Optimizing of the Processing of Sulphide Ores Using Neural Network Technologies

Gulnara Abitova and Elvira Aitmukhanbetova
Department of Intelligent Systems & Cyber Security, and Department of Computer Engineering
Astana IT University
Nur-Sultan, Kazakhstan
gulya.abitova@gmail.com, e.aitmukhanbetova@gmail.com

Leila Rzayeva, Korlan Kulniyazova, and Ali Myrzatay
Department of System Analysis and Control
E.N. Gumilyov University
Nur-Sultan, Kazakhstan
Leilarza2@gmail.com, k_korlan@mail.ru, mirzataitegiali@gmail.com

Abstract

Within the processing of sulphide ores, there are problems related to the quality of products and the efficient use of technological equipment. Usually, such issues are resolved due to the engineering experiences and based on mathematical modeling of processes. The mathematical model for optimizing such operating mode is a very difficult program. Performing calculations is required a fairly large investment of time and resources. In our case, the program of the mathematical model for optimizing the operating mode of the processing equipment's for sinter firing was replaced with a neural network by implementing the process of training the neural networks. The results obtained showed that technologies based on the neural network models given a more accurate and adequate results than mathematical models, which made it possible to solve processing of ores optimization problems of great complexity. The use of neural networks for modeling technological processes has made it possible to increase the efficiency of product quality control systems and automatic control systems for the firing of sulfide ores.

Keywords
Process optimization, Sulphide ores, Mathematical models, Neural networks and Control Systems.

1. Introduction
This part is presented the relevant work and studies of other researchers and practices on the considering questions of research.

1.1 Background of Research
The modeling of complex technological processes in the metallurgical industry is a promising area of application of the tools of the theory of artificial neural networks. In this area the using of mathematical models of technological processes are necessary for the application of effective modern methods and tools for studying the influence of technology on the properties of the final product of the appropriate quality. It is important too for the tasks of optimizing control and making high-quality decisions in the processing of the sulphide ores.

In industry productions usually the mathematical models are often simplified, that limiting their actions to certain assumptions. Now days in the literature does not provide examples of the widely use of neural networks for modeling this kind of dependencies (in particular, in the lead-zinc production of non-ferrous metallurgy), the flexibility of neural network models allows them to be used to simulate of the technological processes and in the metallurgical production of non-ferrous metals during the processing and roasting of sulfide ores.

In the metallurgy industry, the task of introducing new innovative technologies is attractive, which can accelerate research in obtaining new promising metallurgical alloys, improve the quality and safety of methods for obtaining smelted metal, and reduce its cost. Due to the complex nature of the change in material properties, depending on the chemical composition of the ores being processed, the concentration of metals in the ores, heat treatment modes, and test conditions, the ability to choose the exact mathematical relationship between the composition and properties quickly decreases and may become impracticable [1].

A further solution to the problem of optimizing the control of metallurgical processes for the processing of sulfide ores is possible by solving the problems of controlling technological equipment (firing furnaces, oxygen converters, heat-energy equipment, etc.). The introduction of automated neural network systems for control of the processing of sulfide ores will improve the quality of the smelted metal, reduce its cost (including the prime cost) and increase the safety of the technological process.

1.2 Objectives

Now days, in the non-ferrous metallurgy while the processing of the sulfide ores there are often problems connecting with the quality of the decisions made in the operation and control of the equipment as well as connecting with an adequate modeling of technological processes. Because, the decision-making of operation is mainly depending of understanding of the complex chemical-physical processes and multicomponent reactions inside an agglomeration equipment, as well as of complexity of calculation and accuracy of results of mathematical modeling.

Actually, mathematical models of metallurgical processes are often simplified and limited to certain assumptions. As a rule, those models are created on the base of differential equations and integrating-differential equations and several approximations. Usually, these simplicities are depending of many factors in particularly, of multicomponent and high temperature chemical reactions while the agglomeration firing of the sulfide ores. Therefore, it is necessary to find and study an innovative method and a new approach to solve these problems arising at the non-ferrous metallurgy enterprises.

2. Literature Review

The research questions and relevant problems presenting in this work are investigated by many modern researchers and practices of industry. The artificial neural networks are a convenient and effective tool for representing of the information models and its functional defends [1]. In metallurgical industry, the task of introducing innovative technologies is attractive, which can accelerate research in obtaining new promising metal alloys, improve the quality of the product, and reduce self-cost [2].

Traditional methods of searching for the composition of new alloys with the required properties are include repeated smelting of prototypes and complex mathematical processing of the results. However, with different content of impurities in the concentrate, the number of necessary industry experiments also is increased. Due to the complex nature of the change in material properties, depending on the chemical composition of the ores being processed, the concentration of metals in the ores, the operating modes of firing, and test conditions, the abilities to choose the exact mathematical relationship between the composition and properties may become impracticable and difficult. Because of this, the ability to obtain the most promising alloys and metal quality can be complexity and difficult to manage [3].

The creation of neural network expert systems is applied to solve a direct problem - predicting the properties of non-ferrous metal alloys by their chemical composition. To solve the inverse problem, the issuance of recommendations on the chemical composition is used, depending on the set of required parameters (taking into account the cost). All this makes it possible to drastically simplify scientific research and come up with the creation of new complex materials based on innovative technologies necessary for development of modern technologies of the 21st century [4].

A plethora of modern works and research are devoted to the study of neural network algorithms and their application in the control of technological equipment, as well as to the issues of modeling the thermal operation of industrial furnaces in industrial production to ensure the tasks of optimization of control, forecasting, as well as for automated

control of energy consumption. Therefore, the work [5] is to consider the issues of creating, training, and testing an artificial neural network that simulates the thermal operation of a continuous furnace in industry production. The neural network can be used both in solving optimization problems and designing automatic control systems.
Neurocomputers are also actively used in energy systems. Last time, the neural network approach has been actively implemented in the tasks of predicting the load of energy and gas consumption [6]. In the next work is presented an ensemble approach based on learning to a statistical model to predict the short-term energy consumption of a multifamily residential building [7]. Other approaches are proposed in the work [8], where the authors used an ensemble deep belief network to predict electric consumption using three different time-series data sets.

In [9], the authors proposed a novel deep learning-based framework for improving the prediction accuracy of short-term electric load forecasting. Similarly, in [10-11], the authors presented a sister forecasters-based short-term load forecasting approach. The proposed framework presented a family of prediction models called sisters having the same model structures but a different variable selection process. The other authors [12-13] have studied a novel approach based on an evolutionary algorithm to predict short-term load. The proposed hybrid scheme provides optimal parameter tuning for neural networks, thus improving learnability and predictive performance. Similarly, the works [14-15] consider the factors and initial data used in forecasting the loads on power systems and to predict peak electricity consumption.

The same time extensive experience has been accumulated in the field of use in quality control in industry. For example, the neural network used at Intel enterprises to detect defects in the manufacture of chips is a way of rejecting a defective chip with an accuracy of 99.5% [16]. The neural network developed by Mark Waller of Shanghai University specializes in the development of synthetic molecules [16]. Yandex Data Factory tools help in steel smelting: the scrap metal used for steel production is often heterogeneous in composition. According to Yandex, the introduction of neural networks can reduce the cost of expensive ferroalloys by 5% [16]. Similarly, a neural network can help in glass recycling. Now the unprofitable, though useful business needs government subsidies. The use of machine learning technologies will significantly reduce costs [16].

Review of the other economic and production areas is shows that there are widely range of neural networks applications and artificial intelligent using for the control, automation and optimization of the processes and plants in the different areas of control. For example, in the work [17] an encode-decode Seg-Net system via deep learning network incorporated with VGG16 has been proposed in order to identify the lane markings on distinct environmental effects. Also, there is a recent work on the development of COVID – 19 detection system by a transfer deep learning approach where the state – of – the – art CNN models have been used [18].

Other work [19] investigates the method for an accurate estimation of the solar radiation in Indonesia via a new two – step artificial neural network (ANN). The performance of support vector machine (SVM), ANN, SVM with reduced features and hybrid SVM - ANN model in the detection of the breast cancer have been compared.
Recently published papers of other authors are proposed the use ANNs as an intelligent control strategy for a microgrid energy management system [20]. In the other work is investigated the method for the short - term wind speed forecasting system via deep learning algorithm with the applications to wind turbines [21].

Thus, there are many methods for determining the accuracy of mathematical models associated with the energy performance of industrial plants and other industry production. However, today there are no universal methods for their application in lead-zinc production, in particular, for modeling complex processes for processing and agglomeration firing of multicomponent polymetallic sulfide ores. The review confirms the relevance of our research and its perceptiveness in the framework of the development of Industry 4.0.

3. Methods

The research technique of this work involves the use of modern approaches on process optimization such as neural network modeling and mathematical modeling as well as numerical methods and analytical calculations of the obtained results. Also, a method of statistical analysis for decision making and using it's while the learning process of neural network models is used in this research work.

It is necessary to use mathematical models that reflect the operation of the firing furnace and associated technological equipment to make a reasonable choice of a firing plant. The mathematical models used for these purposes in the form of computer programs have a complex structure, large volumes, and take a significant amount of time for calculations.

In this case, the use of neural networks technologies to determine the accuracy of the results obtained when solving heat and energy transfer problems using multi-purpose computing systems is the best way to solve these kinds of problems.

4. Data Collection and Mathematical Modeling

To determine a dependence in the model of the processing of sulphide ores, it is necessary to reasonably set the intervals of variation of the operating parameters. The boundaries of the various intervals are determined based on the following conditions:

1) For the final firing temperature of the metal on the surface, the range of variation is in the range from the temperature at which firing cannot be performed to the melting point of the metal.

2) For the permissible temperature difference at the end of the metal firing, the range of variation is from a temperature drop close to zero (5 - 10 $^\circ$C) to the temperature difference between the melting point of the metal and the firing temperature. In practice, it is advisable to reduce this range somewhat by setting it in the range from 35 to 170 $^\circ$C.

The required dependency and equation of mathematical modeling y = f (x_1, x_2, x_3) is presented in the next form (Eq.1):

$$y = b_1 + b_2 * x_1 + b_3 * x_2 + b_4 * x_3 + b_5 * x_1 * x_2 + b_6 * x_1 * x_3 + b_7 * x_2 * x_3 + b_8 * x_1^2 + b_9 * x_2^2 + b_{10} * x_3^2 \quad (1)$$

where y is an optimization parameter; x_1, x_2, x_3 – variable parameters; b_i, - coefficients.

In order to find the coefficients b_i, a second-order orthogonal planning matrix for a computational experiment is constructed for three factors x_1, x_2, x_3. On the basis of a computational experiment using the planning matrix, the coefficients bi are found for the dependence. The optimization problem is solved taking into account 8 constraints. Using these data presented in table 1 we can determine the differences between existing and valid values that are presented in the form of dependencies between constraints and temperature of the firing process.

The differences between the valid and existing values are determined by the following formula (Eq.2).

$$\Delta y_1 = b_{1,i} + b_{2,i} * x_1 + b_{3,i} * x_2 + b_{4,i} * x_3 + b_{5,i} * x_1 * x_2 + b_{6,i} * x_1 * x_3 + b_{7,i} * x_2 * x_3 + b_{8,i} * x_1^2 + b_{9,i} * x_2^2 + b_{10,i} * x_3^2 \quad (2)$$

where i – current constraint number; y_i – the difference between the valid and calculated values of the i constrains; x_1, x_2, x_3 – variable parameters.

For calculation of these optimization tasks, during the study, it was used several modern computer tools and technics. For example, for analytical solutions were used the programs were designed using the Mathcad package. The numerical methods were used to solve research questions using the PHOENICS package. At the same time, for the processing and analysis of the research results, it was used modeling methods were based on the neural networks using the NonreSolution's package.

5. Results and Discussion

In this part of research, the results of the modeling are proposed for the process of processing polymetallic ores on the Kazakh industry plant. For this purpose, data from real installations of lead-zinc production JSC "Kazzinc" were taken as a basis. The firing furnace is a chamber lined with refractory bricks and enclosed in a metal frame. The agglomeration furnace is loaded and unloaded manually through a working window framed by a water-cooled frame and closed by a water-cooled steel damper lined with lightweight chamotte.

5.1 Numerical Results

The results of calculating the optimal modes of the real industry plant of Kazakhstan are given in table 1. Table 1 is demonstrated just the main results which are important for optimization of the processing mode in the lead-zinc production. Because, they mainly are influencing to the quality and accuracy of modeling results while the processing of polymetallic ores.

Table 1. The calculating results the optimal modes for the processing of sulphide ores

Title of controlled parameter	1	2	3	4	5
Temterature of agglomeration furnace (^{0}C)	870	903	815	810	780
The volume of pallets in the furnace (kg)	560	870	630	730	1200
The firing process temperature (^{0}C)	1470	1980	1320	1850	1950
Temperature difference of firing (^{0}C)	99	87	76	54	82
Gas consumption (m^3/hour)	25	28	22	20	19
Agglomeration time of firing (sec)	1312	1418	1138	1176	1096
Self cost of production (tg/kg)	37,2	38,3	46,9	50,2	48,3

After training on the data obtained from the calculation in the program for optimizing the operating mode of the processing of sulphide ores, the neural network is ready for operation and was used to make forecasts and make instant decisions.

As a result, the best learning outcomes of neural networks were the learning outcomes presented in table 2. Table 2 presents a comparative analysis of the learning outcomes and calculation according to the program to determine the number of pallet blanks in the firing furnace.

Table 2. Comparative analysis of the learning outcomes and calculation

Calculation and learning outcomes	Number of pallets
The total number of pallets obtained from the calculation in the program	- 1 955
The total number of pallets obtained as a result of training the neural network	- 1 943

From this table 2 it is was obtained that the final root-mean-square error is small: MSE = 0.0128.

As the result, according to the numerical experiments and the applying the trained neural network, the deviations were obtained that are presented in table 3.

Table 3. Comparative results of numerical calculations and calculations using neural networks

	Deviations on the number of pallet, pcs.	Deviation on the time of agglomeration, sec.	Deviations on temperature at the end of agglomeration, °C
maximum deviation	15	302	37
mean deviation	12	254	25
minimum deviation	7	9	1

5.2 Graphical Results

The one of the learning outcomes of neural networks were the learning outcomes presented below in figure 1 and figure 2.

Comparison of the number of pallet blanks in the firing furnace, obtained as a result of calculating the mathematical model, with the number of pallet blanks obtained after training the neural network, is also shown in figure 1.

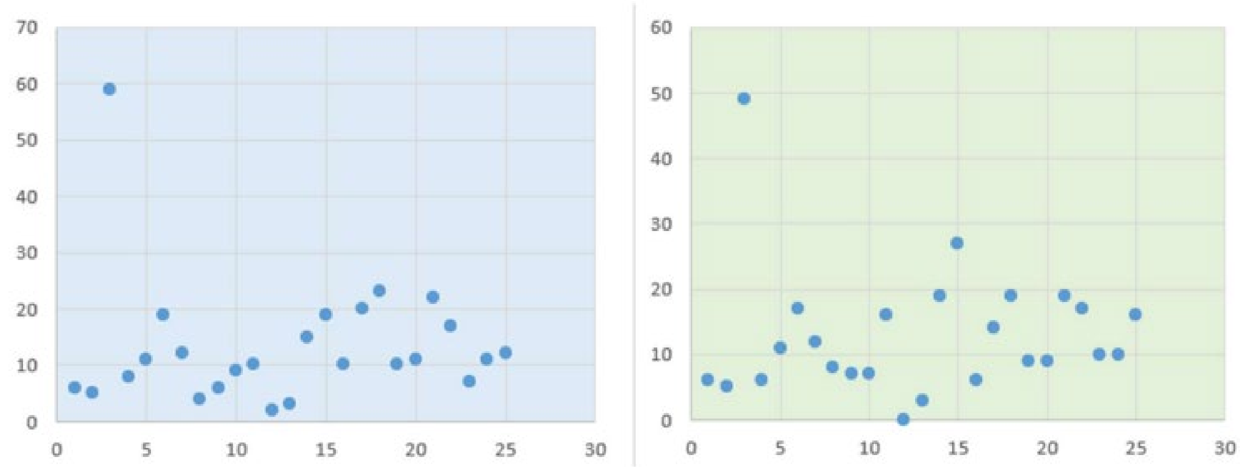

Fig. 1. Comparison of the number of pallet blanks in the furnace, obtained as a result of the calculation and the number of pallet blanks obtained after training the neural network

For clarity, figure 2 shows the dependences of the production cost on the surface temperature of the pallet blanks at the end of firing, obtained on the model of the installation: the processing of sulphide ores.

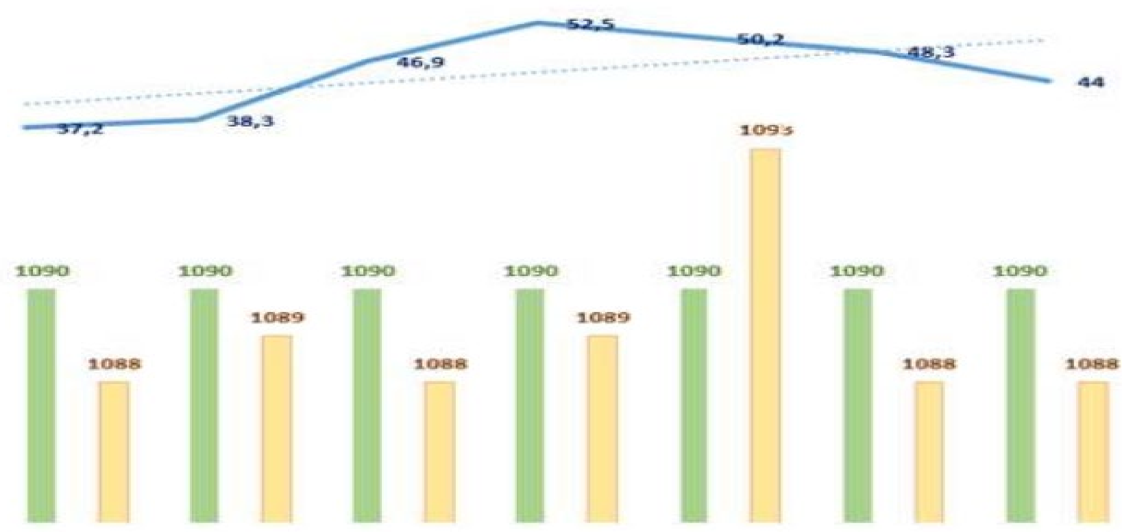

Fig. 2. Dependences of the production cost on the surface temperature

5.3 Validation

Thus, according to the numerical experiments and the applying the trained neural network, it was possible to get the comparative analysis of results of the training and calculation according to the program that provides the determining of the surface temperature of metal ores at the end of firing.

As the result, we have obtained the following outcomes of the training and of the deviations:

- the neural networks calculation errors in the pallets number in the firing furnace ranged from 11% to 24%;
- the neural networks calculation errors in the time of firing of pallet blanks ranged from 0.2% to 7%;
- the neural networks calculation errors in the surface temperature of the pallet blanks were from 0.09% to 3%.

6. Conclusion

The use of neural networks to simulate technological processes of firing of sulphide ores in metallurgical production is provided an increase in the efficiency of product quality control systems and automatic control systems for roasting of sulfide polymetallic ores, optimizing production costs by 3%. Also, it increased the efficiency of energy reproducing. The optimizing the operating mode of equipment is provided the increasing of effectiveness 10%.

Thus, from the above results, it is obvious that the obtained neural models adequately describe the real processes during the processing of sulphide ores and its firing. And it is proving that the research goals of this work are obtained. Future, it can be recommended to use for study the process of the firing of the other ores on the metallurgy plant and for calculating the design features of a heating and power plant. It can also be used to make forecasts and make instant decisions in the designing of any other heat-energy equipment and its optimal control.

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Biographies

Gulnara Abitova is an Associate Professor and Researcher of the Department of Intelligent Systems and Cyber Security at the Astana IT University, Nur-Sultan, Kazakhstan. Professor Abitova received her M.S. degree in Cybernetics from Moscow Institute of Allows and Steel at Moscow, Russia and her Ph.D. in Automation and Control from the State University of New York (SUNY) at Binghamton and L.N. Eurasian National University, Kazakhstan. She graduated the Postdoctoral Program in Control Systems from Binghamton University, USA. Dr. Abitova worked as a Visiting Professor and Researcher at the Department of Electrical and Computer Engineering at Binghamton University, USA. She was an Invited Professor in the Department of Applied Technology and Engineering at the Savonia University of Applied Sciences and Technology in Savonia, Finland. She published more than 100 research articles, 6 monographies and books, and 3 theses. Her current research interest includes control systems and industrial automation, simulation and modeling, neural networks technology and artificial intelligent systems. She is member of IEEE, IEOM, SPIE.

Leila Rzayeva is an Associate Professor, Advisor, and Researcher at the L.N. Gumilyov Eurasian National University, Information Technology Faculty, Nur-Sultan, Kazakhstan. She received her B.S, M.S., and Ph.D. from L.N. Gumilyov Eurasian National University, Astana, Kazakhstan. Dr. Rzayeva is having total teaching experience more than 10 years. Leila Rzayeva has published more than 30 national/international research articles. Her interests are control systems and industrial automation, simulation and design of control information systems, as well as design of neural networks and artificial intelligent systems.

Elvira Aitmukhanbetova is a Senior Lecturer and Researcher of the Department of Computer Engineering at the Astana IT University, Nur-Sultan, Kazakhstan. She received her B.S in Software Engineering from East Kazakhstan State Technical University, Ust-Kamenogorsk, Kazakhstan, and M.S. in Computer Science from the University of Southern California, United States. She has teaching experience of 4 years. She has presented several research papers in international journals. Her scientific interest is in the field of data science, control systems, and mathematical modeling. She is a member of IEEE.

Korlan Kulniyazova is a Senior-Lecturer and Researcher of the Department of System Analysis and Control at the L.N. Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan. She received her M.S. degree in Applied Mathematics from Tomsk Polytechnical University, Russia. Researcher Kulniyazova is having total teaching experience more than 30 years. She has published more than 30 national/international research articles. Her interests are problems of control theory, simulation and design of control information systems, as well as design of neural networks and artificial intelligent systems.

Ali Myrzatay is a Doctoral student in Automation and Control of Information Technology Faculty at L.N. Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan. He received his B.S, and M.S. in Telecommunication Systems from the L.N. Gumilyov Eurasian National University, Astana, Kazakhstan. He has presented several research papers in international and republican journals and conferences. His scientific interests are automation and control, machine learning, neural networks and industrial optimization.