Informative Features Selection for Building an Optimization Model of the Aluminum Electrolytic Cell Thermal Regime

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Abstract

Mathematical modeling is the main tool for optimizing the operation of aluminum electrolytic cells. It helps to get answers to important questions to developers of complex systems in the aluminum industry. It contributes to the intensification and improvement of these systems development in the quality with minimal resources and time. One of the main parameters characterizing the process of aluminum electrolysis is the current efficiency, an output indicator that evaluates the efficiency of the aluminum electrolytic cells. The paper proposes to use modeling regression equations for automatic control of the electrolyte temperature according to the statistical parameters of voltage fluctuations. It helps to control the technological process of electrolysis with correction for the melt temperature quickly. The authors propose a mathematical model of the thermal regime of an aluminum electrolytic cell based on an estimation of the relationship between the melt temperature and the main indicators of the electrolysis process (melt temperature and composition, concentration of dissolved alumina, cryolite ratio, anode-cathode-distance (ACD) and voltage fluctuation parameters.

Key-words: Model, Electrolysis, Aluminum Electrolytic Cell.

1. Introduction

Annually the aluminum consumption in the world grows by an average in 5-7% (in physical terms); the aluminum market is the second one in the steel market only in volume. Therefore, research in the aluminum industry has always the increased interest in new methods and means development on increasing the efficiency of the aluminum production process [1-3].

Aluminum is obtained by electrochemical decomposition of alumina in the electrolyte melt. Its main components are cryolite and aluminum fluoride at the temperature of 950-970 ° C. The

reduction of 3-valent aluminum ions occurs at the cathode, and the discharge of oxygen-containing ions occurs at the carbon anode, resulting in the formation of CO and CO2 [1, 4].

The temperature and composition of the melt, anode-cathode-distance (ACD), and shape of the working space, levels of metal and electrolyte, and electrical parameters affect the efficiency of the electrolysis process. These indicators can be quickly adjusted by changing the anode-cathode-distance (ACD), and the flow rate of alumina and aluminum fluoride loaded into the electrolysis cell. Only the voltage on the electrolytic cell and the current passing through it are controlled under the conditions of aluminum electrolysis [4-6].

The objectives of control are to maintain parameters of the electrolysis process (melt temperature and composition, concentration of the dissolved alumina, cryolite ratio (CR), anode-cathode-distance) near their optimal values.

The most important characteristic of the electrolysis process is the value of the current efficiency [6, 7]. The technological parameters of each system have a decisive influence on the current efficiency and, therefore, on the cell performance and power consumption. Therefore, consider the influence of the main technological parameters on the performance of the bath and evaluate the possibility of their use to automate the operation of the electrolytic cell in more detail.

2. Informative Features of the Automatic Control System for Aluminum Electrolysis

The electrolysis of alumina (Al2O3), dissolved in cryolite (Na3AlF6) in an aluminum electrolytic cell at a temperature of 950 ° C occurs. Small additives of some other salts (magnesium fluoride, calcium, lithium, sodium) are also introduced into the electrolyte [6, 8].

The end result of the electrolysis of cryolite-alumina melts is the release of aluminum at cathode, and gaseous carbon oxides at anode. But it is necessary to bring to the poles of the electrolytic cell (anode and cathode) a voltage exceeding a certain value, called the decomposition voltage to carry out electrolysis. The decomposition voltage is understood as the difference between the equilibrium electrode potentials of the anode and cathode [1, 4].

In general voltage drop across the operating electrolytic cell, the electrochemical component, i.e., decomposition voltage, reaches 30–40 percent; the rest is ohmic losses (losses due to resistance to current flow). The ohmic component of the voltage is in voltage losses to overcome the electrical

resistance of the electrolyte, anode and bus system [6]. The decomposition voltage of alumina depends on the material anodes are made of.

When current passes through the electrolytic cell, alumina dissolved in the electrolyte decomposes into aluminum accumulated at the cathode, and oxygen. It reacts with the carbon of anodes and as a result anodes burn out and spend [1, 9].

The decomposition voltages of AlF3, NaF, MgF2, LiF and CaF2, calculated by thermodynamic data (at T = 1300K), are, respectively, V: 3.97; 4.37; 4.61; 5.11 and 5.16. Therefore, these substances do not undergo electrochemical decomposition during the electrolysis of cryolite-alumina melts.

The participation of ions in electrode processes should not be mixed with their participation in the current transport. During the electrolysis of cryolite-alumina melts, the current is carried by all ions Al3+, Na+, AlO+, Ca+, Mg2+, Li+, AlF63-, AlF4-, F-, AlO2-, AlO33- and, possibly, others. Ions with the most positive (cations) or most negative (anions) discharge potential are discharged at electrodes. In accordance with the values of the discharge potentials during the electrolysis process of cryolite-alumina melts, ions Al3+ and O2- should be discharged at electrodes.

The main process at the cathode is the reduction of trivalent aluminum ions Al3++3e→Al.

The incomplete discharge of aluminum ions is possible with the formation of the subion Al3++2e→Al+ along with the main process.

The discharge of monovalent aluminum ions occurs with the release of metal Al++e→Al.

As a result of the electrolyte's diffusion and convection, as well as oxidation by anode gases, the concentration of Al+ in the near-cathode layer decreases and it contributes to the formation of a subion. Ultimately, these processes lead to an increase in the discharge current losses from Al3+ до Al+.

It was found that in cryolite melt aluminum is more electrically positive than sodium. However, at a relatively high concentration of sodium ions and a high temperature of the electrolyte, sodium ions can discharge at the cathode with the formation of a metal or semi-valent ions Na++e→Na or 2Na++e→Na2+. This process also reduces the yield of the metal, since during its flow the current is lost uselessly [6, 10].

The main process at the anode is the discharge of oxygen-containing ions O2--2e→0,5O2, with further formation of CO and CO2. The primary anode gas for the electrolysis of cryolite-alumina

melts with a carbon anode is CO_2. But analysis of the composition of anode gases shows that they contain up to 60% carbon monoxide. This is due to the occurrence of secondary reactions:

$$2Al+3CO_2=Al_2O_3+3CO;$$

$$3Al^++3CO_2=Al_2O_3+3CO+Al^{3+};$$

$$2Na_2^++CO_2=Na_2O+CO+2Na^+;$$

$$C+CO_2=2CO.$$
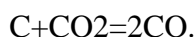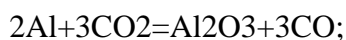
The main losses of electric current and, consequently, a decrease in the productivity of the process during aluminum electrolysis occur due to the occurrence of the first three reactions.

The anode can be passivated to a potential sufficient for the discharge of fluorine-containing ions with an increase in the current density or with a decrease in the concentration of oxygen-containing ions. Then, along with the main process, their discharge will begin at the anode:

$$4F^-+C \rightarrow CF_4+4e \quad or \quad 4AlF_6^{3-}+3C \rightarrow 4AlF_3+3CF_4+12e.$$

It is characterized by an almost instantaneous increase in voltage from 4.1 to 4.3 V in the normal state of the electrolysis process to 35 - 60 V. In this case, the smallest spark discharges occur at the interface between the anode and the electrolyte. The appearance of the anode effect is associated with a decrease in the concentration of alumina, since when it dissolves in the electrolyte, the anode effect stops. With the anode effect, the CF_4 concentration in the exhaust gases reaches 30%. It is noted that with an increase in the voltage of the anode effect, the concentration of carbon fluoride increases.

The anode effects adversely affect the technical and economic indicators of the aluminum electrolysis process, leading to an increase in the consumption of electricity, carbon anode and fluoride salts, a decrease in the productivity of the electrolytic cell, to the need to develop special systems for stabilizing the current and developing a voltage reserve at converter substations.

However, anode effects make it possible to control the operation of aluminum electrolytic cells [4, 11].

One can make a conclusion that alumina is the only electrolyte component spent during electrolysis. A noticeable discharge of other ions, such as Na+, F-, and, consequently, their significant consumption can occur only when deviations from the normal conditions of the process. Violations of normal electrolysis conditions include an increase in the temperature and voltage of the process, significant deviations of the electrolyte composition from the optimal one, and prolonged anode effects.

The efficiency of the electrolysis process is greatly influenced by the interaction of aluminum with cryolite-alumina melt and the associated losses of the cathode metal [6, 12]. This interaction occurs as a result of chemical reactions of the metal with the melt with the formation of compounds of the lowest oxidation state, i.e., subcompounds.

The solubility of aluminum in the cryolite-alumina melt is tenths of the fractional weight per 100 g of the melt, however, metal losses during electrolysis are significant, since the dissolved metal is continuously oxidized by anode gases, and the equilibrium of the reactions given shifts to the right.

A certain volume of aluminum enters the melt as a result of the particles detachment of the cathode metal under the hydrodynamic forces. The main mass of cathode aluminum dissolving in the melt is supplied by the decomposition reaction of subfluoride:

$3AlF = AlF_3 + 2Al$.

The transition of the metal into the salt phase with the formation of a solution is more possible for sodium due to the high pressure and its saturated stream.

Thus, the mechanism of metal losses during the electrolysis of cryolite-alumina melts is represented as a four-stage process:

1) reaction of the interaction at the metal-electrolyte interface;

2) molecular diffusion of the interaction products through the cathode layer;

3) convective transfer through the electrolyte thickness;

4) interaction of dissolution products with anode gases.

The investigations of the various factors influence on the loss of aluminum during the electrolysis of cryolite-alumina melts have established that with an increase in the temperature of the

process, the solubility of aluminum and, therefore, its losses increase. The loss of aluminum decreases with the presence of additives of calcium and magnesium fluorides to the electrolyte. Here, along with a decrease in the solubility of aluminum in the melt, an increase in its viscosity under the influence of fluorides also plays a role, which complicates the transfer of the dissolved metal to the surface of the melt and reduces its oxidation by anode gases [4, 13].

Thus, alumina and carbon material of the anodes are continuously spent in the process of electrolysis and aluminum accumulates on the bottom. It determines the main operations for servicing the electrolytic cell. They come down mainly to feeding the electrolytic cell with alumina, replacing burnt anodes, periodically removing aluminum from the cell, and adjusting the distance between the bottom of the anode array and the metal surface, which changes during the process as a result of the combustion of the anodes and changes in the height of the aluminum column at the bottom of the electrolytic cell.

Moreover, during the electrolysis, some auxiliary operations are carried out, i.e., the replacement of burnt anodes, compensation for the consumption of fluoride salts and some other operations related to the mass transfer process.

The aluminum electrolysis process runs at a high temperature and it is associated with the consumption of large volume of energy (Joule heat) for the electrochemical decomposition of alumina and compensation for heat losses in the surrounding space.

The losses are determined (at a constant temperature) for the given design and current strength, by the height of the metal layer on the bottom, the thickness of the crust solidification under the molten electrolyte and the thickness of the alumina layer loaded on the crust, as well as the surrounding temperature.

At present, it is impossible to use quickly and often these factors for operational regulation of the thermal regime of the electrolytic cell. Therefore, the main and most accessible way of quickly affecting the thermal regime of the electrolytic cell remains the regulation of heat input by changing the anode-cathode-distance, which is carried out by lowering or raising the anode array using an electric actuator.

3. Bounding of the Melt Temperature and the Main Parameters of the Electrolysis Regime and the Parameters of Voltage Fluctuations

The method for measuring temperature from voltage noise is a voltage fluctuation method [6].

The achievement of high technical and economic indicators of aluminum electrolysis is impossible without operational automatic monitoring and control of the electrolysis technological process. Nowadays, the aluminum industry is not yet sufficiently provided with control and measuring devices and, in particular, with primary transducers (PT) for automatic control of the aluminum electrolysis process. The lack of control tools [14, 15] is explained, first of all, by the effect of a high-temperature chemically aggressive medium on the PT while controlling the main technological parameters.

The main parameters characterizing the process of aluminum electrolysis are [4, 6, 16]:

- current efficiency η_T is output indicator evaluating the efficiency of the aluminum electrolytic cell;
- operating voltage of the electrolytic cell Ue;
- electrolyte temperature te;
- electrolyte composition;
- characteristics of the anode effect;
- amount (levels) of metal and electrolyte in the cell;
- anode-cathode-distance (ACD).

The current efficiency η_T is understood as the percentage ratio of the amount of metal actually released during electrolysis to the theoretical, corresponding to the generalized Faraday's law [1]. This value plays the same role in evaluating the efficiency of the electrolysis process, as the efficiency factor in evaluating the efficiency of the equipment. Usually η_T is 82-92% [4].

The operating voltage of the normally operating electrolytic cell is 4.0-4.5 V and is the sum of the decomposition voltage of 1.8-2 V alumina, the reverse emf is 1.4-1.6 V and voltage drops in the bottom and in the anode.

The electrolyte temperature during normal operation of the electrolytic cell is in the range of 950-970 °C. It is determined by the melting point of the electrolyte.

The composition of the electrolyte is characterized by the cryolite ratio KO=NaF/AlF3 (usually in the range 2.6-2.8) and the content of magnesium fluoride 3-4% and calcium fluoride 3-4% by weight of the electrolyte. The total content of additives usually does not exceed 8-10% by weight.

According to one of the hypotheses, the anode effect (flash) is caused by an increase in the voltage across the electrolytic cell due to the non-wetability of the electrolyte anode base [30, 35]. Its characteristics are the number of "flashes" per bath per day 1-2, the voltage on the electrolytic cell at "flashes" 25-35 V and their duration 3-4 minutes.

The metal level of the normally operating electrolytic cell should be at least 25-30 cm from the bottom of the electrolytic cell after pouring the metal, and the electrolyte level is 16-18 cm from the molten metal mirror.

The voltage drop at the bottom (in the metal - cathode rod section) should be no more than 0.35 V. An increase in the voltage drop in the bottom above the allowable one leads to an overconsumption of electricity and therefore is extremely undesirable.

The anode-cathode-distance is the distance between the "bottom" of the anode and the mirror of the molten metal. For electrolytic cells with a normal state of the technological process, it is 4.5-5 cm.

Consider the correlation of the above parameters with the technical and economic parameters of the electrolysis process.

The main output indicator characterizing the efficiency of the aluminum electrolytic cell, as mentioned above, is the current efficiency. It is a comprehensive indicator that htlps to estimate the consumption of raw materials and materials per unit of production. It can be defined as:

$$\eta_T = f(t_e, M\Pi P, I_c, H_m, H_e, KO, C_{Al2O3} \text{ and etc.}).$$

A decrease in the current efficiency η_T shows that the electrolysis process proceeds under unfavorable conditions, due to the deviation of the operating parameters of the aluminum electrolytic cell from their normal (optimal) value.

The melt temperature has the strongest effect on η_T. It is presented in [4, 17] that an increase in the melt temperature due to a violation of the technological regime leads, as a rule, to a decrease in η_t due to an increase in the dissolution of aluminum precipitated at the cathode in the cryolite-alumina melt. Moreover, with an increase in the melt temperature, the service life of the electrolytic

cells decreases, since the skull melts and there is a direct contact of the electrolyte with the lining and metal elements of the electrolytic cell. This leads to mechanical destruction of the cell lining due to the introduction of sodium ions (which receive favorable conditions for penetration) into the graphite lattice.

An increase in the temperature of the melt gives the following:

- labor costs for maintenance of the electrolytic cell increase (maintenance of electrolytic cells includes a set of technical operations associated with the destruction of the "crust" of frozen alumina, filling of alumina and cryolite into the electrolytic cell, removing foam from the surface of molten electrolyte);
- operating conditions deteriorate (with an increase in the temperature of the electrolyte, the release of fluoride compounds, harmful to the human body, sharply increases and the ambient temperature increases, as a result of which working conditions worsen);
- specific power consumption increases;
- quality of aluminum decreases due to an increase in the content of impurities due to the intensive dissolution of metal tools used for processing electrolytic cells, a gas-collecting bell, a turning sheet and due to a number of other reasons.

A decrease in the temperature of the electrolyte below 950°C leads to the appearance of a "cold run" of the cell characterized by an increase in the number and duration of anode effects. It causes excessive consumption of electricity. With a significant decrease in the temperature of the melt, the specific gravity of aluminum and electrolyte become close to each other, as a result of which mixing of aluminum with the electrolyte occurs.

It means that the temperature of the melt must be maintained within optimal limits. For example, analysis of literature data [17-19] shows that while maintaining the electrolyte temperature within 960-965°C (this temperature range is established in practice), there is an increase in the specific economic effect up to 5.8-7 \$/t aluminum in comparison with the economic indicators of the electrolysis process, occurs at the temperature of 955-1000°C.

An increase or decrease in the ACD has a significant impact on the technical and economic indicators of the electrolysis process. The anode-cathode-distance (ACD) mainly determines the operating voltage of the cell. An increase in the ACD and, therefore, the operating voltage of the electrolytic cell to 4.5-5 V leads to an increase in the "heating" voltage. This causes an increase in the temperature of the electrolyte and an overconsumption of electricity for technological needs and

leads, as mentioned above, to a decrease in η_T, due to an increase in the dissolution of the released aluminum in the electrolyte melt. When the voltage decreases to 3.8-4 V, caused by a decrease in the ACD, local short circuits of the anode array to the cathode may occur, which are caused by distortions of the surface of the molten metal and irregularities on the "bottom" of the anode array. Local short circuits, as a rule, lead to local overheating of the electrolyte. The local overheating may cause an increase in the temperature of the entire mass of the melt if local short circuits are not eliminated. It leads to a decrease in η_T.

The chemical composition of the electrolyte has a significant effect on the conductivity of the melt and on the current efficiency. By maintaining the chemical composition of the electrolyte within optimal limits, it is possible to achieve a significant increase in η_T and a decrease in the ohmic resistance of the electrolyte. A decrease in the resistance of the electrolyte leads to a decrease in the release of additional heat and allows maintaining the temperature of the electrolyte within optimal limits.

An increase in the number and duration of "flashes" in the electrolytic cell leads to overheating of the electrolyte and an increase in the specific power consumption. In this case, the technical and economic indicators of the electrolysis process deteriorate due to an increase in the temperature of the melt and a decrease in the current efficiency.

A decrease in the electrolyte level leads to an increase in the melt temperature. This is due to the fact that at an electrolyte level of 5-10 cm, the conditions for heat transfer from under the anode array deteriorate and part of the "base" may become exposed when the angle of installation of the working surface of the anode array deviates from the horizon. In this case, the current is redistributed over the cross section of the anode array and local overheating of the electrolyte occurs. An increase in the electrolyte level above 20 cm causes a decrease in η_T [19], since it forces one to work on electrolytic cells with a low metal level at a given mine depth. An increase in the metal level to 40-45 cm is undesirable, since it leads to a decrease in He at a given depth of the mine. A decrease in Nm to 15-20 cm causes overheating of the electrolyte due to the deterioration of the heat transfer conditions of the electrolytic cell.

The analysis of the literature data on the influence of the main technological parameters on the technical and economic indicators of the operation of electrolytic cells once again shows that their deviation from the optimal value leads to a decrease in the current efficiency η t. In most cases, a

decrease in the current efficiency is due to an increase in the temperature of the melt when one or another process parameter deviates from the optimal value.

The automatic control is necessary for optimal control of the electrolysis process since the current efficiency is the main output indicator characterizing the efficiency of aluminum electrolytic cell. It is possible to control the temperature of the electrolyte in case of impossibility of operational control of ηт. As it was mentioned above, it has a decisive effect on the current efficiency.

4. Mathematical Model of the Thermal Regime of an Aluminum Electrolytic Cell

The method of correlations and regressions analysis was used to evaluate the connection between the melt temperature and the main parameters of the electrolysis regime and the parameters of voltage fluctuations [20]. The methods of correlation and regressive analyzes provide for the statistical indicators calculation of the variation series of the electrolyte temperature values and the parameters of voltage fluctuations obtained as a result of experimental studies. The investigation program provides for the calculation of indicators of pair and multiple correlation of linear and nonlinear. According to their maximum a conclusion is made not only about the strength, but also about the form of connection. In order to obtain mathematical desired connections, calculation of the coefficients of the regression equations of linear and parabolic (second degree) equations was carried out by the least squares method (LSM). According to their minimum error, the final decision on the shape of the connection was made. Indicators and errors of the higher order parabola equations approximation, as well as nonlinear nonparabolic form were not calculated, since with a significant complication of the computational procedure, a significant increase in accuracy is not achieved [6, 19].

The assumption of the normal distribution of the studied traits is very often made in such types of studies. However, it should be taken into account that the indicators of the statistical relationship, i.e., the correlation coefficient and the correlation ratio, are nothing more than the moment of the normal distribution of the variation series, i.e., the mixed fundamental moment of the first order and the square root of the mean of the squares of the conditional main moments of the first order, respectively. In addition, the calculation of the indicators of the regression equations by LS method gives stable results only if the empirical distribution functions agree with the normal distribution [20, 21].

The full implementation of Pearson's chi-squared test for all arrays is impossible due to the small sample size in some of them. It is recommended to use Kolmogorov's criterion for arrays containing more than 100 values and w (Cramer-von Mises tes)t for arrays containing more than 50 values. The paper provides the program for the calculation of the statistics w, but the reliability of the measurement results can be guaranteed only for the ordered series of the second, third and fourth arrays, each containing 50 or more values of the arguments. Therefore, the investigation program includes some statistics by the value of which one can, to a certain extent, judge the shape of the distribution functions of the ordered series under study. In the study of the distribution functions, ordered series of values of the main parameters of the technological mode of aluminum electrolysis and the parameters of voltage fluctuations were compiled:

electrolyte temperature (Te),

integral characteristic of voltage fluctuations (Wi),

average value of fluctuations (Uf),

mean square value of fluctuations (Ufms),

average value of fluctuations corrected for voltage on the electrolytic cell (UfUe),

intersections numbers of the curve of the centered zero-level fluctuation function (ff),

coordinates of the first point of intersection of the curve of the autocorrelation function of the zero level (K1),

depth of the dip of the autocorrelation function (Kmin),

operating voltage on the electrolytic cell (Ue),

series current (Is),

anode-cathode-distance (ACD)

metal level (Hm),

electrolyte level (He),

concentration of alumina (C).

The data analysis showed that the integral characteristic of voltage fluctuations (the correlation coefficient r is 0.77 for the second array and r is 0.9 for the third array) and the multiple correlation coefficient for the connection Te = f (Ic, Ue, ACD, Hm, He) (multiple correlation coefficients Rx is 0.88 for the second, Rx is 0.91 for the third and Rx is 0.7 for the fourth array). However, as it was mentioned above, parameters of the technological regime are not automatically measured. Therefore, for the further study, the integral characteristic of voltage fluctuations Wi is

taken as a parameter that can be monitored to measure the temperature of the electrolyte. Nevertheless, it should be borne in mind that in reality the integral characteristic depends on temperature, and not vice versa. However, due to the fact that it is necessary to control the temperature of the electrolyte, the authors will look for a connection in the form Te = f (Wi), since the automatic measurement of the integral characteristic of labor does not represent.

The authors propose to use modeling regression equations to organize automatic control of the electrolyte temperature according to the statistical parameters of voltage fluctuations. Therefore, it is will be possible to control the technological process of electrolysis with correction for the melt temperature quickly.

Table 1 shows the calculation results of the correlations and regressions of the statistical parameters of voltage fluctuations and the main parameters of the technological mode of an aluminum electrolytic cell as they have the closest connection with the temperature of the electrolyte.

Table 1 - The results of the correlation and regression analysis having the closest link with the temperature of the electrolyte

Indicators	Ufms= f(Te)	K1= f(Te)	UfUe= f(Te)	Wi= f(Te)	Te= f(Ue)	Te= f(ACD)	Te= f(Hm)	Te= f(He)	Uf= f(Te)
r	0,41	-0,29	0,52	0,9	0,41	0,36	-0,29	0,59	0,43
S	0,16	0,12	0,14	0,02	0,1	0,11	0,12	0,08	0,16
	0,47	0,61	0,53	0,91	0,63	0,59	0,66	0,69	0,43
S	-0,12	0,02	-0,13	0,003	0,02	1,79	0,14	0,01	0,1
a	950	973	950	952	916	933	1018	837	952
a	0,7	-12,8	0,25	0,09	11,2	6,2	-1,1	9,4	0,93
b	979	968	960	956	1567	1352	190	2890	952
b	-2,5	-14	-0,1	4,5	-273	-148	66	-264	1
b	0,08	70	0,004	0,0001	30,8	14	-0,9	9,1	
									0,004
S	0,66	1,19	0,62	0,36	0,75	0,76	1,18	0,99	0,66
S	0,66	0,99	0,63	0,34	0,65	0,68	0,94	0,9	0,67

On the basis of these results, the following equations of the correlation between the temperature of the electrolyte and the above parameters can be adopted for operation [Table 2].

Table 2 - Equations of the connection between the temperature of the electrolyte and the main parameters of electrolysis

Equation	Correlation ratio
Te=952 + 0,09Wi	0,9
Te=952 + 0,92Uf	0,43
Te=979 - 2,5Ufms + 0,08Ufms^2	0,47
Te=950 + 0,25UfUe	0,52
Te=1567 - 273Ue + 30,8Ue^2	0,63
Te=1352 - 148L + 14L^2	0,59
Te=968 - 14K1 + 70K1^2	0,61
Te=190 + 66Hm - 0,9Hm^2	0,66
Te=2890 - 264He + 9,1He^2	0,69

Thus, a mathematical model of the thermal regime of the aluminum electrolytic cell will be in the form of the following equation:

$$Te_{gen} = \sum_{i=1}^{N} Te_i k_i / N$$

,

where Tei is value of the electrolyte temperature in the i-th equation;

ki is specific weight of the parameter in the general equation, in%

$$k_i = C_i / \sum_{i=1}^{N} C_i$$

,

where Ci is correlation ratio; N is number of equations.

5. Parameters Identification of the Mathematical Model for Decision Making on the Informative Characteristics of the Electrolysis Process

The identification of objects is understood as the building optimal mathematical models for the realizations of their input and output signals. Ultimately, the task is reduced to a quantitative evaluation of the degree of identity of the model to the real object.

The mathematical model identification of the thermal regime of the aluminum electrolytic cell was carried out by methods of Fisher, Chelyustkin and standardization by the sum of squares [20,

21]. As a result of calculations, the adequacy (averaged over the results of the three methods) of the

mathematical model was about 87% (numerical values of the parameters for the real object and the

mathematical model are given in Tables 3 and 4).

Table 3 - Numerical values of the parameters for the real object

№	Te	Ue	L	Hm	He	Is
1	948	3,8	3,9	45	14	148
2	965	4,1	4,2	42	15	151
3	958	4,0	4,0	43	16	150
4	969	4,5	4,3	40	15	153
5	968	3,8	3,9	37	14	153
6	998	4,6	4,6	36	16	158
7	990	4,3	4,5	36	16	158
8	998	4,4	4,5	36	16	157
9	980	4,5	4,7	36	15	156
10	972	4,3	4,3	32	16	154
11	982	4,5	4,6	34	16	157
12	998	4,7	4,4	36	16	159
13	990	4,6	4,6	35	17	158
14	972	4,3	4,3	36	16	155
15	968	4,2	4,5	39	14	155
16	964	4,0	4,2	40	15	153
17	966	4,1	4,3	40	16	153
18	968	3,9	4,1	37	14	152
19	966	3,9	4,2	38	15	152
20	964	3,8	4,0	40	15	151
21	964	3,9	4,1	41	14	152
22	968	3,8	4,0	37	16	153
23	970	4,2	4,4	35	18	155
24	972	4,3	4,1	32	18	155
25	965	4,2	4,3	36	15	152
26	964	4,1	4,0	42	14	152
27	967	4,3	4,5	42	14	154
28	972	4,5	4,4	32	16	155
29	965	4,1	4,2	40	15	151
30	964	3,8	3,9	41	13	151
31	966	3,9	4,2	38	17	151
32	965	4,0	4,2	40	15	152
33	968	4,0	4,2	37	14	154
34	968	4,0	4,2	37	14	154
35	964	4,4	4,0	40	15	153
36	972	4,5	4,4	38	17	155
37	968	3,8	4,0	37	14	152
38	970	4,2	4,1	38	16	154
39	964	4,3	4,5	40	15	152
40	962	4,1	4,2	38	17	150

Table 4 - Numerical values of the parameters for the real object

№	Te	Ue	L	Hm	He	Is
1	957	3,8	3,8	41	15	150
2	963	4,0	4,1	43	14	149
3	955	3,9	3,9	45	16	151
4	971	4,4	4,2	42	15	152
5	964	3,9	3,8	39	15	151
6	989	4,5	4,5	37	15	157
7	983	4,4	4,6	39	16	158
8	989	4,3	4,5	38	15	158
9	991	4,2	4,5	36	16	155
10	978	4,4	4,4	34	16	156
11	986	4,3	4,5	35	15	158
12	989	4,6	4,2	37	16	157
13	991	4,6	4,5	35	17	159
14	980	4,4	4,6	38	17	155
15	972	4,5	4,4	39	14	156
16	967	4,0	4,2	39	16	154
17	969	4,2	4,1	41	15	153
18	971	3,9	4,2	38	14	153
19	964	4,1	4,0	37	15	152
20	969	3,9	4,2	40	14	153
21	970	3,8	4,0	40	15	151
22	973	3,9	4,2	38	16	154
23	969	4,1	4,3	37	17	153
24	977	4,3	4,2	34	18	152
25	968	4,2	4,0	35	16	155
26	969	4,0	4,1	41	15	151
27	971	4,2	4,4	40	16	153
28	970	4,4	4,5	35	15	154
29	972	4,0	4,3	38	14	151
30	968	3,9	4,0	40	15	152
31	971	4,0	4,1	39	16	152
32	964	4,0	4,2	38	17	151
33	969	3,9	4,2	37	15	153
34	972	4,1	4,3	39	14	154
35	968	4,3	4,1	40	16	154
36	975	4,4	4,4	40	16	154
37	970	3,9	4,5	38	15	153
38	971	4,3	4,3	37	17	154
39	967	4,2	4,0	40	17	153
40	965	4,0	4,2	39	15	152

6. Conclusion

The technological parameters of each cell at aluminum electrolysis have a decisive influence on the current efficiency and, therefore, on the performance of the electrolytic cell. Therefore, complex (systemic) regulation of the main parameters of informative features of the aluminum electrolysis process will reduce the percentage of errors, maintaining these indicators in optimal proportions.

The paper proposes to use modeling regression equations to organize automatic control of the electrolyte temperature according to the statistical parameters of voltage fluctuations. By its solving it is possible to control the technological process of electrolysis with correction for the melt temperature quickly. In our investigations with the proposed model, the temperature regime of the aluminum electrolytic cell deviated from the recommended (optimal) range of values less than in 9 % in average.

Acknowledgements

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