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MODELLING IN MATLAB USING FUZZY LOGIC FOR IMPROVING THE ECONOMIC FACTORS OF MELTING OF COPPER CONCENTRATE CHARGE

The influence of temperature changing rate, the amount of copper in the charge, and the amount of concentrates on the melting temperature of copper concentrate charge is investigated in the paper. Modelling of the melting temperature of copper concentrate charge was carried out in Matlab using fuzzy logic. The proposed model can be applied to choose the optimal input parameters in order to achieve the stabilisation of charge melting temperature. Model experiments allow determining the optimal values of temperature changing rate in the furnace, the amount of copper in the charge, and the amount of concentrates for which the given temperature of the charge melting remains stable. Stabilisation of the charge melting temperature is directly related to the increase of economic efficiency of the technological process.

Keywords: copper concentrates; charge; electromelting; fuzzy logic; temperature stabilisation.

Олександра З. Готра, Шаміль К. Кошимбаєв, Улжан Н. Іманбекова ВИКОРИСТАННЯ МОДЕЛЮВАННЯ В СЕРЕДОВИЩІ "МАТЛАВ" З ДОПОМОГОЮ НЕЧІТКОЇ ЛОГІКИ З МЕТОЮ ПОКРАЩЕННЯ ЕКОНОМІЧНИХ ПОКАЗНИКІВ ПРОЦЕСУ ПЛАВЛЕННЯ ШИХТОВКИ МІДНИХ КОНЦЕНТРАТІВ

У статті досліджено вплив швидкості зміни температури, кількості міді в шихті, кількості концентратів на температуру плавлення шихтовки мідних концентратів. Моделювання температури плавлення шихтовки мідних концентратів проводилося в середовищі "Matlab" з використанням нечіткої логіки. Запропонована модель може бути використана для вибору оптимальних входних параметрів з метою досягнення стабілізації температури плавлення шихтовки. Модельні експерименти дозволяють визначити оптимальні значення швидкості зміни температури в печі, кількості міді в шихті, кількості концентратів, для яких задана температура шихти, що плавиться, залишається стабільною. Досягнення стабілізації температури плавлення шихтовки безпосередньо пов'язане з підвищенням економічної ефективності технологічного процесу.
Ключові слова: мідні концентрати; шихтовка; електроплавлення; нечітка логіка; стабілізація температури.

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Александра З. Готра, Шамиль К. Кошимбаев, Улжан Н. Иманбекова ИСПОЛЬЗОВАНИЕ МОДЕЛИРОВАНИЯ В СРЕДЕ "МАТЛАВ" С ПОМОЩЬЮ НЕЧЕТКОЙ ЛОГИКИ С ЦЕЛЬЮ УЛУЧШЕНИЯ ЭКОНОМИЧЕСКИХ ПОКАЗАТЕЛЕЙ ПРОЦЕССА ПЛАВЛЕНИЯ ШИХТОВКИ МЕДНЫХ КОНЦЕНТРАТОВ

В статье исследовано влияние скорости изменения температуры, количества меди в шихте, количества концентратов на температуру плавления шихтовки медных концентратов. Моделирование температуры плавления шихтовки медных концентратов проводилось в среде "Matlab" с использованием нечеткой логики. Предложенная нами модель может быть использована для выбора оптимальных входных параметров с целью достижения стабилизации температуры плавления шихтовки. Модельные

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эксперименты позволяют определить оптимальные значения скоростей изменения температуры в печи, количества меди в шихте, количества концентратов, для которых заданная температура плавящейся шихты остается стабильной. Достижение стабилизации температуры плавления шихтовки непосредственно связано с повышением экономической эффективности технологического процесса.

Ключевые слова: медные концентраты; шихтовка; электроплавление; нечеткая логика; стабилизация температуры.

Introduction. The important technological processes of copper production at metallurgical plants are the processes of copper melting in reverberatory furnaces, electric furnaces and liquid bath ovens. Six-electrode electric ore-thermal furnaces are used for charge melting. The problems in copper metallurgy such as the increased use of raw materials and oxygen, energy consumption in electric ore-thermal furnaces, irrevocable losses of copper in slags, and maximum energy consumption compared to other branches, have a significant impact of the given technological process, on technical and economic factors of copper melting production (Klein et al., 2010).

For copper concentrate melting the charge, i.e. the mixture of flux materials in certain proportions, processed at metallurgical, chemical, and other plants, is used (Utkin, 1985). The charge is used for receiving the final products with given physical properties (Kruger, 2006).

Temperature is a critical parameter in technological process of charge melting. Consequently, temperature stabilising is also an important condition of technological process. An important and urgent problem of technological process is to reach the given stabilised temperature. Temperature stabilisation leads to the improvement of economic factors. Modelling of the process of temperature stabilization allows obtaining and predicting the results, and their further optimisation. Therefore, using the modelling of temperature stabilisation is a necessary condition for high-quality technological processes.

To simulate the technological process of melting temperature stabilising of copper concentrate charge the fuzzy logic in Matlab can be applied. Fuzzy control is particularly useful in the case of complexity of the processes analysis by conventional quantitative methods or when available sources of information are interpreted qualitatively, inaccurately or uncertainly. It is shown experimentally that fuzzy control gives better results as compared to those obtained by conventional control algorithms. Fuzzy techniques make possible controlling different objects, including the technological processes. Fuzzy logic generally ensures the effective means of displaying uncertainties and inaccuracies of the real world (Wang et al., 2007). The availability of mathematical tools for displaying the initial information fuzziness allows constructing a model relevant to the reality.

Recent research and publications analysis. Such scientists as D.M. Chizhikov (1967), V.A. Vanyukov and N.I. Utkin (1988), A.N. Volskiy (1968) theoretically substantiated the possibility and the advisability of industrial melting of sulphide concentrates. M.I. Muravyov, N.V. Fomchenko and T.F. Kondrat'eva (2011) investigated the biohydrometallurgical technology of copper recovery from the complex copper concentrate. The concept of fuzzy logic was introduced by L.A. Zadeh (1965). In the paper (Zadeh, 1965) the concept of the set was extended by the assumption that the membership function of the element in the set can take any values in the range of

[0...1], not only 0 or 1. Such sets are called fuzzy. The author also proposed different logical operations with fuzzy sets and proposed the concept of a linguistic variable, the values of which are fuzzy sets. In recent years, fuzzy logic is widely used in various industries, including metallurgy (Ishmet'ev and Zykov, 2009).

Research objective. The purpose of the research is to improve the economic efficiency of technological process by choosing the optimal values of the temperature changing rate in the furnace, the amount of copper in the charge, and the amount of concentrates for stabilisation of the melting temperature of copper concentrate charge. In order to choose the optimal conditions for the technological process of charge melting we propose to use the fuzzy logic in Matlab (Ross, 2010).

Key research findings. We analysed the charge melting in six-electrode ore-thermal electric furnace. In order to determine the optimal conditions for stabilising the melting temperature of copper concentrate charge we used fuzzy logic in MatLab (Fuzzy Logic Toolbox). Since charge melting temperature in furnace varies with some inertia, we considered the influence of such important input parameters as the initial temperature of the charge, the temperature changing rate, the amount of copper in the charge, and the amount of concentrates on the following output parameters: the temperature of the charge, the voltage.

Input and output parameters can be displayed using the chart editor interface FIS (Sivanandam et al., 2007).

As input variables we considered the temperature of charge (the first variable), the temperature changing rate (the second variable), the amount of copper in the charge (the third variable), and the amount of concentrates (the fourth variable). The first output variable can be the voltage supplied to the electrodes (Figure 1).

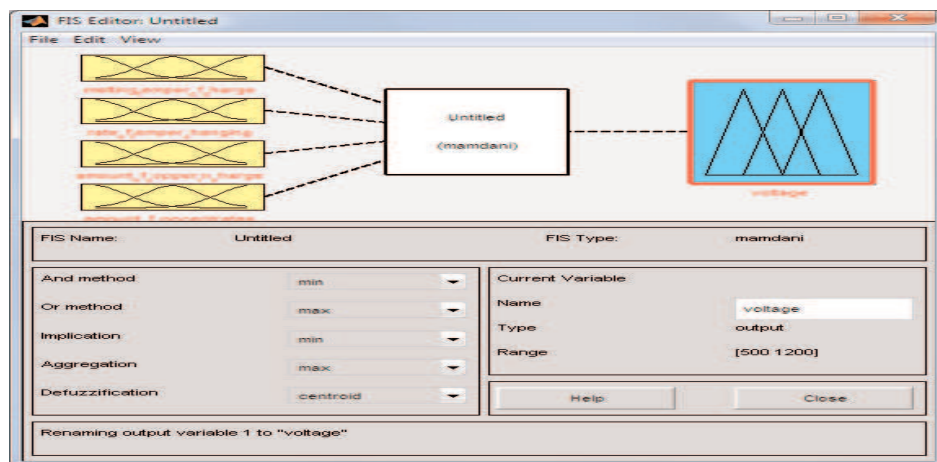


Figure 1. The FIS editor view and functions, authors' development

Figure 2 shows the editor of membership functions for the first input variable (the temperature of the charge, Figure 2a), the second input variable (the temperature changing rate of the charge, Figure 2b), the third input variable (the amount of copper in the charge, Figure 2c), the fourth input variable (the amount of concentrates, Figure 2d), and the first output variable (the voltage, Figure 2).

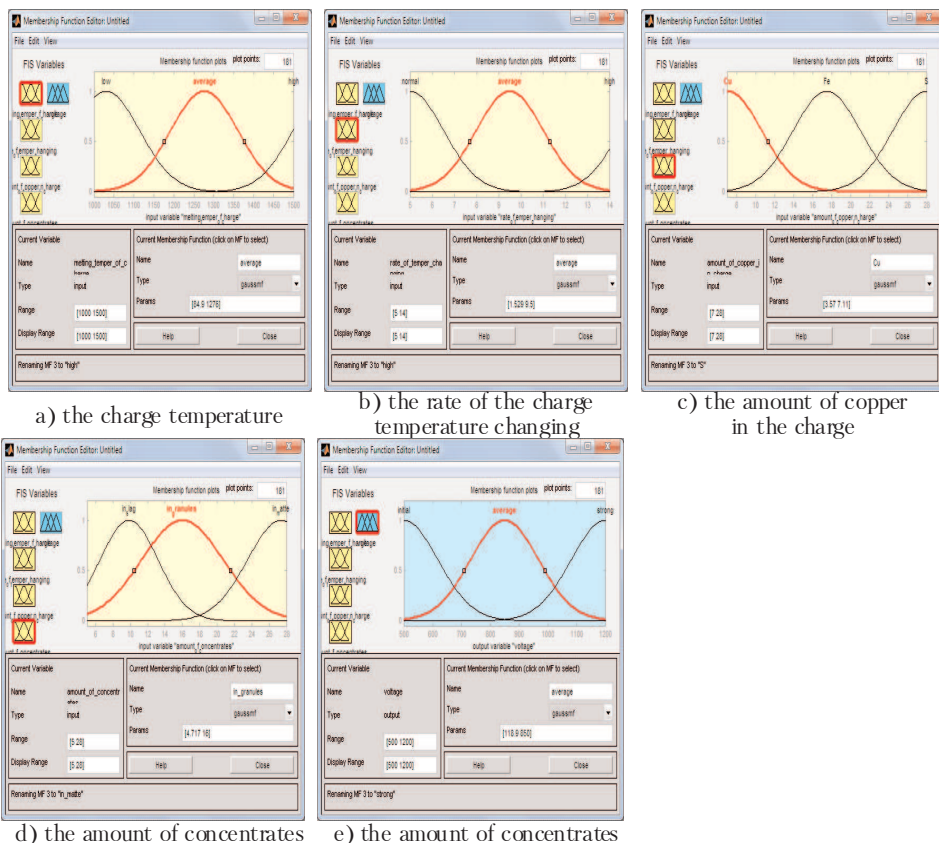


Figure 2. The view of membership functions in Membership Function Editor, developed by the authors

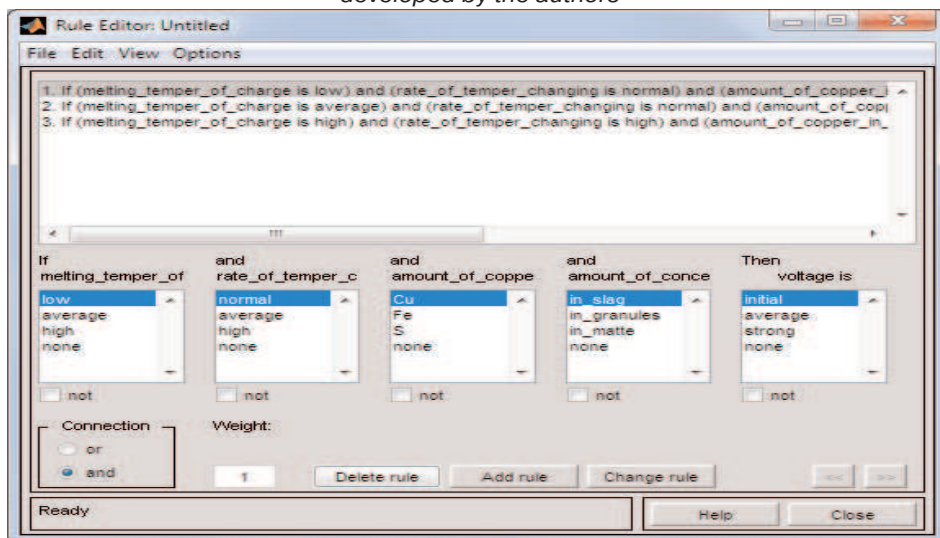


Figure 3. Rule Editor Layout, developed by the authors

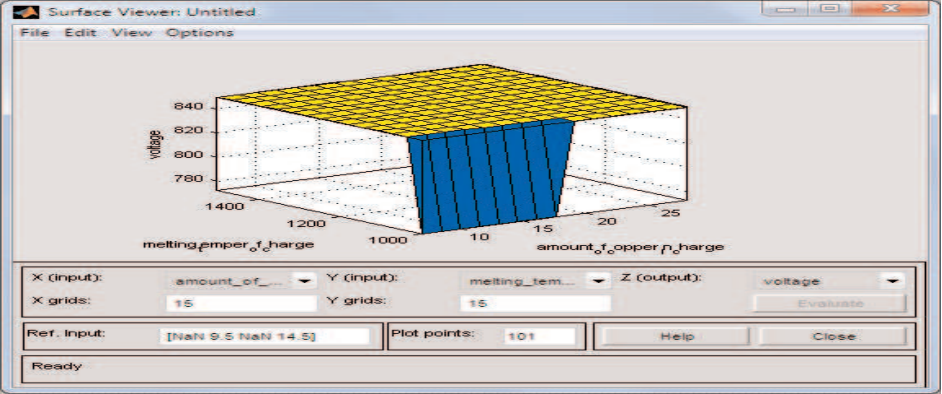


Figure 4. Surface Viewer layout for the amount of copper in the charge (input parameter), the charge melting temperature, and the voltage (output parameters), developed by the authors

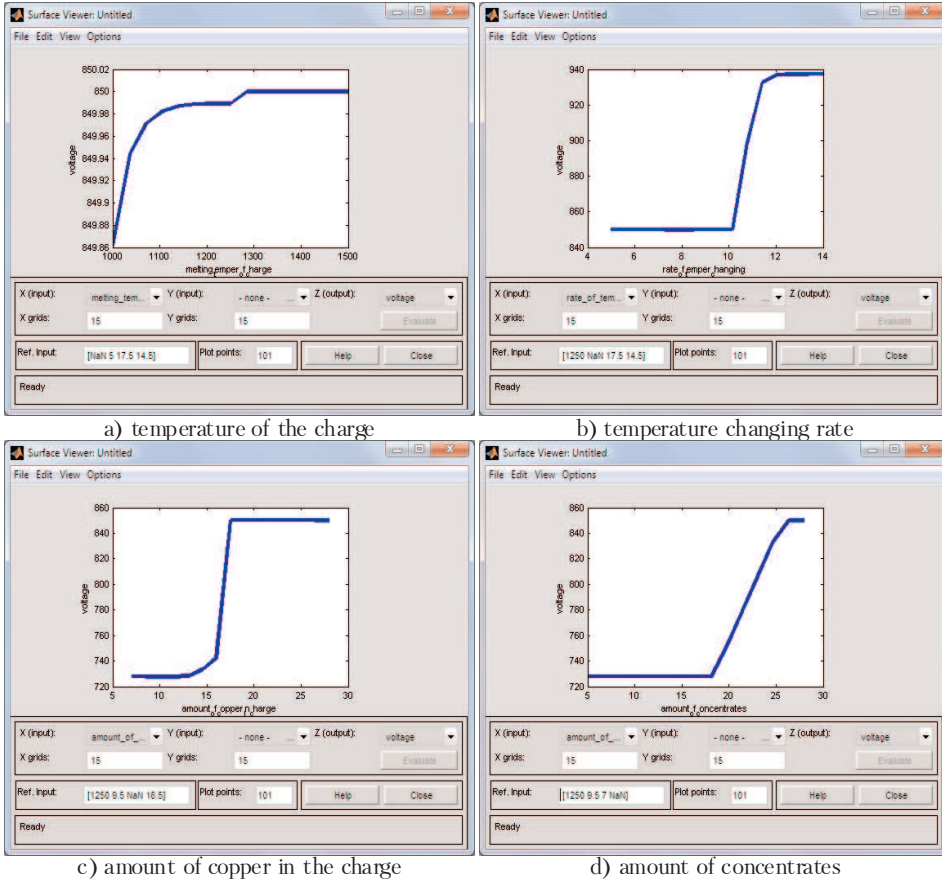


Figure 5. The graph dependencies of the output variable (voltage) on various input variables for the developed fuzzy model, developed by the authors

With the help of the "Rule Edit" we introduce new rules with the linguistic terms of input and output variables using the logical connective (AND, OR, or NOT), enter the weight value and press the button "New Rule" (Figure 3).

To see the created rule of the fuzzy inference and the modelling result we use the "Rule Editor". With the help of the fuzzy inference system surface viewer the results can be viewed as a graphic visualization (Gerla, 2001). An example of a visual display of the dependencies of output parameters (the charge melting temperature and the voltage) on the input parameter (amount of copper in charge) is shown in Figure 4.

Thus, developing a model for temperature control of the charge in the electric furnace using the three-dimensional graph, the dependencies of output variables on input variables could be formed.

One can analyse the dependence of the output parameter on given input variable. Figure 5 shows the dependence of the output variable "voltage" on the following input variables: the temperature of the charge (Figure 5a), the rate of charge temperature changing (Figure 5b), the amount of copper in the charge (Figure 5c), and the amount of concentrates (Figure 5d).

Discussion. Modelling by fuzzy logic systems in MatLab (Fuzzy Logic Toolbox) allows choosing the optimal input parameters in the given range for copper concentrates electromelting in order to obtain the given output parameters. The examples of the modelling results of the charge temperature in the furnace and the voltage are shown in Figures 6 and 7. As one can see, the calculated parameters (the temperature of charge melting in furnace and the voltage) are constant (unchanged) at these rates. The analysis of the modelling results show that both constant charge temperature in the furnace (1250°C) and the voltage (850 V) could be achieved for optimal input values such as the temperature changing rate in the furnace ($10.3^{\circ}\text{C}/\text{min}$ and $18.3^{\circ}\text{C}/\text{min}$ in the ranges of $+5^{\circ}\text{C}/\text{min}$ to $+14^{\circ}\text{C}/\text{min}$ and $+10^{\circ}\text{C}/\text{min}$ to $+24^{\circ}\text{C}/\text{min}$, respectively), the amount of copper in the charge (18 t and 15 t in the ranges $7\text{--}28\text{ t}$ and $14\text{--}28\text{ t}$, respectively), the amount of concentrates (18.3 t and 16.9 t in the range $5\text{--}28\text{ t}$) and the voltage (850 V). All the aforementioned optimal parameters values lead to temperature stabilisation of the charge melting.

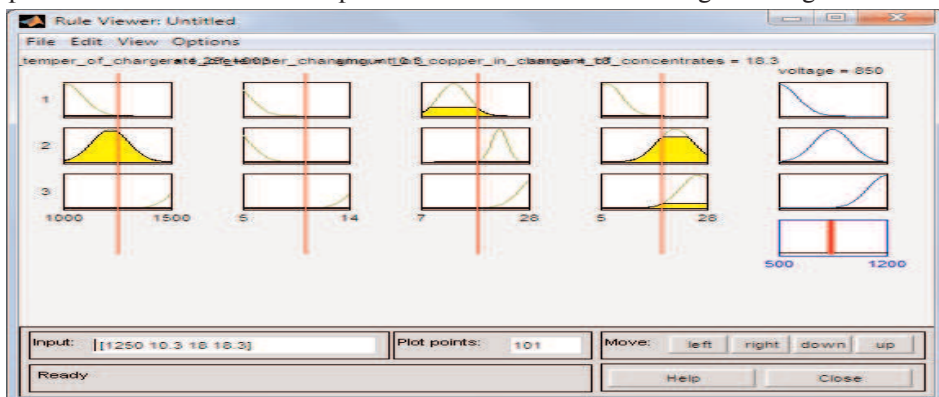


Figure 6. Rule Viewer for modelling results of the charge temperature in the furnace, the rate of charge temperature changing ($10.3^{\circ}\text{C}/\text{min}$), the amount of copper in the charge, the amount of concentrates (18.3 t), and the voltage, developed by the authors

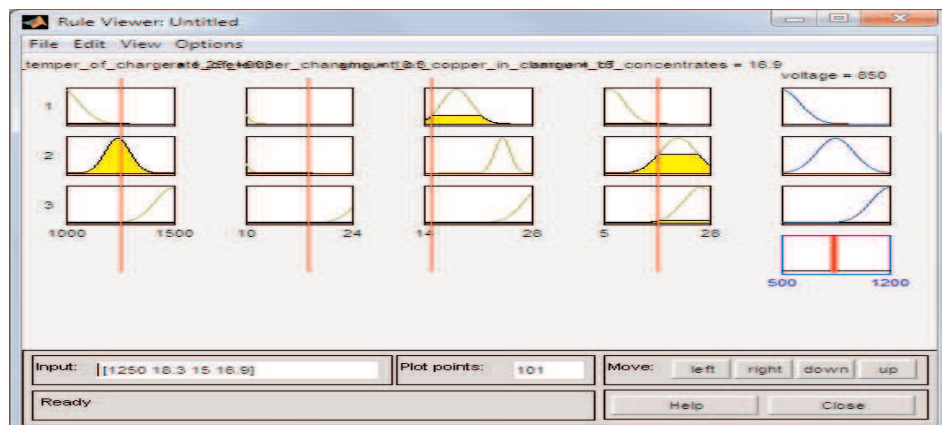


Figure 7. Rule Viewer for modelling results of the charge temperature in the furnace, the rate of charge temperature changing (18.3°C/min), the amount of copper in the charge, the amount of concentrates (16.9 t), and the voltage, developed by the authors

Conclusions. Modelling of the melting temperature for the copper concentrate charge is the basis for the choice of optimal parameters of melting technological process in metallurgy. Application of the modelling results in practice leads to better control of charge melting process. Modelling of the melting temperature of copper concentrates by fuzzy logic in Matlab is applicable. The usage of fuzzy logic systems allows solving the problems of technological design process, choosing the best regime parameters of electric furnace, and analyzing the main statistical data for the optimal control systems of charging and copper concentrates melting processes which ensure the reduction of energy and metal loss during melting. The proposed model considers the influence of input parameters such as the temperature in furnace and the rate of its changing, the amount of copper in the charge, the amount of concentrates on output parameters (the charge melting temperature and the voltage). The proposed model can be used for the choice of optimal input parameters in order to achieve the stabilisation of the charge melting temperature. Stabilisation of the charge melting temperature is directly related to the increase of economic efficiency of this technological process. Stabilisation of the charge melting temperature in the furnace makes it possible to reduce the energy consumption, improve the quality of the output product, reduce the cost of the output product, and change the technological process quickly depending on the conditions and the need.

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