Journal of the Technical University of Gabrovo

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RESEARCH OF METHODS FOR INCREASING THE EFFICIENCY OF PRODUCING OXYGEN-HYDROGEN MIXTURE

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ARTICLE INFO

Article history:
Received 22 February 2019
Accepted 14 March 2019

Keywords:
hydrogen, ultrasonic field, electrolysis, energy efficiency, efficiency

ABSTRACT

In the study methods of increase of an overall performance of an electrolyzer for hydrogen-oxygen mix obtaining are considered and their influence on system efficiency are investigated. Based on the results of the analysis of existing studies of hydrogen generators, it was established their low efficiency and the original design of the hydrogen generator was proposed. Experimental setup to test the efficiency of the device and determine its performance was designed. There were carried calculations of increasing the efficiency of a gas generation with the presence of an ultrasonic field.

Analysis of the experimental and theoretical results of the study made it possible to determine the rational frequency and amplitude of the ultrasonic field. The results of the experimental data confirmed the increase in the efficiency of the device for gas producing. Directions for improving the performance of the cell by applying an ultrasonic field and pulse width modulation for maintaining rational operating modes have been determined, as a result of which it is possible to increase the productivity of the hydrogen-oxygen mixture up to 40%.

1. INTRODUCTION

Nowadays hydrogen is one of the alternative fuels. Hydrogen energy is very promising, devoid of environmental problems, typical for the use of hydrocarbon fuels. The technology of producing hydrogen by electrolysis of water is known, which is rational for the case of low productivity. The electrolyzer, as a technological equipment, has become widely used in hydrogen energy [1, 2]. Electrolysis of water differs from other methods of producing hydrogen by the simplicity of the technological scheme, the availability of water as a raw material, the ease of maintenance and the reliability of technological equipment.

Hydrogen energy is absolutely environmentally safe because when hydrogen is burned only water is formed.

The variety of ways to produce hydrogen is one of the advantages of hydrogen energy, as it increases energy security and reduces dependence on certain types of raw materials [1-3].

The following methods for producing hydrogen are known:

- steam conversion of methane and natural gas;
- gasification of coal;
- electrolysis of water;
- pyrolysis;
- partial oxidation;
- biotechnology;
- chemical reactions.

At the moment, the most common way of obtaining hydrogen for motor vehicles is the electrolytic decomposition of water (electrolysis, hydrolysis). However, this method has a low efficiency.

2. EXPOSITION

Electrolytic hydrogen is the most affordable and, at the same time, the most expensive in the energy sector. In industrial and pilot plants, the efficiency of the cell is ~ 70-80% at a current density of less than 1 A/cm^2, including for electrolysis under pressure. In hydrogen generators, which are used in cars, the efficiency on average is 30-60%.

However, the simplicity of the device and the technological design make this method promising. In the modern world, the transition to renewable energy sources is becoming ever more urgent, as one of the main goals of introducing hydrogen energy is to reduce greenhouse gas emissions and the introduction of an embargo on oil and gas production in the future. Such renewable sources can be wind energy or solar energy, which allows realizing the technology of water electrolysis.

Electrolysis of water is one of the most well-known and well-studied methods of producing hydrogen. It ensures the production of a pure product (99,6 – 99,9% H_2) in one technological stage. The economy of the process mainly depends on the cost of electricity.

The operating principle of the cell is shown in the diagram (Fig. 1).

A so-called "dry" electrolyzer is presented in which the current is supplied to the side plates-the anode and the cathode. The cell contains an electrolyte-filled container in which the metal plates forming the cells are located. The

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voltage of the power supply is divided by the total number of cells. By means of electrical pulses, water molecules (H_2O) break up into two molecules of hydrogen and one molecule of oxygen.

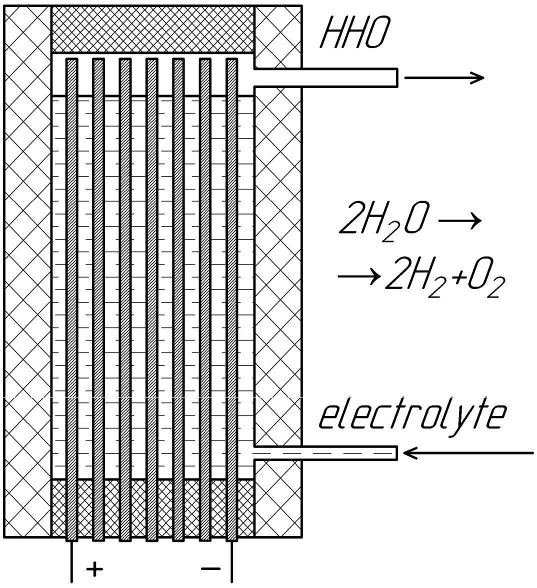

Fig. 1. The scheme of the device and the operating principle of the electrolyzer

Evaluation of the energy efficiency of the use of hydrogen-oxygen flame, obtained by burning a mixture produced by an EWG (electrolysis-water generator) could be performed as follows. A quantitative assessment of the efficiency of the electrolysis process can be estimated by calculating the amount of consumed electrical energy and thermal energy generated during the combustion of the mixture obtained during the electrolysis of water.

Comparing the specific heat of combustion, it can be noted that the combustion of hydrogen produces more energy than when using other fuels. Thus, the heat of combustion of hydrogen is 141 MJ/kg, acetylene - 50.4 MJ/kg, household gas - 46.1 MJ/kg, gasoline - 44 MJ/kg, diesel fuel 42.7 - MJ/kg.

According to the Faraday law, the mass of substance m released on the electrode is directly proportional to the electric charge q that passes through the electrolyte:

$$m = k \cdot q = k \cdot I \cdot t\ ,$$

if a constant current with a current I is passed through the electrolyte for a time t.

The proportionality coefficient k is called the electrochemical equivalent of a substance. It is numerically equal to the mass of the substance released during the passage of a single electric charge through the electrolyte and depends on the chemical nature of the substance. For hydrogen and oxygen, the value of the electrochemical equivalent is 0,0376 and 0,298 g/Amp-hour, respectively.

Thus, it is possible to estimate the possible amount of produced gas during the operation of the electrolyzer.

To obtain 1 m^3 of the hydrogen-oxygen mixture by electrolysis of water on an EWG of the bipolar type, an average of about 4 kWh (14.4 MJ) of energy is consumed. By burning 1 m^3 of the hydrogen-oxygen mixture, 6.75 MJ of heat is obtained [3].

The efficiency η_{EVG} of converting electrical energy into heat during the production and combustion of hydrogen-oxygen mixture in the best models of bipolar EWG is:

$$\eta_{EWG} = \varepsilon_{GC} / \varepsilon_{EL} \approx 0{,}40 \div 0{,}60$$

The addition of 5,5% of gasoline vapours to the hydrogen-oxygen mixture (HOM) increases 2,5 times the release of thermal energy when the gas mixture is burned and 2,2 times when the HOM is saturated with 16% ethyl alcohol. In this way. It is possible to significantly increase the efficiency of flame use when burning the mixture [3].

As a result of the thermodynamic calculation of the hydrolysis of water, we obtain the consumption of electricity for the production of 1 m^3 of hydrogen – 2,37 kWh. While molecular-kinetic calculation yields 2,07 kWh. According to Faraday's law, this figure is 1,96 kWh. In practice, in some US patents, for example, Stanley A. Meyer [4], this figure is much smaller. However, in industrial production, the figure of 5,2 kWh was fixed on all electrolyzers without exception. for 1m^3 of hydrogen. The best indicator, fixed by the American manufacturers of electrolyzers, is 4,25 kWh.

There are following ways to increase the energy efficiency of hydrogen production by electrolysis:

- intensification of processes due to the application of vibrations of the electrolyte;
- use of pulse-width modulation;
- adjustment of rational operating modes (maintenance of temperature regimes, electrolyte concentration, reactor design parameters) and other methods [1-7].

The efficiency of hydrogen or hydrogen-oxygen mixture (HHO) generation by increasing the level of technical equipment and the development of methods for producing hydrogen is constantly increasing (Fig. 2)

As can be seen, the most effective method of producing hydrogen is the use of an ultrasonic field and a mechatronic control system.

Pulse width modulation (PWM) is the process of controlling the latitude (duration) of high-frequency pulses according to the law given by the low-frequency signal. In electronics, this can be used to control the average voltage value by changing the duration of the closed state of the electronic (electromechanical) key, for example, in the circuit of the key voltage regulator.

Due to the use of PWM, it is possible to control the value of the current passing through the electrolyzer. Also, the impulse supply of power to the electrodes can be useful from the point of view of increasing the efficiency of operation, since when the gas is released on the plate its effective contact area with the electrolyte decreases and it takes some time for the bubbles to detach from the plate.

A feature of PWM is a small loss of energy on an electronic switch. It is mainly located or in the off state when its resistance is maximum, or in the saturation mode with a minimum resistance, that is, either the current or the voltage drop on it are close to zero.

PWM also fits well with digital technology

The ultrasonic field excited in the electrolyte has a strong mixing effect at the molecular level, qualitatively different from the usual mechanical mixing, significantly reduces the ion concentration gradient in the near-cathode layer, thereby affecting the polarization of the electrodes, and substantially increases the limiting diffusion current during electrolysis.

The ultrasonic field in the process of electrolysis has a significant effect on the kinetics of electrode processes. Under the influence of ultrasound, the processes occurring in the electrolyte itself are also intensified.

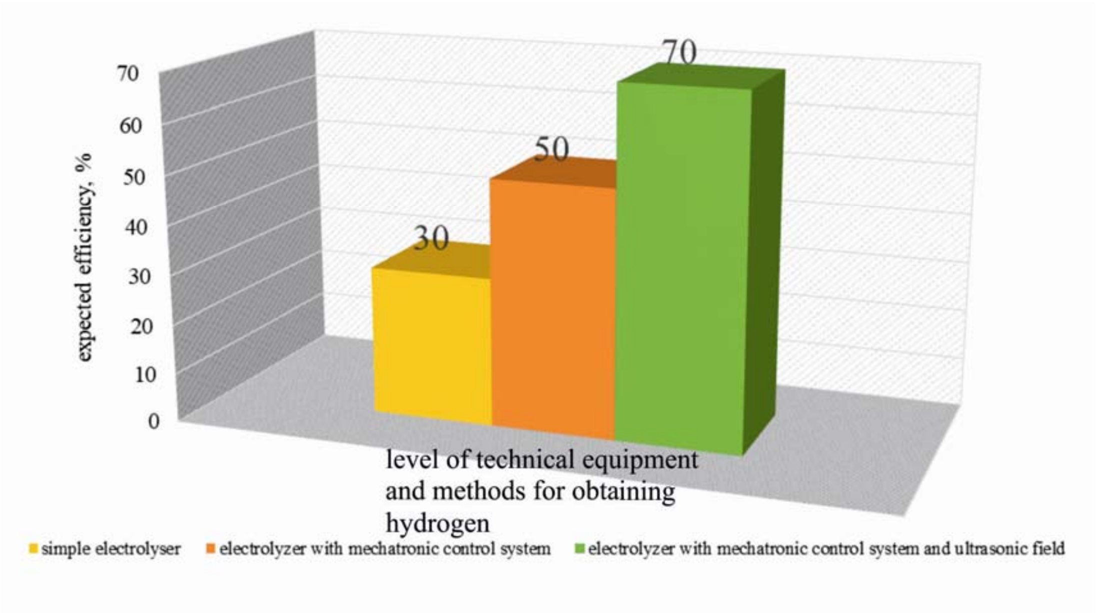

Fig. 2. Methods for increasing the energy efficiency of hydrogen generation

The equation of longitudinal oscillations of a piezoelectric composite converter in general form can be written as [9]:

$$S\frac{\partial^2 U}{dt^2} = C^2\frac{\partial}{\partial x}\left(S\frac{\partial U}{\partial x}\right),$$

where U is the longitudinal displacement, C is the speed of sound, and S is the cross-sectional area.

The HHO bubbles released during the electrolysis at the cathode are obtained in an ultrasonic field by an accelerating shock as a result of the reflection of the sound wave from the "solution-gas" interface. This accelerates the motion of gas bubbles along the surface of the cathode Fig.3.

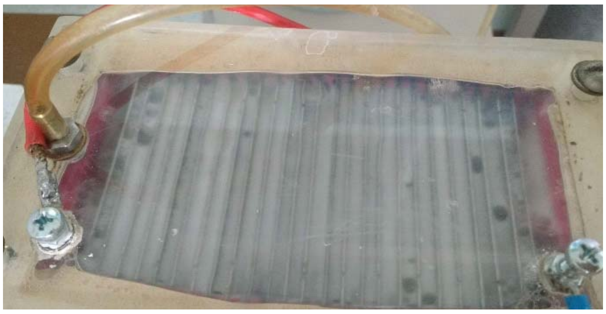

Fig. 3. Visualization of the electrolyzer operation. Gas emission is observed on all plates

Acceleration increases with increasing intensity of the ultrasonic field. Gas bubbles move in the electrolyte along the cathode surface, as a result of which the electrolyte layer in the cathode space is continuously renewed.

The effect of ultrasound increases with increasing cathode current density, which increases the depletion of the near-cathode layer and increases the number of hydrogen bubbles [2].

An experimental prototype of anHHO generator has been created, the scheme of which is presented in Fig.4.

A measurement system and a methodology for conducting research were developed.

The circuit includes an electrolyzer with the ability to supply voltage to the plates both directly from the power supply unit (PS) and through the pulse width modulation (PWM) module. The pulse frequency of the module is 100 Hz, the duty cycle is 50%.

The amplitude of pulses is 60 V.Number of plates - 25 pieces. The dimensions of the plates are 60x75x1mm. The plates are made of AISI 316 stainless steel.

A half-wave ultrasonic piezoelectric radiator located in the bottom of the cell body was excited by an ultrasonic frequency generator (USG) with an intensity exceeding the threshold for the onset of cavitation. During the research, the frequency of the ultrasonic generator was set at 28, 30 and 32 kHz. Accordingly, the resonance dimensions of the piezoelectric radiator were also corrected. The obtained results of experimental studies made it possible to determine the dependence of the hydrogen-oxygen mixture consumption on temperature for different ultrasound frequencies (Fig.5).

The obtained results show that the frequency of ultrasonic oscillations affects the intensity of the hydrogen-oxygen mixture evolution.

Three modes of operation of the cell were considered: direct current, pulsed current and ultrasonic field.

In the study of the operation of the cell, the discharge of gas was measured, the temperature of the electrolyte and the current passing through the electrolyzer were recorded.

To verify the efficiency of the cell in these modes, the experimental setup Fig.6 was assembled.

The discharge of the gas was recorded using a rotameter and a volumetric method. The control of the electrical parameters of the PWM and the ultrasonic frequency generator was performed with an oscilloscope. The dependences obtained as a result of the experiment are presented in Fig. 7. Three modes of operation of the cell were compared: with DC power, pulse power supply (PWM), and ultrasonic field imaging with pulse power (Ultrasonic).

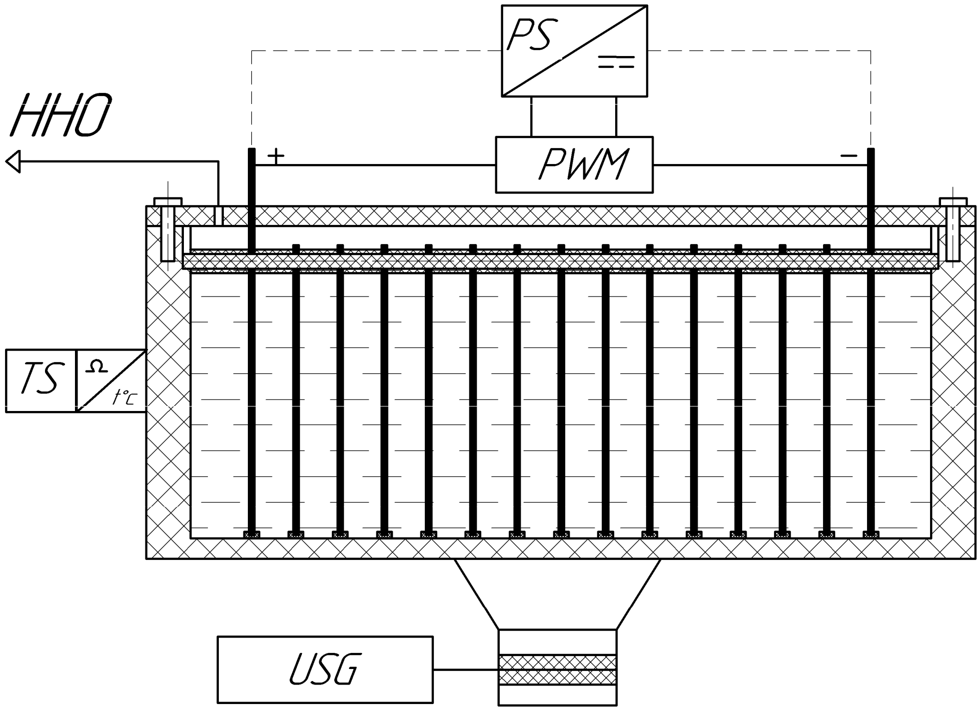

Fig. 4 Connection diagram of the test cell under investigation: PS - power supply unit, PWM - pulse width modulator, TS - temperature sensor, USG - ultrasonic generator

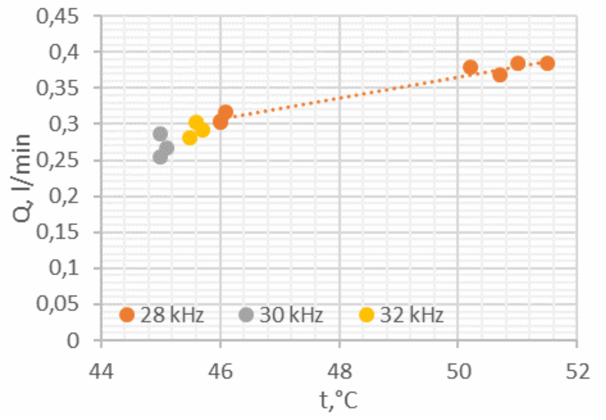

Fig. 5.Dependence of hydrogen-oxygen mixture production on temperature for different ultrasound frequencies

As can be seen from the graphs, the intensity of the electrolyser's operation is affected by the current passing through the electrolyzer and the temperature of the electrolyte. The analysis showed that the effect of the temperature of the electrolyte on the amount of gas released is practically linear.

It has been experimentally established that when the cell temperature rises above 55-60°C, instability of the technological process occurs.

The cell works most effectively at a temperature of 50-55 ° C, that is, the efficiency depends directly on the temperature conditions. To prolong the time of stable operation of the cell, it is necessary to cool the electrolyte (Fig. 7).

Comparison of the dependencies obtained in different modes of operation shows that the application of pulse modulation of the supply voltage (PWM) leads to an increase in the amount of released gas by 10-15% (Fig.7).

Maximum efficiency is achieved by switching on an ultrasonic radiator (Ultrasonic). At the same time, an increase in the discharge of the released gas to 40% was observed (Fig. 7).

The current flowing through the electrolyzer changed with increasing temperature of the electrolyte and was practically independent of the mode of operation of the apparatus.

To reduce power consumption, a pulse generator with an electronic control unit is used. It should also be noted that cavitation caused by ultrasound cleared the plates from the formed deposits and coagulated the sediment on the bottom of the electrolyzer.

3. CONCLUSION

Thus, the proposed modernized circuit supports rational operating conditions of the cell, and the use of an ultrasonic field has increased the energy efficiency of the electrolysis process as a whole.

It should be noted that one of the main factors affecting the processes of electrolysis is the temperature conditions of operation (the temperature of the electrolyte), which necessitates the rigging of the system by the unit for maintaining a rational temperature (heat exchanger).

In the future, it is planned to create an autonomous electrolyzer with control from a computer and with a solar panel as an alternative power source.

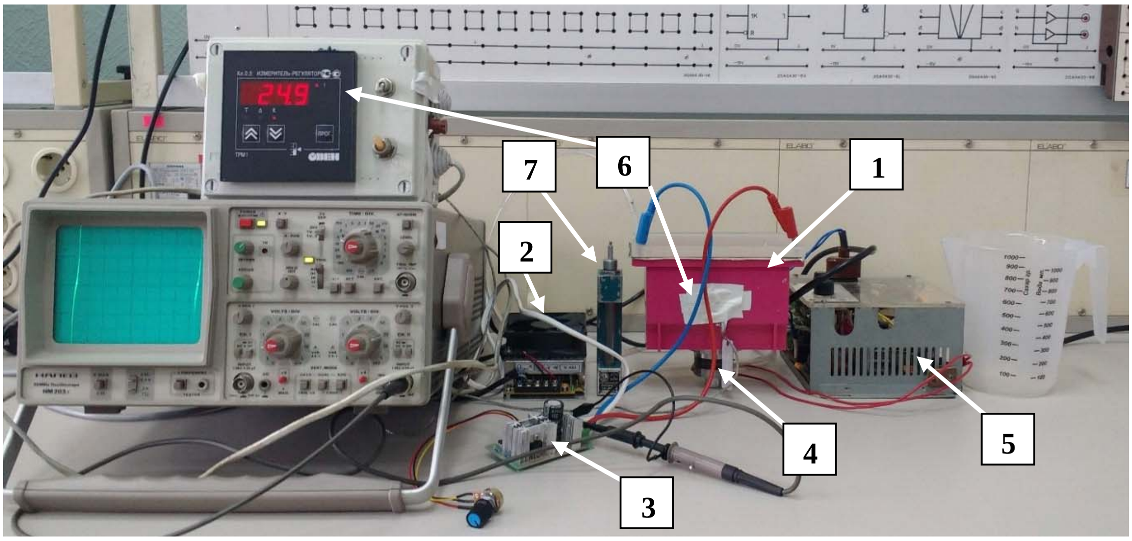

Fig. 6. Stand for testing the cell: 1 - electrolyzer, 2 - power unit, 3 - pulse width modulator, 4 - ultrasonic radiator, 5 - ultrasonic generator, 6 - temperature measurement module, 7 - rotameter, 8 - oscilloscope.

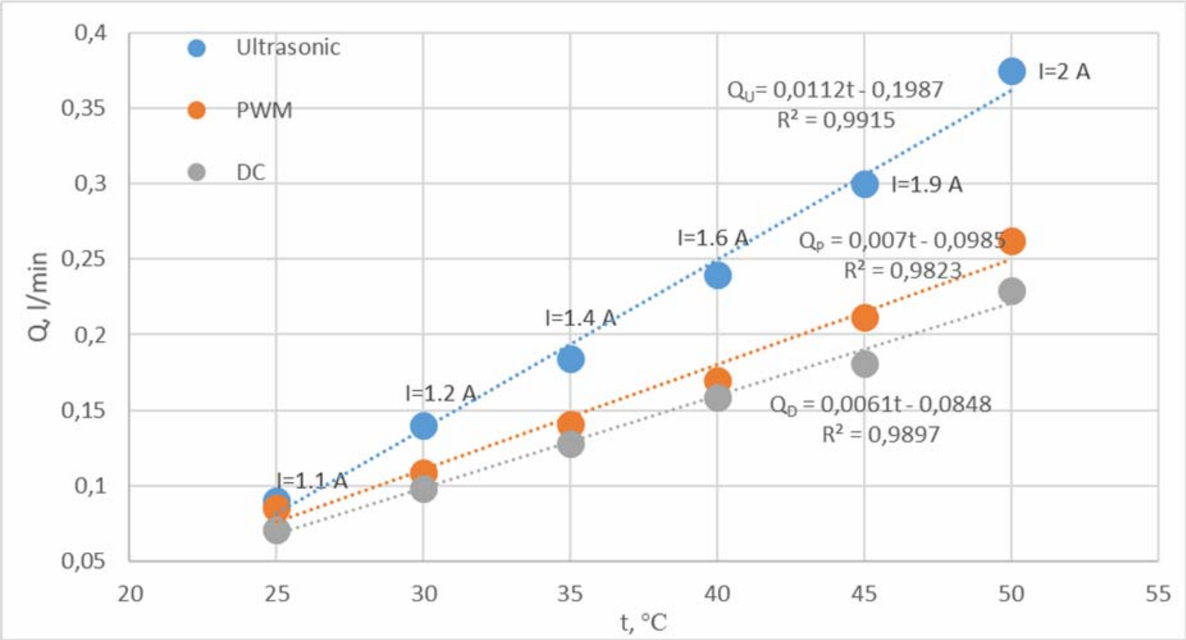

Fig. 7. Dependence of the flowrate of the hydrogen-oxygen mixture on the temperature of the electrolyte at different

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