Multi-criteria optimization of the process of electrolytic alkali’s evaporation in order to develop a resource-saving chemical-technological system

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Abstract. Development of resource-saving chemical-technological systems requires maintenance of process parameters within the specified limits. The article describes the use of artificial neural networks for modeling of technological process of electrolytic alkali evaporation. The simulation was carried out in Statistica software. The simulation results were used to perform multi-criteria optimization by proper simplex minimization and Nelder-Mead minimization methods to reduce costs and improve process performance and product quality.

1. Introduction
In the technological process of production of chlorine, hydrogen and electrolytic alkali, it is necessary to obtain products without impurities. Evaporation of electrolytic alkali has a number of features. Precipitation from the solution of solid salt and sodium sulfate creates the possibility of their deposition on the heating surfaces of evaporators and deterioration of heat transfer conditions. With the proper conduct of the evaporation process, the presence of solid NaCl in the evaporated alkali does not have a harmful effect, and salinization of heating surfaces can be completely avoided. For this purpose, it is necessary to maintain the process parameters within the specified limits [1-3].

The optimization criterion is the mass concentration of NaOH, which should be 124.2 ÷ 156.8 g/dm³. This quality parameter is the target optimization function, which is most influenced by the temperature of the solution maintained less than or equal to 125°C and the temperature of the juice vapor - no more than 125°C. The data array was collected during the technological process for one month.

2. Results and discussion
After creating and filling in the data table, neural networks were created, trained and tested in Statistica [4].
The required number of neurons in the hidden layers of the perceptron, which you want to specify in the settings of the neural network, can be determined by the formula, which is a consequence of the Arnold-Kolmogorov-Hecht-Nielsen theorems [5-8]:

$$\frac{N_y Q}{1 + \log_2 (Q)} \leq N_w \leq N_y \left( \frac{Q}{N_x} + 1 \right) (N_x + N_y + 1) + N_y, \tag{1}$$

$$\frac{1 \cdot 35}{1 + \log_2 (35)} \leq N_w \leq 1 \cdot \left( \frac{35}{2} + 1 \right) \cdot (2 + 1 + 1) + 1,$$

$$6 \leq N_w \leq 75,$$

where $N_y$ is the dimension of the output signal ($N_y = 1$); $N_w$ is the required number of synaptic connections; $N_x$ is the dimension of the input signal ($N_x = 2$); $Q$ is the number of elements of the set of training examples ($Q = \frac{200 \cdot 70}{400} = 35$).

Next, the required minimum and maximum number of neurons in the hidden layers of the two-layer perceptron was calculated

$$N = \frac{N_w}{N_x + N_y}; \quad N_{\text{min}} = \frac{6}{2 + 1} = 2; \quad N_{\text{max}} = \frac{75}{2 + 1} = 25. \tag{2}$$

The default interval for varying the number of neurons proposed in Statistica software is within the allowable interval calculated by the Arnold – Kolmogorov – Hecht-Nielsen formula, so the interval proposed by the Program is left unchanged.

The number of networks for training, equal to 20, and the number of neural networks for preservation, having the smallest values of the mean square error in the control and test samples, equal to 5, was chosen (figure 1).

![Figure 1. The saved neural network.](image-url)
Using neural network having been trained on the original data a graph of dispersion for the training set of 5 trained neural networks on the coordinate plane was constructed where the x-axis is target (source) value of the function, and on the y-axis there is the output function value obtained by the neural network (figure 2).

![Graph of dispersion](image)

**Figure 2.** Scatter plot on a training sample of 5 trained neural networks.

The graph shown in figure 3 shows a training sample on a three-dimensional surface, where the x-axis is the temperature of the solution, °C, the y-axis is the temperature of the juice vapor, °C, the z-axis is the concentration of the solution, g/dm³.

![Three-dimensional representation](image)

**Figure 3.** Three-dimensional representation of the training sample.

For the objectivity of calculation and analysis of the results, multi-criteria optimization was carried out by the methods of minimization by the correct simplex and Nelder-Mead minimization [9].

To estimate the obtained result, a line map of the level of the target function, presented in figure 4, is constructed. The x-axis displays the temperature of the solution, °C, the y-axis-the temperature of
the juice vapor, °C. The value of the mass concentration of NaOH at these input parameters is shown as level lines.

![Figure 4. Map of level lines of the objective function.](image)

Combining the neural network and the method of minimization by the correct simplex, the following optimal parameters were obtained: the temperature of the solution is 108.44063 °C, the temperature of the juice vapor is 114.033812 °C, the alkali concentration is 124.202431 g/dm³.

The combination of the neural network and the Nelder-Mead method gave the following results: the optimal parameters are: the temperature of the solution is 108.634317 °C, the temperature of the juice vapor is 114.098 °C, the alkali concentration is 124.204514 g/dm³.

The following results were obtained by combining the neural network and the Nelder-Mead method of minimization by basis vectors: solution temperature 108.7156°C, juice vapor temperature 114.425°C, alkali concentration is 124.256742 g/dm³.

3. Conclusion
As a result of multi-criteria optimization, the optimal parameters of the technological process were obtained by the proposed methods. All methods achieved the required accuracy and the required value of the target function—the mass concentration of NaOH in solution. The parameters obtained by the method of minimization of the correct simplex are chosen as optimal, since this method gave the least of the obtained values of the objective function. The accuracy of calculating the value of the target function in Statistica is 10⁻⁶, the accuracy of calculating the coordinates of points is 10⁻⁴.

The obtained optimal parameters are used in writing a control program (Unity Pro XL) for a programmable logic controller (Modicon M340) to achieve the required value of the mass concentration of NaOH in solution and improve the quality of the product.

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