

UDC 544.6.018.42

## BASIC OPERATION PRINCIPLES AND CONTROL ALGORITHM FOR A HIGH-PRESSURE MEMBRANE-LESS ELECTROLYSER

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*A technology of the cyclic generation of hydrogen and high-pressure oxygen, implemented in a single-module and multi-module electrolysis installation, is considered. A schematic operation diagram for implementing the method with four series-connected modules is given. During the cyclic supply of alternating potentials to the active and passive electrodes to obtain each of the gases separately in time while the other gas is being simultaneously and reversibly absorbed by the active electrode, the process can be carried out with both single-module and multi-module circuits series-connected to an electrical circuit and either separate modules or electrolyzer blocks removed (by shunting) from the electrical circuit without interrupting the process of producing gases with the optimal regulation of gas productivity under the conditions of the technological process. This makes it possible to realize the operation of an electrolysis installation with low current loads, reducing the risk of electrical breakdowns inside electrolyser modules. A four-module electrolysis installation control algorithm is described. The optimal parameters for regulating the performance of gases are determined according to the requirements of the technological process. An analysis of the cyclogram of hydrogen and oxygen generation with the limitation of the reaction voltage from 0.5 to 1.8 V has been carried out. The range of operating temperatures of the developed electrolysis process is in the range from 280 to 423 K, and the pressure range is 0.1 to 70 MPa. The dependence of the volt-ampere characteristics of a high-pressure electrolyzer power supply system on the number of series-connected modules of a given performance is given. The optimal regulation of gas performance on demand of the technological process or in cases of removing individual modules from the electrical circuit without interrupting the process of generating gases has been carried out by controlling the amount of current in the electrical system according to inversely proportional dependence from the number of connected modules. The appearance of an electrode assembly design using a gas absorption electrode is considered. Recommendations for implementing an electrolysis installation operation with low current loads and reducing the risk of electrical breakdowns inside electrolyzer modules are indicated.*

**Keywords:** electrolyzer, gas absorption electrode, hydrogen, oxygen.

### Introduction

Searching for alternative energy sources is one of the most important tasks of our time. Researchers are continuing to focus on the possibility of producing hydrogen from water. Technologies of hydrogen production, based on the processes of water decomposition by electrolysis, are widely used in various fields of modern engineering. Compared to other methods of hydrogen production, electrolysis is characterized by the simplicity of the technological scheme, availability of raw materials, and relative ease of servicing power plants. An essential disadvantage of the electrochemical method of producing hydrogen is the high energy intensity of the water decomposition process. Therefore, the problem of developing electrochemical technologies for generating hydrogen from water with minimal energy consumption [1] is very urgent, especially in the light of expanding use of hydrogen as an environmentally friendly energy source and technological raw materials.

### Research Task Purpose and Formulation

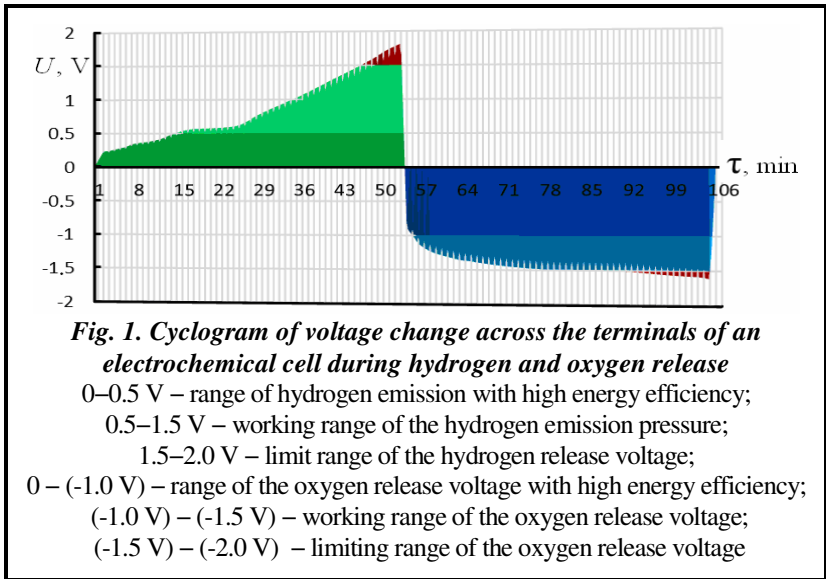
The A. Podgorny Institute of Mechanical Engineering Problems of the National Academy of Sciences of Ukraine has developed a technology for the electrochemical production of hydrogen  $H_2$  and high-pressure oxygen  $O_2$  [2–9] using a gas-absorbing electrode in membrane-less electrolyzer structures. The developed electrochemical method of water decomposition is cyclic, consisting of alternating in time hydrogen and oxygen release processes (Fig. 1).

The range of operating temperatures of the developed electrolysis process is in the range from 280 to 423 K, and the pressure interval is 0.1–70 MPa. The main purpose of the research is to develop an algorithm for controlling the operation of a high pressure electrolyzer in accordance with the number of connected modules.

The task is achieved in that in the method of operation of the electrolysis installation designed for producing high pressure hydrogen and oxygen by the electrochemical decomposition of an electrolyte during the cyclic feeding of alternating potentials to the active and passive electrodes with the production of each of the gases separately in time while simultaneously reversing the absorption of the other gas by the active electrode

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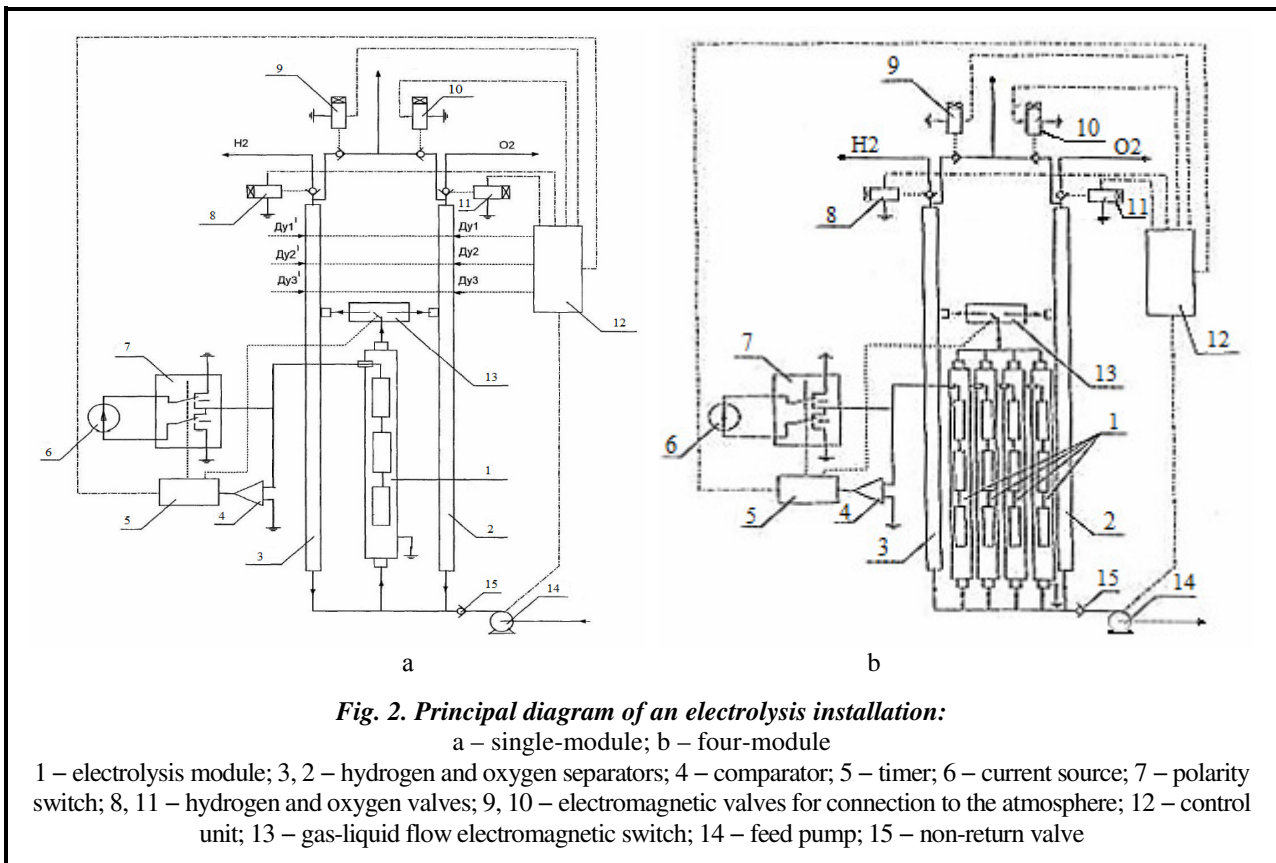
process can be conducted using either the single-module or multi-modal scheme. The series connection of individual modules or blocks of electrolyzers to an electric circuit and their removal (by shunting) from the circle makes it possible for the installation to operate without interrupting the process of obtaining gases with the optimal regulation of the their productivity under the conditions of the technological process. The magnitude of current (I) in an electric circuit is maintained in the intervals of correspondence of the inversely proportional dependence on the number of connected modules.



**Experimental results**

Fig. 2 shows the operating principle diagram of a single-module and multimodal electrolysis unit for implementing a method with four series-connected modules.

A method for producing high-pressure hydrogen and oxygen is realized either in a single-module (Fig. 2a) or four-module (Fig. 2, b) electrolysis installation containing four electrolytic sections each of which consists of four vertically fixed electrolytic modules series-connected in one unit (1) with passive and active electrodes. The sections of the electrolysis installation with the module blocks are connected via a polarity switch (2) with a current source (3) and via a comparator (4) and a timer (5) – with a control unit (6). The timer (5) is also connected to the polarity switch (2) and a gas-liquid flow electromagnetic switch (7) whose



hydrogen and oxygen valves (8), (9) are respectively connected to the output fittings of hydrogen and oxygen separators (10), (11), equipped with liquid level sensors. The separators (10) and (11) are connected to a block of series-connected electrolysis modules (1) of the electrolysis installation and a feeding pump (12). The output fittings of the separators (10) and (11) are connected to the control unit (6) through the electromagnetic valves (8) and (9) and are respectively connected to the consumer hydrogen and oxygen gas lines. The system includes valves (13) and (14) that connect the separators (10) and (11) to the atmosphere, and a non-return valve (15) to cut off the fluid supply line.

The work of an electrolysis installation for producing high-pressure hydrogen and oxygen is controlled by the control unit (6). At the time of the opening the non-return valve (15), at which the valves (13) and (14) connecting the atmospheric separators (10) and (11) are open, and the valves (8 and 9) on the hydrogen and oxygen supply lines are closed, the feed pump (12) pumps the working electrolyte solution into the electrolysis system, filling the modules to the level at which the level sensors are activated, on whose signals the control unit (6) disconnects the feed pump (12) and closes the non-return valve (15).

Thus, in each of the sections of electrolysis modules series-connected to an electrical circuit, an electrochemical decomposition occurs during the cyclic feeding of the alternating potential to the active and passive electrodes in each module. This ensures the possibility of the distributed over time alternating generation of one of the gases on the passive electrode with simultaneous reverse absorption of another gas by the active electrode. The gas generation process proceeds with successive hydrogen and oxygen half-cycles.

During the hydrogen cycle, the timer (5) sets the flow switch (2) to the position where the hydrogen separator (10) is connected to the sections of the electrolysis modules (1), and the polarity switch (7) – to the position of the corresponding hydrogen release. The passive electrodes of the modules (1) receive a negative potential, turning them into cathodes, whereas the active ones receive a positive potential, turning them into anodes. Under such conditions, the cathodes release hydrogen that flows through the flow switch (2) into the hydrogen separator (10) and then through the open electromagnetic valve 8 into the hydrogen line to the consumer. At the same time, the oxygen released at the anodes is absorbed and chemically bound to the active mass of the active electrodes. The isolation of hydrogen lasts until all the active mass of the electrodes is oxidized. The hydrogen cycle is accompanied by an increase in the voltage on the electrodes controlled by the comparator (4) and is maintained within 0.3–0.5 V. When the voltage reaches the value of the corresponding active electrode electrochemical capacitance loss (0.5 V), the comparator (4), via the timer (5), sets the polarity switch (2) to the off position for the period of time necessary to degas the electrolyte for the electrodes to be de-energized and completely degas the electrolyte from the gas residues generated in the previous gas cycle. The flow switch (2) remains in the state of the electrolyzer (1) sections being connected to the hydrogen separator 10. After the degassing time has elapsed, the timer (5) sets the flow switch (7) to the position of the electrolyzer sections being connected to the oxygen separator (6), sets the polarity switch (2) to the opposite polarity corresponding to the next oxygen cycle. Under this condition, the passive electrodes of the cell (1) receive a positive potential while the active ones receive a negative potential. The passive electrodes become anodes, releasing oxygen, which flows via the flow switch (2) to the oxygen separator (11) and then, via the open electromagnetic valve (9), to the consumer oxygen line. At the same time, the active electrodes of the modules regenerate (recover) the oxidized active mass. The process of oxygen release occurs when the voltage on the electrodes is from 1.4 to 1.5 V and lasts until the end of the electrochemical regeneration of the active mass. Under this condition, the comparator 4 connected to the control unit (6), having reached the value of 1.4 V, through the timer (5) sets the polarity switch (2) to the off position for the time of degassing, during which the flow switch (7) remains in the controlled position of the oxygen cycle. Further, the process of changing the cycles continues in the same order.

At the same time, the magnitude of current (I) in an electric circuit is maintained in the intervals of correspondence of the inversely proportional dependence on the number of connected modules. [10, 11].

As an active mass of gas-absorbing electrodes, metals with variable valence of a given structure are used (Fig. 3).

The container of the reaction chamber of each of the electrolyzer modules was filled with the 20% potassium hydroxide solution in water to a density of 1.21 mg/liter. The cyclic process of time-separated gas generation was automatically regulated by the control system, in compliance with the regime parameters during the continuous operation of the installation. The installation included a 2.5 kV DC source, an electronic polarity switch of the electrode potential, an electronic comparator for controlling the operating range of the voltages on the electrodes,

an electronic timer for controlling the time of degassing, a control unit, devices and mechanisms for observing the installation operating modes.

The operating pressure of the generated gases is 0.1–15 MPa, which is determined by the strength characteristics of the module body and electrolyzer gas-liquid lines (Fig. 4).

The density of stabilized current strength is 200.0 A/m<sup>2</sup>. The optimal specific power consumption in the hydrogen semicircle is 0.88 kWh/m<sup>3</sup>, while in the oxygen semicircle it is 3.28 kWh/m<sup>3</sup>. The total specific electricity consumption for gas production does not exceed 4.16 kWh/m<sup>3</sup>. The gases produced under high pressure were stored in receivers.

In order to increase the efficiency of the electrolyzer under consideration, it is possible to increase the number of series-connected electrolysis modules with the proportional growth of the gases produced and reduction of thermal losses. The optimal control of gas productivity required by the technological process or in case of removing individual modules from the electric circuit without interrupting the process of generating gases was carried out by controlling the amount of current in the electrical system in accordance with the inversely proportional dependence on the number of connected modules.

In Fig. 5 is shown the dependence of the current loads in a the high-pressure electrolyzer power supply system from the number of series-connected modules of a specified productivity with the working current density.

To obtain the appropriate volumes: of hydrogen (1 m<sup>3</sup>) and oxygen (0.5 m<sup>3</sup>) according to the single-module scheme, the maximum values of currents are 2.5 kA. For the four-module scheme they decrease by 4 times to 0.63 kA. This makes it possible to realize the work of an electrolysis installation with low current loads and reduce the risk of electric breakdowns inside the modules of electrolyzers.

### Conclusions

1. When implementing an electrolysis installation under the multi-module scheme, the series-connected modules placed in the module sections are provided with high productivity in terms of the quantity of the produced gases with low specific energy consumption in the oxygen (up to 3.28 kWh/m<sup>3</sup>) and hydrogen (up to 0.88 kWh/m<sup>3</sup>) half-cycles.

2. In each of the electrolysis modules an electrochemical decomposition occurs during the cyclic feeding of the alternating potential to the active and passive electrodes, which provides the possibility of

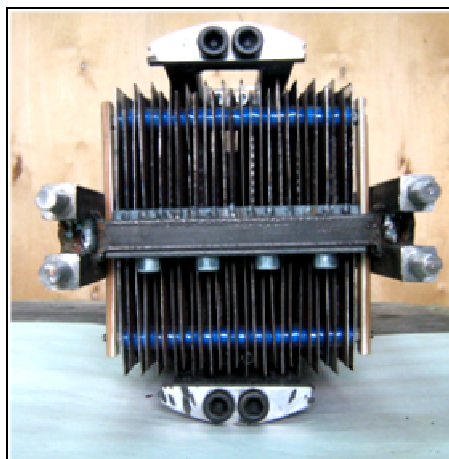


Fig. 3. Construction of an electrode assembly using a gas-absorbing electrode

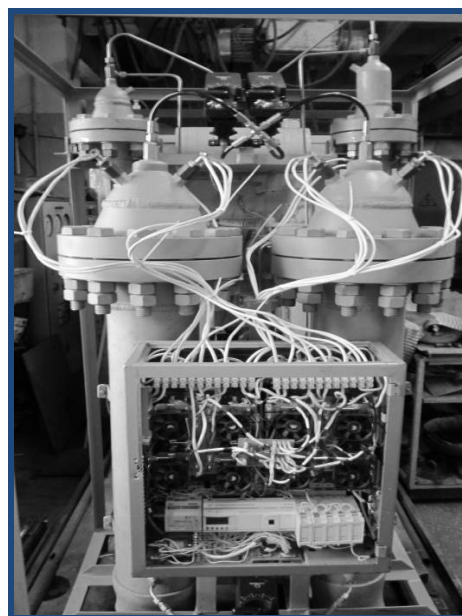


Fig. 4. Construction of a high-pressure electrolyzer with the main elements installed (15.0 MPa)

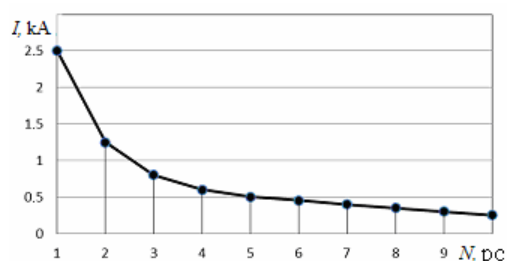


Fig. 5. Dependence of current loads in the high-pressure electrolyzer power supply system on the number of series-connected modules of a specified productivity

implementing the time-separated alternating generation of one of the gases on a passive electrode with simultaneous chemical transformation of another gas by an active electrode.

3. Under the four-module connection scheme, the maximum current value is reduced by 4 times from 2.5 to 0.63 kA for producing 1 m<sup>3</sup> of hydrogen and 0.5 m<sup>3</sup> of oxygen, which makes it possible to realize the work of an electrolysis installation with low current loads and reduce the risk of electric breakdowns inside the modules of electrolyzers.

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Received 16 August 2018

**Основні принципи роботи і алгоритм керування безмембранним електролізером високого тиску**

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*Розглянуто технологію циклічного генерування водню та кисню високого тиску, що реалізується в одномодульній і багатомодульній електролізній установці. Наведено принципову схему її роботи для реалізації способу із чотирма послідовно підключеними модулями. Під час циклічної подачі знакозмінних потенціалів на активний і пасивний електроди з одержанням кожного з газів роздільно в часі за одночасного оборотного поглинання іншого активним електродом процес можливо проводити як за одномодульною, так і багатомодульною схемою з послідовним підключенням в електричне коло і виведенням (шунтуванням) з кола окремих модулів або блоків електролізерів без переривання процесу одержання газів з оптимальним регулюванням продуктивності газів за умовами технологічного процесу. Це дозволяє реалізувати роботу електролізної установки з низькими струмовими навантаженнями та знизити ризики виникнення електричних пробойів усередині модулів електролізерів. Описано алгоритм керування чотирьохмодульною електролізною установкою. Визначено оптимальні параметри регулювання продуктивності газів на вимогу умов технологічного процесу. Проведено аналіз циклограми з обмеженням напруги протікання реакції від 0,5 до 1,8 В при генерації водню і кисню. Діапазон робочих температур розробленого процесу електролізу знаходиться в межах від 280 до 423 К, а інтервал тисків становить 0,1–70 МПа. Наведено залежність вольт-амперних характеристик системи живлення електролізера високого тиску від кількості послідовно з'єднаних модулів заданої продуктивності. Оптимальне регулювання продуктивності газів на вимогу умов технологічного процесу або у випадках виведення з електричного кола окремих модулів без переривання процесу генерації газів здійснювалось шляхом керування величиною струму в електричній системі згідно з обернено пропорційною залежністю від кількості підключених модулів. Розглянуто зовнішній вигляд конструкції електродної збірки з використанням газопоглинаючого електрода. Вказано рекомендації з реалізації роботи електролізної установки з низькими струмовими навантаженнями та зниження ризиків виникнення електричних пробойів усередині модулів електролізерів.*

**Ключові слова:** електролізер, газопоглинаючий електрод, водень, кисень.

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