІ АВТОМАТТАНДЫРЫЛҒАН БАСҚАРУДЫҢ МІНДЕТТЕРІ

Аңдатпа. Бұл мақалада мыс балқыту кешені бақылау объектісі ретінде қарастырылады және кешенді басқару міндеттері арасындағы байланыстың технологиялық диаграммасы келтірілген. Металлургиялық кешеннің жекелеген кезеңдері үшін бақылау мәселелерінің маңызды тұжырымдары тұжырымдалған. Нақты бақылау есебінің мысалы ретінде зарядты оңтайлы дайындау есебінің математикалық тұжырымы және оны шешу әдісі қарастырылады.

Соңғы жылдары мыс металлургиясының дамуы шикізатты пайдаланудың артуымен, оттегінің қолданылуымен, мыс концентраттарын зарядтау мен балқытудың автоматтандырылған бақыланатын процестерімен сипатталады. Технологиялық процестерді басқарудың автоматтандырылған жүйелерін құру түсті металлургияны дамытудың маңызды бағыттарының бірі болып табылады. Түсті металлургия-халық шаруашылығының негізгі салаларының бірі. Жалпы менеджмент және металлургия өндірісін басқару, атап айтқанда, өндірісті басқару жүйесінің жұмыс істеуінің алдын-ала тұжырымдалған мақсатына қол жеткізілген жағдайда материалдық процестің жүзеге асырылуын қамтамасыз ететін ақпараттық сипаттағы процесс.

Түйінді сөздер. Мыс концентраттары, электр балқыту, конверсиялау, күнгірт, қож, технологиялық кешен, процесс.

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ЗАДАЧИ АВТОМАТИЗИРОВАННОГО УПРАВЛЕНИЯ ТЕХНОЛОГИЧЕСКИМИ ПРОЦЕССАМИ НА МЕДЕПЛАВИЛЬНОМ ЗАВОДЕ

Аннотация. В статье рассматривается медеплавильный комплекс как объект управления, приводится технологическая схема взаимосвязи задач управления комплексом. Сформулированы содержательные постановки задач управления для отдельных стадий металлургического комплекса. В качестве примера конкретной задачи управления рассмотрены математическая постановка задачи оптимального приготовления шихты и метод ее решения.

В последние годы развитие медной металлургии характеризуется увеличением использования сырья, применением кислорода, автоматизацией управляемых процессов шихтовки и плавки медных концентратов. Создание автоматизированных систем управления технологическими процессами является одним из важных направлений

развития цветной металлургии. Цветная металлургия является одной из важнейших отраслей народного хозяйства. Управление вообще и управление металлургическим производством в частности представляет собой информационный по своей природе процесс, обеспечивающий реализацию материального процесса при условии достижения заранее сформулированной цели функционирования системы управления производством.

Ключевые слова. Медные концентраты, электроплавка, конвертирование, штейн, шлак, технологический комплекс, процесс.

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