OS INIBIDORES DE CORROSÃO MAIS EFICAZES PARA UMA CÉLULA ELETROQUÍMICA DE LIGA DE ALUMÍNIO USADA COMO UM GERADOR DE HIDROGÊNIO CONTROLADO

THE MOST EFFICIENT CORROSION INHIBITORS FOR ALUMINUM ANODE OF ELECTROCHEMICAL CELL USED AS A CONTROLLED HYDROGEN GENERATOR

НАИБОЛЕЕ ЭФФЕКТИВНЫЕ ИНГИБИТОРЫ КОРРОЗИИ АЛЮМИНИЕВОГО СПЛАВА ДЛЯ ЭЛЕКТРОХИМИЧЕСКОЙ ЯЧЕЙКИ, ИСПОЛЬЗУЕМОЙ В КАЧЕСТВЕ УПРАВЛЯЕМОГО ГЕНЕРАТОРА ВОДОРОДА

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RESUMO

Neste artigo, apresentamos os resultados de um estudo sobre o desenvolvimento da mais eficiente combinação anodo-eletrólito para uma célula eletroquímica hidrônica com uma liga de alumínio, desenvolvida com base no sistema eletroquímico H_2O/Al e considerada como um gerador de corrente e fonte de hidrogênio como produto final. Nós mostramos que o alumínio A995 deve ser usado como ânodo para células eletroquímicas hidrônicas usadas como geradores de hidrogênio, uma vez que esta classe tem uma menor taxa de corrosão quando imersa em soluções alcalinas em comparação com ligas que contêm um aditivo ativador de índio. Descobrimos que 4M NaOH + 12 g/L dos ions de tartarato de sódio + 1,6 g/L CaO e 4M KOH + 12 g/L de tartarato são mais eficazes para células eletroquímicas hidrônicas com liga de alumínio A995 e contêm eletrólitos alcalinos à base de 4M NaOH e KOH. Demonstramos que o eletrólito inicial é melhor em termos de inibição da corrosão da liga de alumínio A995, enquanto o segundo é melhor tanto para a polarização do ânodo A995 quanto para a potência total de saída e pode ser recomendado para uso em células eletroquímicas hidroquímicas.

Palavras-chave: *célula eletroquímica, liga de alumínio, célula de combustível de hidrogênio-oxigênio, fonte de alimentação, geradores de hidrogênio.*

ABSTRACT

In this article the authors have presented the results of the research into the development of the most efficient anode-electrolyte combination for a hydronic electrochemical cell fitted with an aluminum anode, designed on the basis of the H_2O/Al, electrochemical system, and viewed as both a current generator and a source of hydrogen as an end product. We have demonstrated that the A995 grade aluminum should be used as the anode for hydronic electrochemical cells used as hydrogen generators, because the grade in question has slower corrosion rate when submerged in alkaline solutions, compared with alloys that contain an activating indium additive. We have found that 4M NaOH + 12g/L tartrate ion + 1.6g/L CaO and 4M KOH + 12g/L tartrate ions are the most efficient for hydronic electrochemical cells fitted with A995 aluminum anodes and containing

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4M NaOH and KOH-based alkaline electrolytes. We have demonstrated that the former electrolyte is better in terms of inhibiting corrosion of the A995 aluminum anode, while the latter one is better in terms of both polarizations of the A995 anode and the total output performance, and can be recommended for use in hydronic electrochemical cells.

Keywords: *electrochemical cell, aluminum anode, hydrogen-oxygen fuel cell, power supply unit, hydrogen generators.*

АННОТАЦИЯ

В этой статье авторы презентовали результаты исследования по разработке наиболее эффективной комбинации анода-электролита для гидронной электрохимической ячейки с алюминиевым сплавом, разработанной на основе электрохимической системы H_2O/Al и рассмотренной, и как генератором тока, так и источником водорода в качестве конечного продукта. Мы показали, что алюминий марки А995 следует применить в качестве анода для гидронных электрохимических ячеек, используемых в качестве генераторов водорода, поскольку этот класс имеет более низкую скорость коррозии при погружении в щелочные растворы по сравнению со сплавами, которые содержат активирующую добавку индиума индия. Мы обнаружили, что 4M NaOH + 12 г/л ионов тартрата + 1,6 г/л CaO и 4M KOH + 12 г/л тартрата являются наиболее эффективными для гидронных электрохимических ячеек с алюминиевым сплавом А995 и содержат щелочные электролиты на основе щелочными электролитами 4M NaOH и KOH. Мы продемонстрировали, что исходный электролит лучше с точки зрения ингибирования коррозии алюминиевого сплава А995, в то время как последний лучше как в вопросе поляризации анода А995, так и общей выходной мощности и может быть рекомендован для использования в гидрохимическом гидронных электрохимических ячейках.

Ключевые слова: *электрохимическая ячейка, алюминиевый сплав, водородно-кислородный топливный элемент, блок энергопитания, генераторы водорода.*

INTRODUCTION

The hydrogen economy is currently among the most rapidly developing, the most promising, and the environmentally safest electricity generation fields for a wide range of end users. The practically unlimited amounts of hydrogen contained in world water resources, the purity of water – the product generated through oxygen reacting with hydrogen, and the high specific energies of reactions in question (119.0 MJ/kg or 33.1 kWh /kg) are the advantages of a hydrogen economy.

Hydrogen-oxygen (O_2/H_2) fuel cells that are among the most efficient fuel cells have the highest energy efficiency among standalone power supply units that use hydrogen as fuel. As of now, O_2/H_2-based power supply units are efficient for many autonomous technical systems, including PEDs, reserve power sources, transportation, aviation and aerospace areas.

O_2/H_2 – based ground-operated power supply units tap the ambient air oxygen, whereas hydrogen has to be stored, which is one of the topical problems for O_2/H_2 – based power supply units. Methods of hydrogen storage span a number of approaches, including high-pressure, cryogenic, and “chemically bound” storage. High-pressure storage in gas cylinders, primarily steel cylinders, considerably decreases specific energy and mass parameters of the entire power supply unit, while cryogenic storage, in spite of its high efficiency, should not be used while long operation pauses, seeing as cryogenic liquids evaporate rapidly. Moreover, the latter storage method has high costs due to the costs of the cryogenic equipment, strict technological operation restrictions, and is advisable for specific purposes only. As power supply systems contain pure hydrogen, both high-pressure and cryogenic storage methods present fire and explosion hazards.

Autonomous hydrogen generation units are used on site of consumption to produce hydrogen from, e.g., metals that actively restore hydrogen from water when reacting with it. The latter “bound” storage method is the safest of all. Those storage systems, including derivative standalone hydrogen generators, are being developed and promoted rapidly due to the advantages listed above.

Please refer to Table 1 for estimations of hydrogen generation methods by reactions between metals or metal hydrides and water in terms of mass consumption of reagents required to produce one mole (2 grams) of hydrogen.

Aluminum is one of the metals that have the highest potential in terms of hydrogen generation by reactions between metals and water. Table 1 above suggests that the aluminum-water system is one of the most efficient in terms of hydrogen generation efficiency per mass unit of reagents when restoring hydrogen from water, coming second to the sodium borohydride-water, lithium hydride-water, and lithium-water systems. The advantages of aluminum are that it has a low cost (especially technical grades), and aluminum manufacturers operate widely on an industrial scale; moreover, being an amphoteric metal, aluminum displaces hydrogen from both water (under certain conditions provided) and aqueous solutions of acids, alkali, and salts. Due to the advantages in question, research into and design of the aluminum-water electrochemical system and derivative autonomous hydrogen generators have been given high priority (Edan *et al.*, 2013).

However, hydrogen generators based on a direct mixture of aqueous solutions of alkali with granulated finely dispersed aluminum (or various aluminum alloys in required proportions) are designed for the needed purpose (Jung *et al.*, 2008; Wang *et al.*, 2009; Soler *et al.*, 2007). Highly complicated adjustment of hydrogen production rate by altering proportions of reagents is viewed as the principal disadvantage of hydrogen generators in question. Other disadvantages include aluminum surface passivation problem (aluminum granule passivation) due to the reaction, which results in an incomplete aluminum reaction, leaving the reaction unfinished, thus decreasing the very efficiency of such generators.

Hydrogen production rate is much easier to regulate when aluminum reacts with water by producing hydrogen electrochemically – by means of an electrochemical cell with aluminum anode (Okorokova *et al.*, 2011a; Kravchenko *et al.*, 2011; Okorokova *et al.*, 2010, Okorokova *et al.*, 2011b), where hydrogen production rate can be controlled by altering discharge current. In a H2O/Al electrochemical system-based cell (hydronic electrochemical cell), water is used as the oxidant, and an inert metal is used as a cathode on which hydrogen is produced from water. Please refer to Figure 1 below for the circuit of a hydronic electrochemical cell with alkaline electrolyte, with the locations where principal reactions occur marked.

It is obvious that an anode cell reaction occurs when the hydronic electrochemical cell with an aluminum anode in alkaline electrolyte works (Equation 1), while hydrogen is reduced from water on the cathode from the inert material, following the reaction – Equation 2.

The overall cell reaction in a hydronic electrochemical cell with alkaline electrolyte can be expressed by an Equation 3. As aluminum is thermodynamically unstable in water, the anode is consumed as the cell reaction occurs due to corrosion reaction that is expressed by the same overall Equation 3, with the difference that hydrogen is produced on cathode areas of corroding aluminum.

Aluminate solution produced by dissolving aluminum in alkali is extremely prone to supersaturation; however, as soon as it reaches a certain degree of supersaturation, it decomposes, producing solid aluminum hydroxide that crystallizes in the form of Gibbsite (Equation 4). In a neutral salt electrolyte, cell reaction and corrosion reaction are expressed by the overall reaction (Equation 5).

It follows from Equations 4 and 5 that reactions occurring in both alkaline and neutral electrolytes yield the same reaction products – $Al(OH)_3$ and H_2; however, aluminum hydroxide becomes precipitated out of a neutral electrolyte in the form of a gel. Aluminum and water are the consumable materials of a hydronic electrochemical cell with an aluminum anode, as it was mentioned earlier. Thus, aluminum hydroxide $Al(OH)_3$ and hydrogen are the reaction products in a hydronic electrochemical cell. Seeing as hydrogen is the target product, a hydronic electrochemical cell is essentially an electrochemical hydrogen generator.

Processes that occur on the anode of a hydronic electrochemical cell are identical to those occurring in air-aluminum electrochemical cells; this is shy the same aluminum alloys can be used for anodes of a hydronic cell as the one used for an air-aluminum cell, where the ambient air oxygen is the oxidant. However, both hydronic and air-aluminum cells are intended for inhibition of aluminum corrosion, the function that is applied to the regulation of hydrogen production rate in a hydronic cell.

Consequently, the choice of optimal anode-electrolyte compounds for the power unit in question should meet the criteria listed below

– minimal polarization and the most negative value of the anode;

– minimal corrosion of the anode;

– corrosion behavior of the aluminum anode, most favorable for electrochemical control.

The latter of the above criteria allows for not so strict compliance with the minimal corrosion of the anode used, as necessary for an air-aluminum cell. It is certainly desirable that the anode meets the minimum corrosion requirement to enhance the power output of the power supply unit; however, the requirement in question is not critical for a hydronic electrochemical cell that acts as s hydrogen generator. This assumption provides a possibility of a broader compromise when choosing between minimum corrosion of the anode and higher power output of the hydronic cell.

Earlier (Karonik *et al.*, 1988), we proposed SnO_3^{2-} stannate ion additive for an air-aluminum electrochemical cell using alkaline electrolyte as a corrosion inhibitor. Stannate ion is one of the most efficient inhibitors for a wide range of aluminum alloys used currently as anodes of electrochemical cells with an alkaline electrolyte. A number of other works on air-aluminum electrochemical cells (Egan *et al.*, 2013; Doche *et al.*, 1997; Macedo *et al.*, 2017) also mentioned the advantages of the use of stannate ion. In one of our subsequent work (Okorokova *et al.*, 2015), we also considered using the inhibitor in question in hydronic cells.

EXPERIMENTAL

The following electrolytes were used in the experiment: NaOH and KOH 4M aqueous solutions, pure or with various inhibitor additives: $Na_2SnO_3{\cdot}3H_2O$ stannate ion, 12g/L; $C_3H_5O(COO)_3^{3-}$ citrate ion, 12g/L; $C_3H_5O(COO)_3^{3-}$, 12g/L citrate ion + CaO, 1.6 g/L; $C_4H_4O_6^{2-}$ tartrate ion, 12 g/L; and $C_4H_4O_6^{2-}$ tartrate ion, 12 g/L + CaO 1.6 g/L. “Chemically pure” and “chemically pure for analytical applications” grade reagents and single-distillation water were used to prepare solutions. Solution concentrations were assessed by titling upon preparation.

High-purity aluminum, Al 99.995% (aluminum (over 99.995%), gallium (less than 0.003%), silica and iron (less than 0.0015% each), and other impurities (less than 0.001% each) was used as anode material. A gas-diffusion carbon-graphite cathode was used as cathode material. A test bench and a lab test cell were custom-designed and custom-made in a lab of Moscow Aviation Institute (MAI) to conduct electrochemical research, see Figure 2.

The diameter of the electrodes installed inside the cell was 60 mm. The surface area of the electrodes installed in the assembled cell was 19.6 sq cm. The electrolyte temperature in the test cell was 333 K, the set value being maintained at an accuracy of ±2º with a thermostat by pumping the coolant from the reverse side of the anode.

The instruments and equipment used in the experiment were

1. Thermostat with temperature accuracy class within ±0.5º.

2. P-150S potentiostat manufactured by Elins, LLC.

3. The standard saturated Ag-AgCl reference electrode and Luggin capillary.

4. Thermoelectric thermometer.

5. Pressure gauge, accuracy class within 0.5.

Electrochemical parameters of electrodes were assessed by coulometry and voltammetry. The galvanostatic mode was used among other voltammetric research methods, which was a stepwise alteration of current, with the delay interval of each mode being at least 5 min. The volt-ampere (V-A) characteristic referred to in this work is stationary, that is, plotted from set stationary values of electrode potentials (Lurie *et al.*, 2015). The time delay at each current step to take a measurement of the changed potential of the electrode under study was at least 5 min.

The anode corrosion rate for each discharge current density was measured volumetrically. The gas production rate was found from the pressure change rate within the system with a buffer volume of a known value V_T, fitted with a shutoff valve, see Figure 2 above.

Taking measurements of the time that it takes the pressure to increase to reach a certain value within a system with or without a buffer volume allows finding the corrosion current density by Equation (6), where ΔP is the pressure leap, water column mm;V_T is the buffer volume value, cu m;F is the Faraday constant;R is the gas constant;T_T is the temperature within the buffer volume, K; S is the electrode area, sq m; and $\Delta\tau$ is the difference between the pressure increase time with or without an added buffer volume.

The data obtained on corrosion characteristics for each mode (for its respective discharge current mode) were verified by gravimetry, by measuring the total loss of the anode mass throughout the experiment (that is, throughout the time span when the anode was submerged in the electrolyte). The verifications were done while taking into account the duration of each mode, and the discharge current density that occurred throughout the experiment (Formalev *et al.*, 2015).

Each experiment was reproduced at least five times. The experimental results were processed by mathematical statistics methods. The dots on diagrams presented in this work denote the experimental data, and the curves denote the approximating dependences that are the most similar to the nature of the change in a characteristic.

RESULTS AND DISCUSSION:

It is advisable to use organic aluminum alkaline corrosion inhibitors as additives to electrolytes for hydronic electrochemical cells, as organic compounds are normally incapable of restoring themselves on the inert cathode of hydronic cells when the cathode in question has negative potentials. Aluminum corrosion rate in alkaline electrolytes is slowed down by the formation of chemisorbed films on the metal surface, containing Al^{3+} ions, and organic acids anions.

In our earlier work (Okorokova, 2012), we researched organic inhibitors that suppressed corrosion of aluminum anodes of air-aluminum electrochemical cells. We conducted the research on aluminum alloys activated with indium, namely, an experimental alloy (A995 + 0.6% of In content), on AP4N industrially manufactured alloy, and on A995 pure aluminum grade used to replace stannate ions; added to the alkaline electrolyte in an air-aluminum electrochemical cell, stannate ions caused production of tin on cathode areas of the aluminum cathode; as the cathode gradually dissolved, the tin precipitated to form sludge, potentially leading to short-circuiting the electrochemical cell. We researched 4M and 8M NaOH-based electrolytes at 333K, with citrate ions and benzoate ions used as additives (citric acid and benzoic acid anions) with the concentrations of 0.052 moles/L.

The research results found that citrate ions considerably reduced the corrosion rate of the A995 aluminum anode, especially at low current densities (less than 500 A/sq m), while impairing the very V-A characteristic of the anode. Adding citrate ions influences the characteristics of indium-activated alloys anodes in an opposite manner, reducing their polarization, with the anode corrosion rate increasing considerably, however. It is obvious that the anode process, in this case, is limited primarily by the process of diffusion of sizable aluminum complex compounds with an organic inhibitor into electrolyte in viscous aluminate solutions; the rate of the process, in turn, is determined by the ratio between rates of the following processes: electrochemical dissolution of aluminum, that is, renewal of its surface, adsorption of organic additives occurring on it, formation of phase films, and removal of reaction products. When current densities are high, complexes being form too rapidly to be removed from the anode surface due to a high rate of dissolution, blocking the anode process.

Looking for the most efficient anode + electrolyte + corrosion inhibitor combination of reagents for a hydronic electrochemical cell as a controlled hydrogen generator is one of the topical problems caused by the two target functions of an electrochemical cell, namely, hydrogen generation from water (aqueous electrolyte), and electricity generation.

We chose A995 aluminum among other organic inhibitors for hydronic electrochemical cells, because it was least prone to corrosion in alkaline solutions in comparison with doped alloys. Please refer to Figure 3 below for V-A and corrosion characteristics of A995 aluminum in 4M NaOH and 4M KOH pure alkali. Figure 3 suggests that A995 aluminum in both alkalies has a pronouncedly positive difference effect and is practically linearly dependent on the discharge current density.

Citrate and tartrate ions – the anions of multi-base citric and tartaric hydroxy acids – were introduced into the electrolyte of a hydronic electrochemical cell as organic additives. The advantages of the use of the compounds in question for inhibition of alkaline corrosion were described in works (Perchenok, 1996; Shao *et al.*, 2002; Nazarenko, 1984; Orashev and

Nazarenko, 1980; Nazarenko *et al.*, 1982; Or *et al.*, 1983). The works in question also pointed out that introduction of additive alkaline earth metal ions, e.g., Ca^{2+} ions, could form intermolecular synergy effect when alkaline earth cations contribute to strengthening aluminum complex compounds with organic anions that are a part of inhibitive chemisorbed films that form on the anode surface.

This article presents the results of research into the influence of tartrate and citrate ions, both pure and containing calcium oxide (CaO) additive, on the V-A and corrosive characteristics of A995 aluminum 4M KOH and 4M NaOH alkaline electrolytes. Please refer to Figures 4-7 to see the results. By way of illustration, the diagrams also contain V-A characteristics and corrosion current densities for A995 with stannate inhibitor (SnO_3^{2-}) added.

It follows from the Figures above that the introduction of citrate- and tartrate-ion-based corrosion inhibitors into an alkaline electrolyte considerably decreases the corrosion rate of the pure aluminum anode, with the positive differential effect observed in all type electrolytes, and no pronounced minimums or maximums of the corrosion characteristics. The tartrate-ion-based inhibitor alone reduced the anode polarization better than any other inhibitive additive introduced into 4M NaOH and KOH solutions, thus enhancing the V-A characteristic of the A995 anode across the whole range of current densities of the electrochemical cell.

Of all mixed additives tested, in both alkali types, the tartrate ion+ CaO has proved to be the strongest corrosion inhibitor. However, this inhibitor combination not only suppresses corrosion but also increases the anode polarization considerably, in comparison with other combinations. In the latter case, 4M NaOH electrolyte is preferable, as the A995 anode submerged in it is somewhat less prone to polarization than in 4M KOH electrolyte.

Comparing the inhibitive action of citrate ions and tartrate ions, we found that lesser anode corrosion was observed in an electrolyte with tartrate ions added, than in citrate ion electrolytes, thus proving the assumption made in the earlier works (Perchenok, 1996; Shao *et al.*, 2002; Nazarenko, 1984; Orashev and Nazarenko, 1980; Nazarenko *et al.*, 1982; Or *et al.*, 1983) that the inhibition of alkaline aluminum corrosion decreased as carbon chains in an organic acid lengthened, with the acid anion used as inhibitor.

CONCLUSIONS:

The conclusions that can be drawn from the research results are as follows:

1. Citrate ion additive is the most efficient organic corrosion inhibitor for an air-aluminum chemical cell filled with 8M NaOH high-concentration electrolyte.

2. It is not advisable to use the most efficient anode-electrolyte compositions in hydronic electrochemical cells, which were designed for air-aluminum electrochemical cells, as the components of the compositions in question affect the cathode characteristics of the hydronic cell.

3. As for hydronic electrochemical cells, 4M NaOH + 12g/L tartrate ion + 1.6 g/L CaO electrolyte is the ideal in terms of corrosion inhibition on A 995 aluminum anodes. The 4M KOH + 12g/L tartrate ion electrolyte is ideal in terms of both the V-A characteristic of the A995 anode and the overall energy characteristics of the hydronic electrochemical cell as a whole. Of these two advantageous electrolytes for hydronic electrochemical cells, the 4M KOH + 12 g/L tartrate ion is preferable, as the polarization of the A995 anode is considerably lower when it is submerged in this electrolyte, which considerably enhances the energy characteristics of the hydronic electrochemical cell that contains the electrolyte composition in question, and compensates somewhat a faster corrosion rate of the anode submerged in this electrolyte. Thus, A995 aluminum + 4M KOH + 12 g/L tartrate ion is the most efficient anode-electrolyte composition for hydronic electrochemical cells.

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$$Al - 3e + 4OH^{-} \rightarrow [Al(OH)_4]^{-} \tag{1}$$

$$2H_2O + 2e \rightarrow 2H_2 \uparrow + 2OH^{-} \tag{2}$$

$$2Al + 6H_2O + 2OH^{-} \rightarrow 2[Al(OH)_4]^{-} + 3H_2 \uparrow \tag{3}$$

$$Na[Al(OH)_4] \rightarrow NaOH + Al(OH)_3 \downarrow \tag{4}$$

$$2Al + 6H_2O \rightarrow 2Al(OH)_3 \downarrow + 3H_2 \uparrow \tag{5}$$

$$j_{corrosion} = \frac{2 \cdot 9.81 \cdot \Delta P \cdot V_T \cdot F}{R \cdot T_T \cdot S \cdot \Delta\tau} \tag{6}$$

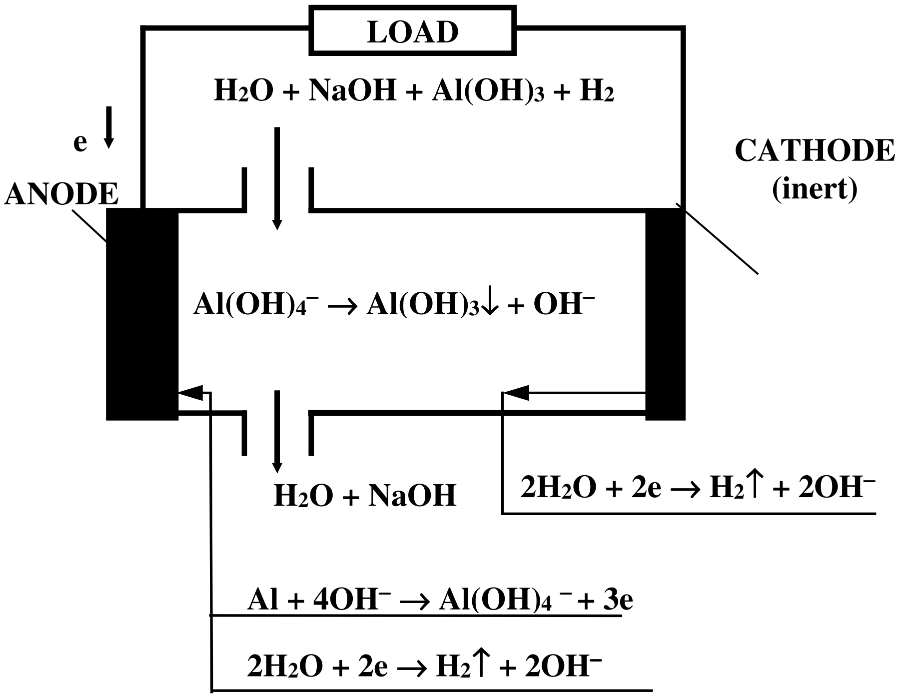

Figure 1. *The circuit of a hydronic current supply unit with the aluminum anode and an alkaline electrolyte*

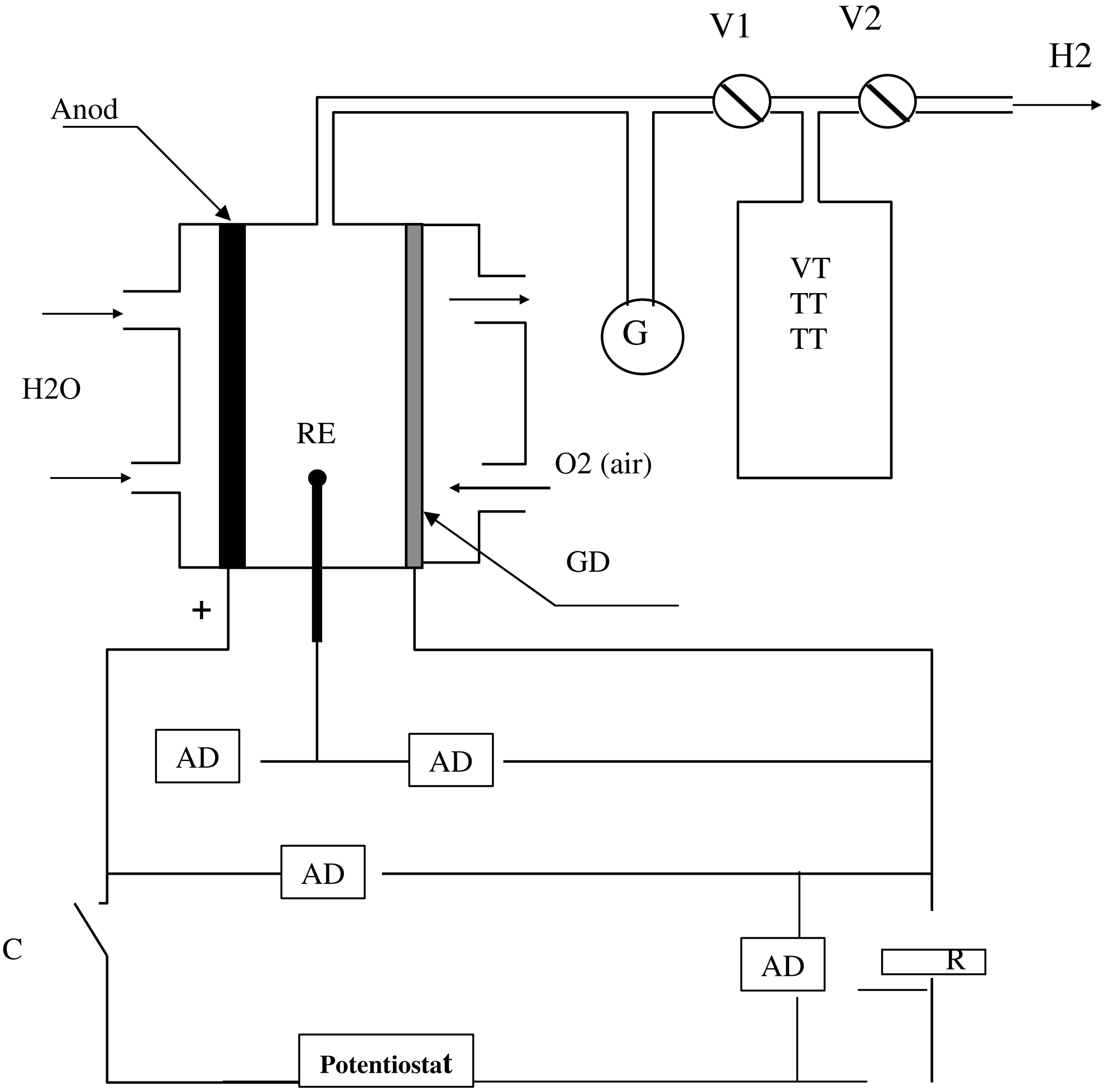

Figure 2. *Test bench circuit: H_2O –water fed from thermostat; V_1, and V_2 – gas valves; G – pressure gauge; Vm – tared volume; Tm – tared volume temperature; GDC – gas-diffusion cathode; RE – reference electrode; CB – circuit breaker; ADC – analog-to-digital converter*

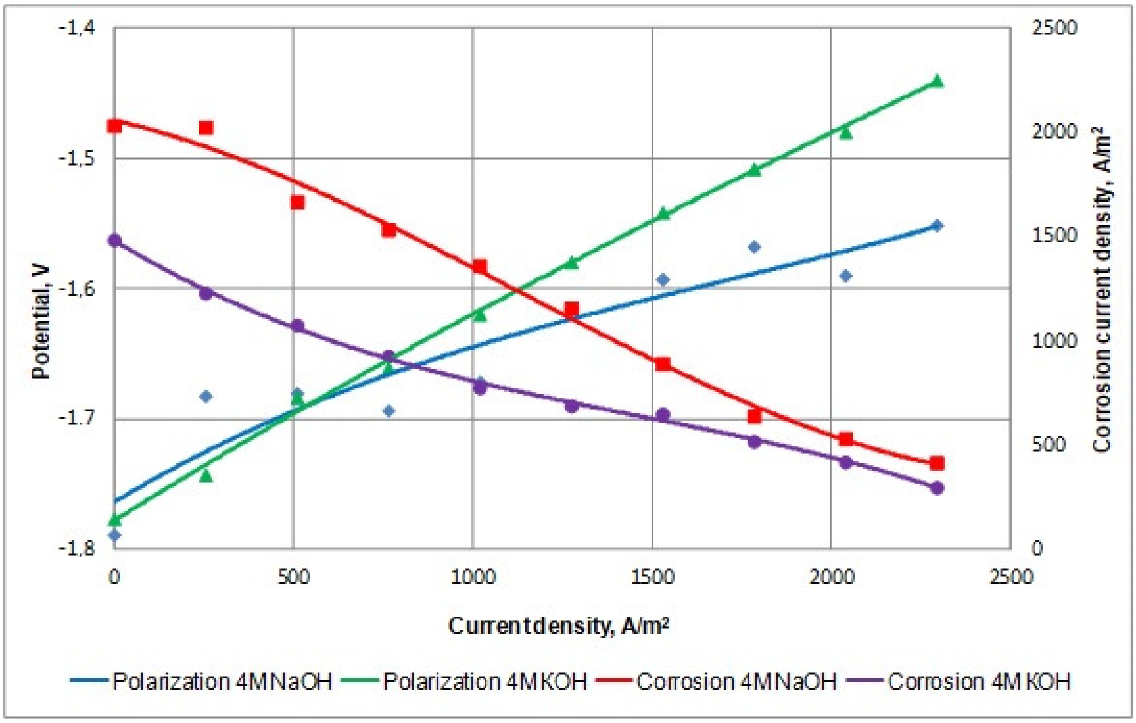

Figure 3. *V-A and corrosion characteristics of aluminum in 4M NaOH and 4M KOH at 333 K*

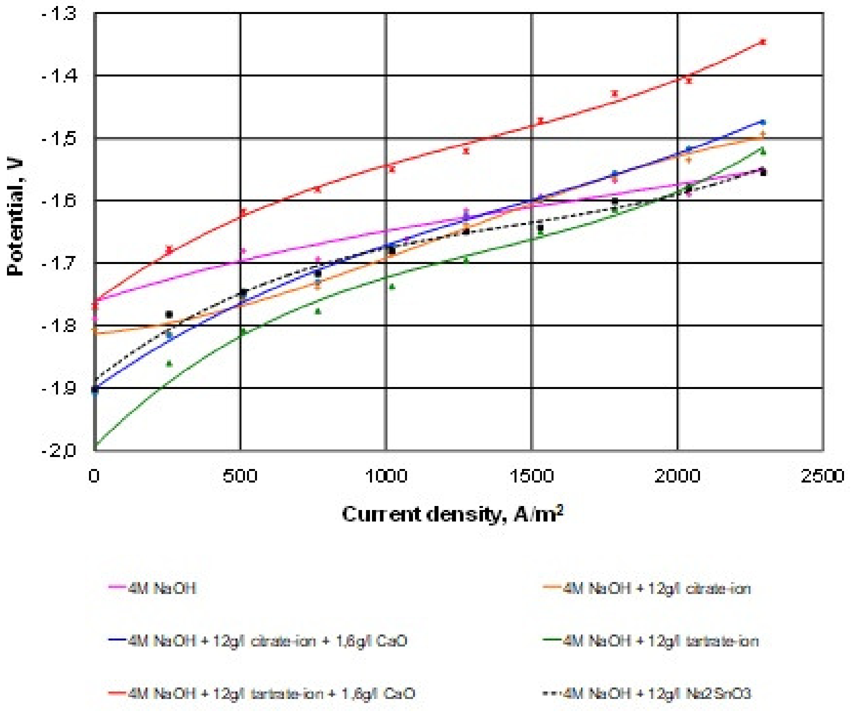

Figure 4. *V-A characteristic of the A995 anode in 4M NaOH with various type inhibitors added at 333 K*

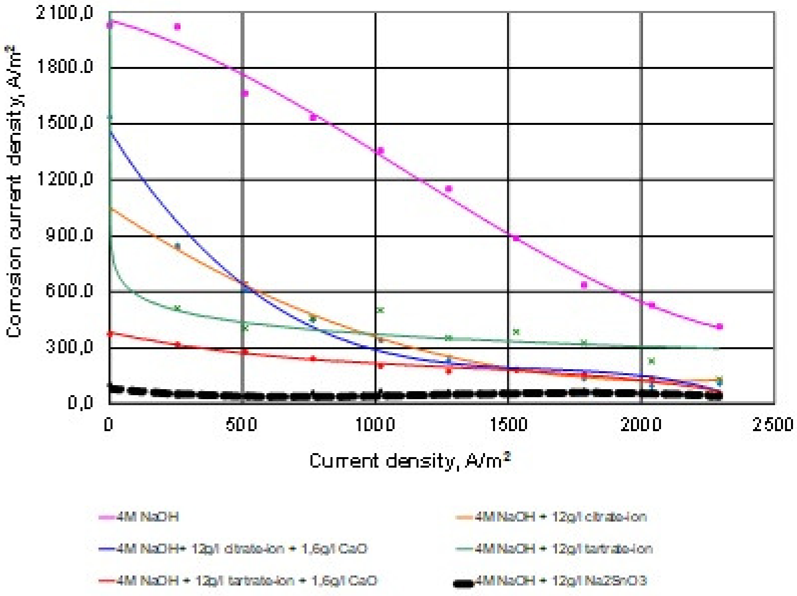

Figure 5. *Corrosion characteristics of the A995 anode in 4M NaOH with various type inhibitors added at 333 K*

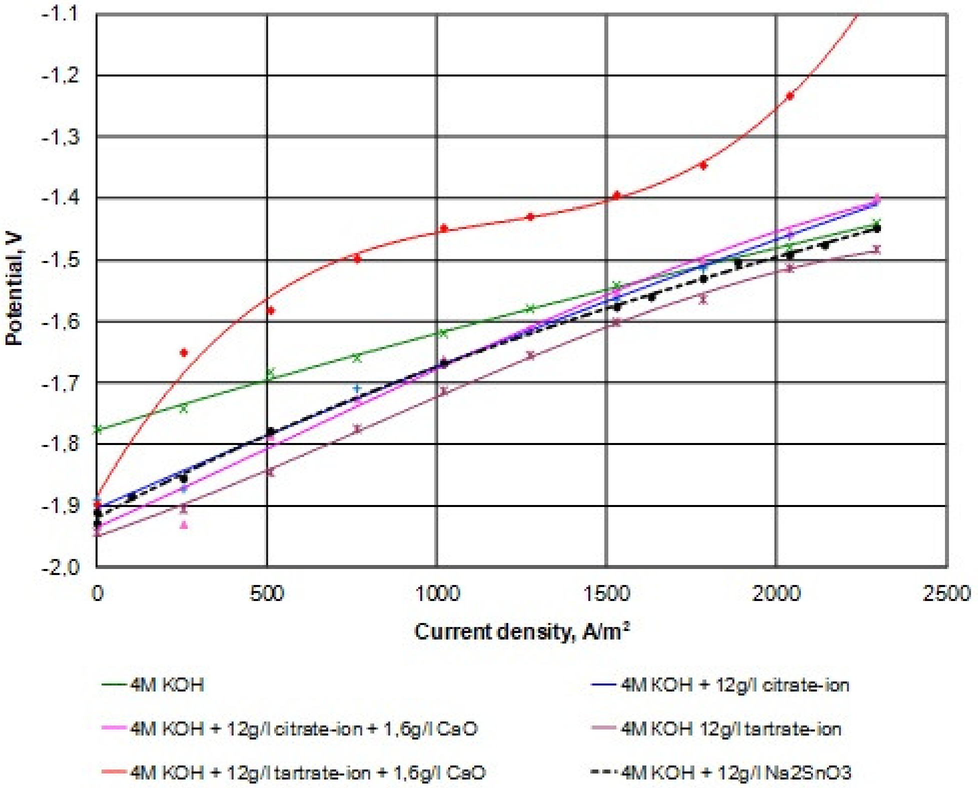

Figure 6. *V-A characteristic of A995 в 4M KOH anode with various type inhibitors added at 333K*

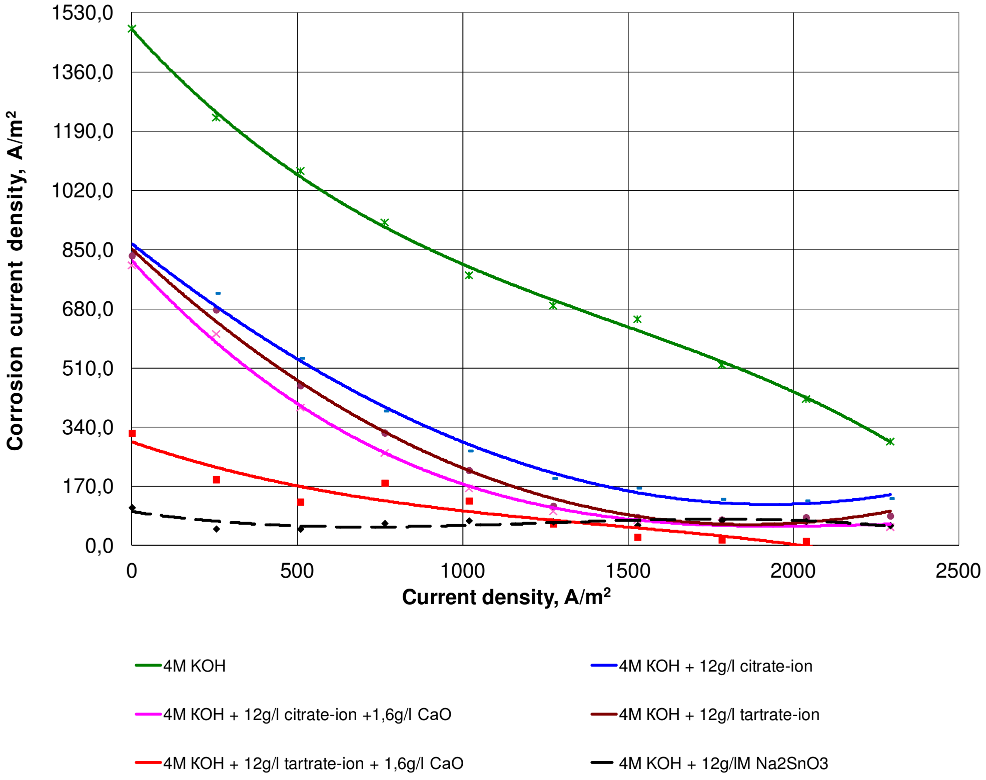

Figure 7. *Corrosion characteristic of the A995 anode in 4M KOH with various type inhibitors added at 333 K*

Table 1. *Estimation of hydrogen generation method by reactions between metals and water*

Reaction	Specific reagent consumption g/(mole hydrogen)
Reactions between metal hydrides and water	
$NaBH_4 + 2H_2O \rightarrow 4H_2 + NaBO_2$	18.45
$2\ LiH + 2\ H_2O \rightarrow 2\ LiOH + 2\ H_2\uparrow$	26
$MgH_2 + 2\ H_2O \rightarrow Mg(OH)_2\downarrow + 2\ H_2\uparrow$	31.15
$2\ AlH_3 + 6\ H_2O \rightarrow 2\ Al(OH)_3\downarrow + 6\ H_2\uparrow$	28
Reactions between metals and water	
$2\ Li + 2\ H_2O \rightarrow 2\ LiOH + H_2\uparrow$	50
$2\ Na + 2\ H_2O \rightarrow 2\ NaOH + H_2\uparrow$	82
$Mg + 2\ H_2O \rightarrow Mg(OH)_2\downarrow + H_2\uparrow$	60.3
$2\ Al + 6\ H_2O \rightarrow 2\ Al(OH)_3\downarrow + 3\ H_2\uparrow$	54

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