ANNOTATION
dissertation on the topic:
"SYNTHESIS OF A HYBRID CONTROL SYSTEM FOR A COMPLEX TECHNOLOGICAL COMPLEX OF COPPER SMELTING PRODUCTION"

submitted for the degree of Doctor of Philology (PhD) in the specialty 6D070200 – "Automation and Control"
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General characteristics of the work. The widespread and rapid development of modern methods of control of complex technological complexes, such as intelligent technologies, has led to a significant increase in publications on the practical application of these methods in the creation of control systems. In particular, in the field of non-ferrous and ferrous metallurgy, petrochemistry, energy, etc., these methods make it possible to use mineral resources more rationally, save heat and electrical energy, and reduce environmental problems, to increase the economic return from production. One of the most promising pyrometallurgical processes for melting sulfide polymetallic raw materials is the complex technological complex "Vanyukov Smelting", which belongs to the class of "autogenous" processes, which provide for the efficient use of heat released during the oxidation of metal sulfides and thereby reduce fuel consumption for melting the charge [1, 2].

At present, Vanyukov's industrial furnaces for smelting in a "liquid bath" are steadily operating at the Balkhash copper smelter of the Kazakhmys Corporation in Kazakhstan, as well as at the enterprises of OJSC MMC Norilsk Nickel and the Middle Ural Copper Smelter (SUMZ) in Russia. This technology has great prospects in non-ferrous and ferrous metallurgy. The principal advantages of ISR over other autogenous methods are: continuity of the process, the possibility of melting raw (up to 8% moisture) and lump charge, high specific productivity, low dust removal, high efficiency of physical and chemical processes in the melt, low content of valuable components in the slag, the possibility of obtaining "rich" matte and waste gases (for sulfur dioxide), utilization of the generated heat, etc.

The technological complex for melting copper concentrates in the Vanyukov furnace (TC PV) includes the following stages and units: charge preparation (stack charge tank), the Vanyukov furnace itself with conveyor lines, hoppers and feeders for loading raw materials, and "siphons" for the production of smelting products, an electric sedimentation tank for slag, a waste heat boiler, gas ducts for removing waste sulfur-containing gases and supplying them to sulfuric acid production. The matte enters the converter compartment to produce blister copper, and the slag from the electric sedimentation tank is sent to the dump.

The automated process control system (APCS) of the TC PV at the Balkhash Copper Smelter (BMZ) was developed and implemented simultaneously with the construction and commissioning of the first ISR production complex in the late 80s of the last century. The system was implemented on modern (at that time) technical means of automation and third-generation control computers (SM-2M and TVSO).

Then this system was replicated for the second PV complex. At the present time, BMZ has an automated process control system for the ISR metallurgical complex based on modern microprocessor technology, with a traditional three-level structure. The lower ("field") level includes various control and measuring devices and shut-off and control valves. The middle technological level is implemented as a shieldless control and control system. The upper (operator) level is implemented on the basis of a SCADA system. The control of the ISR process is carried out by the operator (shift foreman) in accordance with the technological instructions based on experience, intuition and subjective analysis of the current readings of control and measuring devices (temperatures, flows, pressures, vacuums and other variables, at various points in terms of units and material flows, the position of actuators and shut-off equipment), the results of chemical analyses arriving with a significant delay, as well as visual data observations of maintenance personnel (melt level, condition of the flow and transport system, bunkers, pipelines, gas ducts and other equipment). The variety of emerging production situations, different qualifications of personnel, the complexity of the TC IS, which belongs to the class of stochastic, multidimensional, non-stationary objects, make it impossible, under the conditions of the existing automation system, to have high-quality control of the complex, which leads to deviation of process indicators from the specified ones, equipment failures, unproductive shutdowns and losses, as well as the occurrence of emergencies [3, 4, 5].

The continuous nature of production and technological restrictions on the operating modes of the equipment impose strict requirements on the control system of the complex in terms of coordinating the loads of adjacent stages and ensuring the effective functioning of individual processes and the complex as a whole.

The development of autogenous processes was carried out during the period of active introduction of technical means and automation systems into production and the use of mathematical modeling methods in scientific research. During the introduction of the "Vanyukov melt", along with physical and chemical studies and development of the design parameters and operating parameters of the PW TC, including related equipment, work was carried out to build mathematical models of the process and use them in control systems, which were developed simultaneously with the development of the new technology. Such work was carried out at the copper plants of the Norilsk and Balkhash mining and metallurgical plants [3-8].

In all the works on the creation of automation systems, it was planned to use mathematical models for the purpose of effective control of the process of fire protection, but for a number of objective reasons, mainly related to the low level of technical means of automation and the limited capabilities of Soviet control computers of that generation, these goals were not realized.

In recent years, intelligent technologies and systems that formalize the experience and knowledge of experts in process control have become widespread. In particular, in the work of Suleimenov B.A. [9], an overview and detailed description of the advantages of intelligent technologies and their application for the control of various chemical and metallurgical processes is given.

Various aspects of the application of intelligent technologies for controlling the processes of autogenous smelting, including Vanyukov smelting, are devoted to the works [9 - 12].

Relevance of the dissertation:

The relevance of the dissertation is associated with the solution of the following tasks that lead to an increase in production efficiency and competitiveness:

1. Control of the complex, not individual processes: the work is devoted to the development of a control system not for a separate process, but for an interconnected technological complex of copper smelting, including blending, melting and waste gas heat recovery.
2. Taking into account the requirements of related industries: the control system takes into account the requirements of the converter department of the copper smelting shop and the sulfuric acid shop.
3. Use of mathematical and intelligent models: to form expert opinions, expand the information base of decision-making and create a management system using predictive models and "virtual" sensors.
4. The task of managing the technological complex expands the management capabilities using higher-level optimization criteria with the assignment of tasks to individual processes.

The purpose of the dissertation:

Synthesis of an effective hybrid control system for copper smelting production, which makes it possible to switch to a high-level optimization criterion that takes into account the tasks for the main processes.

The main idea of the work:

Development of algorithms and control models based on intelligent and hybrid technologies, accumulated knowledge that takes into account the experience and intuition of process operators and data obtained in real time.

Advantages:

- reduction of the time for the development of the management system;
- improving the accuracy and efficiency of the management system.

Objectives of the study:

1. Assessment of the technical condition of the technological complex of copper smelting production and formulation of the concept of creating a hybrid control system based on an analytical review.
2. Theoretical substantiation of the basis for the synthesis of the hybrid control system of Vanyukov smelting (PW) as a complex technological complex.
3. Development of the structure of a mathematical model of a hybrid control system for the technological complex of copper smelting.
4. Synthesis of models and control algorithms based on the analysis and processing of big data of the technological complex of copper smelting.
5. Testing of a prototype of a hybrid control system and a study for sensitivity, stability, unambiguousness and assessment of its adequacy.

Object of research:

The object of this research is a complex technological complex for smelting copper concentrates in the Balkhash copper smelter.

Research methods:

To solve the tasks, the methods of mathematical modeling, optimization of technological processes, identification methods and methods of statistical dynamics are used in the work.

Modern MATLAB application packages were used as modeling tools: Fuzzy Logic Toolbox and System Identification Toolbox and Comsol Multiphysics.

Scientific novelty of the work:

In the dissertation, the following scientific provisions were developed and presented, which are distinguished by unique characteristics:

1. For the first time, the problem of managing not a separate process, but an interconnected technological complex, including successive stages taking into account the requirements of related industries, is considered.

2. A hybrid approach and a PI management algorithm have been developed, combining the accumulation and processing of big data and knowledge to formulate a rule base.

The following scientific provisions are submitted for defense:

- Methods and tools for developing hybrid models of the facility management process;

- the structure of the mathematical model describing the processes taking place in the supra-tureper zone and the zone of smelting product sedimentation;

- Tools for integrating the industrial controller with the environment for modeling and statistical evaluation of the Matlab model parameters;

- experimental data obtained and tests of intelligent control algorithms in industrial conditions of the Balkhash copper smelter;

is a model implemented in the Comsol Multiphysics program for assessing the thermal regime of the complex in aggressive environments.

Practical significance of the results of the research:

The process of smelting sulphide raw materials in the Vanyukov furnace is one of the most advanced processes in non-ferrous metallurgy. However, its widespread use in world practice is very limited, which is mainly due to the lack of an effective automatic control system. In Kazakhstan, another autogenous process ISASMELT™ was chosen for the metallurgical complex of Kazzinc LLP, under the license of the Australian company Xstrata, the automation system of which is supplied on a turnkey basis, and includes, in addition to the traditional control and regulation of the process, a number of calculation modules that provide the selection of the best modes based on mathematical models.

Proposed methods and tools:

- open up opportunities for the creation of intelligent and hybrid control systems for a wide range of complex technological processes;
- in the context of Vanyukov smelting will contribute to the introduction of this method at domestic and foreign non-ferrous metallurgy enterprises.

Developed ISR control system:

- will ensure more efficient conduct of the technological process;
- will reduce the cost of its implementation;
- reduce the volume of harmful emissions;

- will lead to a significant economic and environmental effect.

Results:

- will create a reliable (proven in practice) tool for the development of intelligent and hybrid systems for optimal control of complex technological processes;
- can be used to create similar systems for various technological facilities in different sectors of the economy of Kazakhstan and the world.

Assessment of the expected economic effect: it is possible only after testing the proposed control algorithms in the industrial conditions of the enterprise.

The specific personal participation of the author in obtaining scientific results is as follows:

- setting research tasks and the way to implement them;
- Inspection of the control object, collection of expert opinions of experienced operators-technologists for modeling control processes;
- conducting a correlation analysis of the processing of experimental data and developing the structure of a mathematical model describing the processes taking place in the sup-tureper zone of the ISR furnace and the stratification zone of melting products (sedimentation zone)
- conducting a study of the developed management models for sensitivity, stability, unambiguity and assessing the degree of their adequacy;
- development of a physical model of a temperature control device in aggressive environments, implemented using the Comsol Multiphysics software platform, which allows you to assess the thermal regime of the complex;
- Testing of intelligent control algorithms in industrial conditions at the Balkhash Copper Smelter.

Approbation of the work. The main provisions and results of the work were reported and discussed at domestic and foreign scientific conferences: the International Scientific Conference "Computational and Information Technologies in Science, Technology and Education" (CITech-2015, Almaty-Novosibirsk: KazNU, 2015); the International Satpayev Readings "The Role and Place of Young Scientists in the Implementation of the New Economic Policy of Kazakhstan" (Almaty: KazNTU, 2016); the foreign scientific conference "Conference Lubelskie Dni Nauki i Biznesu WD 2016" (Lublin, 2016); International Scientific Conference "European Science of the 21st Century - 2016"; foreign scientific conference "Environmental Engineering V: Proceedings of the fifth National Congress of Environmental Engineering" (Lublin, 2016).

Publishing. The main results of the research are published in 13 publications, including 8 articles in international scientific conferences, including 4 in foreign conferences (Lublin, Poland), 1 article in an engineering and technical journal, 3 articles in publications recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Higher Education of the Republic of Kazakhstan and 2 articles in international peer-reviewed scientific journals included in the Scopus/Web of Science database.

Structure and volume of the thesis: The thesis consists of an introduction, four chapters of the main content, a section of the main conclusions and results, a

list of sources used from 63 titles and 5 annexes. The thesis contains 124 pages, 50 figures and 10 tables.

The first section of the work provides a general description of the technical condition of the technological complex of copper smelting, including a description of the Vanyukov smelting process as a control object. General information about hybrid control systems and a description of the advantages and disadvantages of intelligent technologies in the creation of hybrid control systems for metallurgical processes are given. The current state of automation of this process is analyzed. In addition, the section formulates the purpose and main tasks of research and the general methodology of research work.

The second section proposes a general concept for creating a hybrid control system, a description of a mathematical model of the kinetics of chemical reactions, and a description of a hydrodynamic model. In addition, a comparative analysis of existing control systems for various metallurgical processes is given in order to substantiate the choice of control of the technological process "Vanyukov smelting".

The third section presents a mathematical description of the technological regime, develops a mathematical model of the technological complex, including the structure of the model of technological and thermal modes. Then the implementation of a computer model for controlling the thermal and material modes of the melting process is described. After that, the problem of synthesis of a hybrid control system is formulated. Vanyukov's smelting complex. This section covers everything from basic mathematical equations to specific control algorithms.

In the fourth section, under the conditions of the Balkhash copper smelter, large data of the technological complex of the Vanyukov furnace were obtained, an analysis was carried out, and parametric identification of the mathematical model was carried out on their basis.

In the fifth section, a prototype of a hybrid control system is tested and an industrial study is carried out. A system for monitoring the thermal regime in the Vanyukov furnace is developed based on the experimental method in the Comsol Multiphysics program. Then a mathematical description of the thermal regime in the Vanyukov furnace is presented. Next, software is selected for the implementation of the model and heat transfer in the physical model is simulated. modes of operation. Parameters are predicted using a neural network. In conclusion, a study is carried out to determine the stability of the furnace thermal regime using regulators.

In the conclusion of the thesis, based on the results of the presented developments and research, the main conclusions of the work are formulated.

The appendices of the thesis present experimental data, the results of modeling in Comsol Multiphysics, the results of an experiment on heating fireclay bricks under various temperature conditions, documentation confirming the implementation of the research results in practice, a certificate of the implementation of scientific and experimental work related to the dissertation research and the act of implementation of the scientific results of the dissertation.