Process control system based on a fuzzy controller

E A Muravyova and Y V Stolpovskaya
Ufa State Petroleum Technological University Branch in Sterlitamak, Sterlitamak, Russian Federation

E-mail: muraveva_ea@mail.ru

Abstract. The object for the control system is an electrolysis plant for the production of chlorine, hydrogen and electrolytic alkali by the method of diaphragm electrolysis. It is necessary to develop an improved system for controlling the process of diaphragm electrolysis. To create a control system for the electrolysis process, a fuzzy controller with the following output parameters was developed: the percentage of opening of the electromagnetic valve for supplying NaCl solution to the electrolyzer, the percentage of opening of the actuator for supplying asbestos suspension, the percentage of opening of the control valve for draining NaCl solution through a special device, voltage value. Control output parameters control input parameters: anolyte level and caustic concentration. Controlling of the output parameters is based on the information received from the input sensors of the concentration of caustic and the level of anolyte. The control algorithm modeling is performed in the Matlab package. The programming of the Modicon M340 controller and its connection is made using the Unity Pro CASE system. An automated workstation for controlling the electrolysis process is performed in the Vijeo Citect SCADA system. The introduction of a multidimensional automated control system that controls the entire electrolysis process allowed us to solve the problem posed: optimal control of the process output parameters.

1. Introduction
Electrolysis is the process that allows to obtain pure form of metals, the mass fraction of the element itself in which is almost hundred percent. Metals like sodium, nickel, as well as pure hydrogen and other substances can obtained only this way.

The study of electrochemical processes, the determination of factors affecting them, determination of new ways of electrolysis processes application in industrial conditions continues to this day. Many factors are not yet clear, and the details need to be improved [1].

The primary tasks are to improve the process of diaphragm electrolysis, so that production is most profitable, with the lowest cost of electricity and with the highest products yields. At the same time, it is necessary to take into account various factors influencing the quantity and quality of electrolysis products: maintenance, control and regulation of the input and output parameters of this unit.

Today, a team of highly qualified specialists continuously monitors the correct operation of the electrolysis unit. Anolyte is an aqueous solution of salt (brine).

In this regard, it is necessary to replace outdated control systems with a newer and more modern one, which will improve product quality, lead to lower production costs, and ensure the safety of staff.
2. Description of the process
Electrolysis of sodium chloride solutions in baths with a steel cathode and a graphite anode makes it possible to obtain electrolytic alkali NaOH, chlorine Cl₂ and hydrogen H₂ in one electrolyzer. Direct electric current is passing through an aqueous solution of sodium chloride, producing chlorine and oxygen:

\[
2\text{OH}^- - 2e^- \rightarrow \frac{1}{2}\text{O}_2 + \text{H}_2\text{O}
\]

or

\[
2\text{Cl}^- - 2e^- \rightarrow \text{Cl}_2.
\]

On graphite anodes, the oxygen overvoltage is much higher than the overvoltage of chlorine and therefore they will mainly discharge the Cl⁻ ions with the release of gaseous chlorine.

The discharge of sodium ions from aqueous solutions on a solid cathode is impossible due to the higher potential of their discharge in comparison with hydrogen. Therefore, the hydroxyl ions remaining in solution form an alkali solution with sodium ions [2].

That is, chlorine is formed at the anode, and hydrogen and electrolytic alkali at the cathode figure 1.

![Figure 1. Electrolysis scheme: 1 – perforated cathode, 2 – diaphragm, 3 – cathode space, 4 – anode, 5 – anode space.](image)

3. Conceptual model of a fuzzy controller
It is necessary to collect a set of data to control the process of electrolysis using a fuzzy controller [3]. A data set is a set of values for the input and output variables of an object figure 2.

![Figure 2. Conceptual model of a fuzzy controller for controlling the electrolyzer.](image)
The following input and output parameters of a multidimensional system of the electrolysis process must be considered to control the electrolysis unit:

Input parameters:

- NaOH concentration - A, (115 ÷ 140) g / dm³;
- anolyte level - L, (100 ÷ 600) mm.

Output Parameters:

- the percentage of opening of the electromagnetic valve for supplying brine to the electrolyzer - NaCl, (0 ÷ 100) %;
- the percentage of opening of the electromagnetic valve for asbestos suspension supplying - As, (0 ÷ 100) %;
- voltage level on the electrolyzer plates - T, (0 ÷ 100) %;
- the percentage of opening of the solenoid valve for discharging NaOH through the drain device - S, (0 ÷ 100) %.

4. Description of linguistic variables

The linguistic variables of the inputs and outputs of a fuzzy controller are described by a range of clear values and membership functions for each term [4].

Input Variables:

- NaOH concentration in catholyte – A, g / dm³;
- Anolyte level in the electrolyzer – L, mm.

Output Variables:

- The percentage of opening of the electromagnetic valve, controlling the flow of brine into the electrolyzer – NaCl, %.
- The level of voltage drop – T, %.
- The percentage of opening of the valve controlling the flow of asbestos suspension – As, %.
- The percentage of opening of the valve, controlling the discharge of alkali S, %.

To develop a fuzzy algorithm, we define the production rules:

1. IF A = A₁ and L = L₁, then NaCl = NaCl₁, T = T₂, As = As₁, S = S₁.
2. IF A = Low and L = Low, then NaCl = Open, T = Optimal, As = Closed, S = Closed.
3. IF A = A₁ and L = L₂, then NaCl = NaCl₂, T = T₂, As = As₁, S = S₂.
• IF A = Low AND L = Normal, then NaCl = Semi Open, T = Optimal, As = Open, S = Semi Open.
• 3. IF A = A₁ and L = L₃, then NaCl = NaCl₁, T = T₃, As = As₂, S = S₃.
• IF A = Low and L = High, then NaCl = Closed, T = Maximum, As = Semi Open, S = Closed.
• 4. IF A = A₂ and L = L₁, then NaCl = NaCl₂, T = T₁, As = As₂, S = S₁.
• IF A = Normal and L = Low, then NaCl = Open, T = Minimum, As = Semi Open, S = Closed.
• 5. IF A = A₂ and L = L₂, then NaCl = NaCl₂, T = T₂, S = S₂, As = As₁.
• IF A = Normal and L = Normal, then NaCl = Semi-open, T = Optimal, S = Semi-open, As = Closed.
• 6. IF A = A₂ and L = L₃, then NaCl = NaCl₁, T = T₁, As = As₁, S = S₁.
• IF A = Normal and L = High, then NaCl = Closed, T = Maximum, As = Closed, S = Open.
• 7. IF A = A₁ AND L = L₁, then NaCl = NaCl₂, T = T₁, As = As₃, S = S₁.
• IF A = High and L = Low, then NaCl = Semi open, T = Minimum, As = Open, S = Closed.
• 8. IF A = A₂ AND L = L₃, then NaCl = NaCl₂, T = T₂, As = As₃, S = S₁.
• IF A = High AND L = Normal, then NaCl = Semi Open, T = Optimal, As = Open, S = Closed.
• 9. IF A = A₁ AND L = L₃, then T = T₁.
• IF A = High and L = High, then T = Minimum
• Simulating control system in MATLAB

We will make a simulation of the developed algorithm using the FIS Editor in MATLAB.

To define linguistic variables, we will use 3 terms with triangular membership functions. Variables A - NaOH concentration, L - anolyte level, NaCl - percent of valve opening, regulating brine flow, As - percent of valve opening, controlling asbestos suspension, S - percent of valve opening, controlling alkali discharge, T - level of voltage drop on electrolyzer plates [5].

We will enter a certain rule base linking the input and output variables and implementing the control algorithm of the electrolyzer figure 5.

Figure 4. Conceptual model setting in MATLAB.

Figure 5. Rule base.
5. Implementing a control system in unity pro and vijeo citect
For correct operation of automatic control system and input and output parameters control, it is necessary to tune the equipment that is part of the unit [6].

We will connect the programmable logic controller using the Unity Pro software; the controller will be controlled from a PC using the Vijeo Citect SCADA system. Communication with the controller is carried out via TCP/IP [7].

Creating a program to control the unit is carried out in the language ST. The variable editor window is shown in figure 6.

![Figure 6. Input and output variables description.](image)

We checked the performance of the program using the "Animation table".

The operator’s automated workplace (AWP) of the control system has been created in the Vijeo Citect SCADA, and it conveniently displays the technological process [8].

We make an express setup of I/O devices, this function will automatically configure our computer to work with the PLC, using a minimum of parameters entered by the developer of the SCADA system. Next, create variable tags, focusing on previously created variables in the Unity Pro program [9].

We create graphical visual page of the technological process. It is possible to enter values of input variables, instruments for displaying the values of output variables, as well as visualization of the technological process on the created screen figure 7.

![Figure 7. Process visualization in vijeo citect.](image)

6. Conclusion
During the study a fuzzy controller for the electrolysis process control was designed. This controller allows to control the opening of the valve supplying brine into the electrolyzer, the valve for filling asbestos slurry, the valve for alkali draining and to calculate the value for the voltage controller depending on the NaOH concentration in the catholyte and the anolyte level in electrolyzer.
A multi-dimensional control system has been set up. The introduction of an automatic control system that takes into account the basic parameters of a multi-connected object and is capable of controlling the entire electrolysis process has made it possible to solve the following problem: stabilization of the input parameters and control of the output parameters of the process.

References

[1] Kuznetsov Yu A and Perova V I 2007 Application of simulation packages for the analysis of mathematical models of economic systems: study guide (Nizhny Novgorod) 98
[2] Muravyova E, Sagdatullin A and Emekeev A 2015 Intellectual control of oil and gas transportation system by multidimensional fuzzy controllers with precise terms Applied Mechanics and Materials 756 633
[3] Muravyova E, Bondarev A, Kadyrov R and Rahman P 2016 The analysis of opportunities of construction and use of avionic systems based on cots-modules ARPN Journal of Engineering and Applied Sciences 11
[4] Muravyova E A, Solovev K A, Soloveva O I, Sultanov R G and Charikov P N 2016 Simulation of Multidimensional Non-Linear Processes Based on the Second Order Fuzzy Controller Key Engineering Materials 685 816-22
[5] Rahman P A, Muraveva E A and Sharipov M I Reliability Model of Fault-Tolerant Dual-Disk Redundant Array Key Engineering Materials 685 805-10
[6] Muravyova E, Sagdatullin A and Sharipov M 2016 Modelling of Fuzzy Control Modes for the Automated Pumping Station of the Oil and Gas Transportation System IOP Conference Series: Materials Science and Engineering 132
[7] Muravyova E A 2017 Simulation of salt production process IOP Conference Series: Earth and Environmental Science 87 052018
[8] Muravyova E A, Sagdatullin A M and Emekeev A A 2015 System-integrative approach to automation of the oil and gas fields design and development control Oil industry 3 92
[9] Muravyova E A, Grigoryeva T V and Salikhova D R 2019 Electrolisys control system based on a fuzzy controller Neftegazovoe delo 5 239-73