Analysis of Aluminium Electrolysis Data in the Context of Extreme Values of Technological Parameters*

Anna Metus[0000-0003-0547-5999] and Tatiana Penkova[0000-0002-0057-0535]

Institute of Computational Modelling of the Siberian Branch
of the Russian Academy of Sciences, 50/44 Akademgorodok, Krasnoyarsk, 660036, Russia
metus@icm.krasn.ru

Abstract. This paper presents the results of monitoring data analysis for experimental areas producing primary aluminum based on the RA-300 and Soderberg technologies. The authors considered the events of technological disorders, such as anode effects and formations on anode face, carried out the statistical analysis of technological parameters and process disruptions in relation to the extreme values of the parameters. The results of analysis allowed us to obtain new knowledge about technological disorders and features of abnormal working states of aluminum reduction cells, detect the technological patterns, conditions and causes for the occurrence of technological disorders.

Keywords: Aluminium Electrolysis, Extreme Values, Technological Disorders, Statistical Analysis.

1 Introduction

Quality control of the aluminum smelting process is based on monitoring the technological parameters of aluminum reduction cells [1]. Controlled parameters include measurements of the chemical composition of the melt, physical characteristics of the melt, energy balance, and other working variables. The most common technological disorders in aluminum production include anode effects and distortions of the anode geometry formed during electrolysis [1-2].

Anode effect is a phenomenon characterized by decreasing in the alumina dissolution and a significant increase in the cell voltage. Distortions of the anode geometry are classified into formations on the anode face (“spikes”, “laggings”, “chunks”), and anode destruction (“corner shedding”). “Spike” is a formation of a cylindrical or conical shape [3]. “Lagging” is the formation of a rectangular cross-section or unevenness, occupying up to 50–60% of the anode bottom [3]. “Chunk” is a special term, adopted at Bratsk aluminum smelter, for formations of any form weighing up to several hundred kilograms on the Soderberg type of carbon anodes.

"Corner shedding" is a physical loss of large carbon pieces from the anode surface [4]. Statistical analysis of the monitoring data allows us to obtain new knowledge about technological disorders and features of abnormal working states of aluminum reduction cells.

This paper presents the results of the monitoring data analysis in the context of extreme values of technological parameters in order to explore technological patterns and detect the technical conditions and causes for the occurrence of technological disorders.

2 Analysis of the Monitoring Data in the Context of Extreme Values of Technological Parameters

The analysis was carried out on monitoring data for three experimental areas: Khakas aluminum smelter (KhAZ), Boguchansky aluminum smelter (BoAZ), that use the RUSAL's proprietary RA-300 technology, and Bratsk aluminum smelter (BrAZ) with Soderberg technology. Technology determines the design features of aluminum reduction cells and plants and, as a result, the scope of controlled technological parameters and types of process disruptions [5, 6]. In the experimental area of KhAZ, there were 6784 cases of "spikes" and 8123 anode effects over the observation period of 2014-2019 years. In the experimental area of BoAZ, there were 3872 cases of "laggings", 349 cases of "spikes" and 4689 anode effects over the 2019 year. In the experimental area of BrAZ, there were 30989 cases of "corner shedding", 2986 cases of "chunks" and 73412 anode effects over the observation period of 2015-2019 years.

To determine the extreme parameter values, the variability of a set of parameter values was estimated for each cell, and the ranges of reliable values were found as $\mu \pm \sigma$, where μ is the mean value of the data series, σ is the standard deviation. Parameter values outside this range are considered as extreme values. The result of the analysis of the statistical characteristics showed that the cells, in the context of the same parameters, differ significantly both in the average values of the parameters and in their deviation intervals. For each experimental area, the parameters with the largest percent of anomalies over entire observation period were determined, among them: for KhAZ – *Back EMF*, *Dose of alumina*, *Coefficient of anode-cathode distance*; for BoAZ – *Cryolite ratio*, *Coefficient of anode-cathode distance*, *CaF_2 concentration*, for BrAZ – *AlF_3 dose*, *Minimum distance*, *MgF_2 concentration*.

In order to explore the events of technological disorders in relation to the extreme values of the parameters, we considered the dates of disorders detection (in cases of anode effects) and the five-day period preceding the registration of the disorder (in cases of any formations). As a result, for each type of disorder, the distribution of cases accompanied by extreme values of the parameters was obtained (Tables 1, 2).

Table 2. The part of anode formations accompanied by extreme values of technological parameters (fragment).

Parameter	Spikes KhAZ	Spikes BoAZ	Laggings BoAZ	Chunks BrAZ	Corner sheddings BrAZ
AlF_3 dose (kg)	-	0.46	**0.58**	**0.79**	**0.84**
Duration of pouring (sec)	0.60	0.45	0.47	-	-
Dose of alumina (kg)	0.30	0.28	0.31	-	-
Number of Alumina doses (pcs)	**0.72**	0.46	0.51	0.41	0.33
Cryolite ratio	0.51	0.37	0.38	0.35	0.33
Min. distance (cm)	-	-	-	**0.99**	**0.99**
Cell voltage (V)	0.24	0.32	0.42	0.26	0.27
Back EMF (V)	0.41	0.25	0.25	-	-
Velocity ratio (kg/cm)	0.52	-	-	-	-
Anode void (cm)	-	-	-	0.66	0.60
Coefficient of anode-cathode distance (mV/s)	**0.76**	**0.73**	**0.74**	-	-
Anode consumption rate (cm/day)	-	-	-	0.51	0.40
CaF_2 concentration (%)	0.33	0.37	0.35	0.46	0.46
MgF_2 concentration (%)	0.36	-	-	0.29	0.38
CPC temperature (C^0)	-	-	-	0.51	0.45
Electrolyte temperature (C^0)	**0.87**	**0.61**	**0.66**	0.62	0.60
Aluminium level (cm)	0.51	**0.56**	0.56	0.33	0.37
Electrolyte level (cm)	0.44	0.44	0.53	**0.67**	**0.63**

In the table, highlighted parameters are most specific to a particular type of disorder in the experimental area. Most of the “spikes” occurred at KhAZ while the values of *Electrolyte temperature* or *Coefficient of anode-cathode distance* or *Number of AlF3 doses* were extremes. At BoAZ most of the “spikes” were accompanied by extreme values of *Coefficient of anode-cathode distance* or *Electrolyte temperature* or *Aluminium level*. Most of the “laggings” occurred at BoAZ while *Coefficient of anode-cathode distance* or *Electrolyte temperature* or *AlF3 dose* were extremes. Most of both the “corner sheddings” and the “chunks” occurred at BrAZ while *Min. distance* or *AlF3 dose* or *Electrolyte level* were extremes.

Table 3. The part of anode effects accompanied by extreme values of parameters (fragment).

Parameter	KhAZ	BoAZ	BrAZ
AlF_3 dose (kg)	-	0.08	**0.5**

Duration of pouring (sec)	0.22	0.06	-
Dose of alumina (kg)	**0.35**	0.09	-
Number of Alumina doses (pcs)	0.25	0.08	0.17
Cryolite ratio	0.1	0.05	0.09
Min. distance (cm)	-	-	**0.4**
Cell voltage (V)	0.15	0.07	0.11
Back EMF (V)	**0.34**	**0.15**	-
Velocity ratio (kg/cm)	0.19	-	-
Anode void (cm)	-	-	0.3
Coefficient of anode-cathode distance (mV/s)	0.29	**0.15**	-
Anode consumption rate (cm/day)	-	-	0.25
CaF_2 concentration (%)	0.09	0.05	0.1
MgF_2 concentration (%)	0.09	-	0.08
CPC temperature (C^0)	-	-	**0.38**
Electrolyte temperature (C^0)	**0.3**	0.11	0.25
Aluminium level (cm)	0.21	**0.1**	0.3
Electrolyte level (cm)	0.25	0.09	0.24

Most of the anode effects occurred at KhAZ while *Dose of alumina* or *Back EMF* or *Electrolyte temperature* were extremes, at BoAZ most of the anode effects were accompanied by extreme values of *Counter EMF* or *Coefficient of anode-cathode distance* or *Aluminium level*, at BrAZ most of the anode effects were accompanied by extreme values of *AlF_3 dose* or *Min. distance* or *CPC temperature*.

In most cases, technological disorders occur when several parameters have extreme values at the same time. The distribution of disorders events in the experimental areas by the number of parameters with extreme values is shown below in Figures 1, 2, 3.

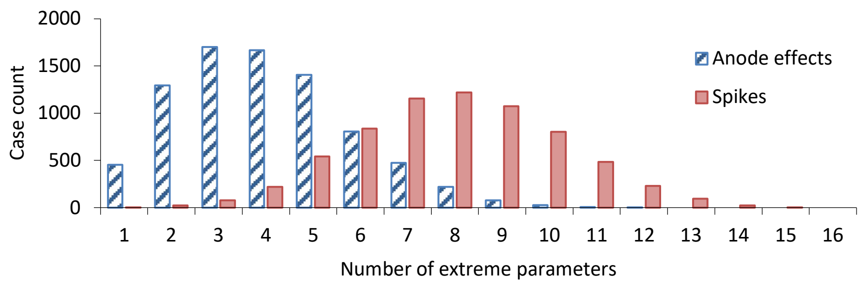

Fig. 1. Distribution of disorders events by the number of parameters with extreme values at KhAZ.

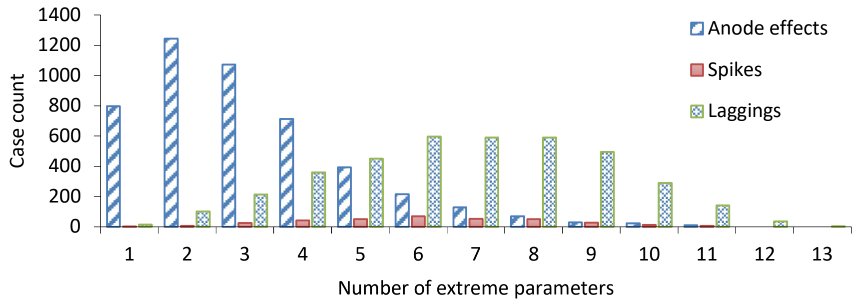

Fig. 2. Distribution of disorders events by the number of parameters with extreme values at BoAZ.

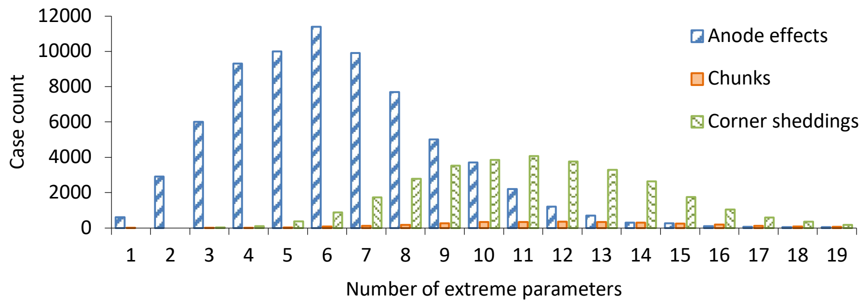

Fig. 3. Distribution of disorders events by the number of parameters with extreme values at BrAZ.

It can be seen from the diagrams that during the period of occurrence of disorders, as a rule, outliers of values are observed for several parameters, but there are cases when technological disorders occurred when the values of the parameters were within the statistical norm. At the same time, the number and composition of parameters are different for different types of disorders.

Moreover, regardless of the aluminum production technology, in the case of anode effects, the number of parameters with extreme values is less than in the case of formations on the anodes. So, KhAZ is characterized by extreme values of 2-4 parameters for the anode effect and 6-8 parameters for “spikes”; BoAZ is characterized by extreme values of 1-2 parameters for the anode effect, 5-7 parameters for “lagging” and 4-6 parameters for “spikes”; BrAZ is characterized by extreme values of 4-6 parameters in case of anode effects, 9-11 parameters in cases of “corner shedding” and “chunks”.

Also, this research included the correlation analysis of parameters in part of extreme values. The result demonstrated a quite strong relationship between the following parameters: for KhAZ: *Duration of pouring* and *Velocity ratio* with correlation coefficient -0.69, *Amperage* and *Bus voltage* with correlation coefficient

0.74; for BoAZ: *Electrolyte temperature* and *Cryolite ratio* with correlation coefficient 0.91, *Cell Voltage* and *Electrolyte level* with correlation coefficient 0.82, *Cell Voltage* and *Number of Alumina* doses with correlation coefficient -0.86; for BrAZ: *Distance from anode face* and *Anode void* with correlation coefficient 0.96, *Number of Alumina doses* and *Time of Alumina doses* with correlation coefficient 0.9, *Aluminium level* and *Electrolyte level* with correlation coefficient -0.84.

The distribution of the number of parameters with extreme values and the number of technological disorders for each cell showed that in most cases (75%-95% depending on the disorder type) a large number of disorders are accompanied by a large number of extreme values of technological parameters. Additionally, it was possible to identify periods of everyday disorders with varying duration and to rank the cells of the experimental areas by the number of technological disorders.

The analysis of detailed data made it possible to detect the dependence of the number of technological disorders on the location of the anodes in the cells (Figures 4, 5). For instance, at KhAZ we can observe significantly more "spikes" on the anodes of the front side of the cells – in its central part (anodes No. 9 and No. 10) and along the edges (anodes No. 1 and No. 18). At BoAZ, in contrast, we can observe more “spikes” and “laggings” on the anodes of the backside of the cells – mostly around the edges (anodes No. 22, 23 and 33, 34).

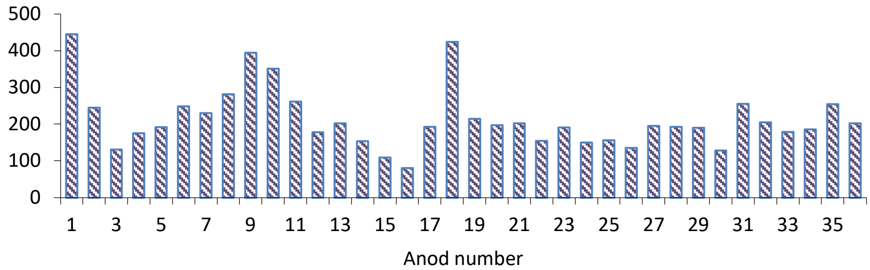

Fig. 4. Distribution of “spikes” cases by the cell anodes at KhAZ.

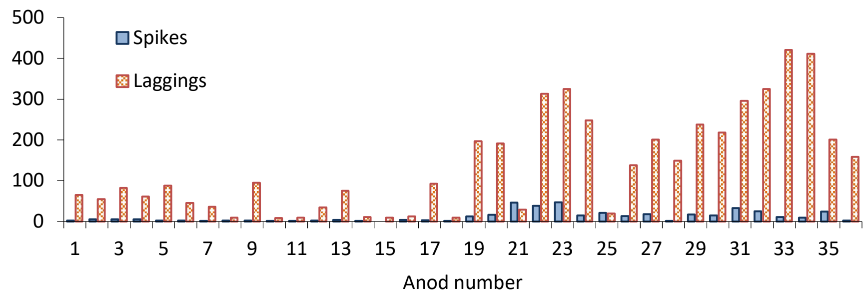

Fig. 5. Distribution of “spikes” and “laggings” cases by the cell anodes at BoAZ.

Thus, as a result of a detailed analysis of the monitoring data in the context of extreme values of the controlled technological parameters, the authors determined the characteristic dependencies and features of the functioning of individual units of the aluminum production complex in atypical operating modes.

3 Conclusion

In this paper, the authors carried out the analysis of the aluminum production process disruptions in terms of the extreme values of the technological parameters for three experimental areas: KhAZ, BoAZ and BrAZ.

The analysis of the statistical characteristics showed that the cells, in the context of the same parameters, differ significantly both in the average values of the parameters and in their deviation intervals. Within the study, for each experimental area, the parameters with the largest percent of anomalies were determined. The distribution of disorders events (in the cases of anode effects and formations on the anode face) by the number of parameters with extreme values was obtained. The results showed that in most cases (75%-95%) a large number of disorders are accompanied by a large number of extreme values of technological parameters. The analysis of detailed data revealed the dependence of the number of technological disorders on the location of the anodes in the cells.

Thus, the results of research allowed us to obtain new knowledge about technological disorders and features of abnormal working states of aluminum reduction cells, detect the technological patterns, conditions and causes for the occurrence of technological disorders.

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