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## DISSOLUTION OF STAINLESS STEEL UNDER ALTERNATING CURRENT POLARIZATION

**Abstract.** The present work studies the dissolution of stainless steel electrode (12X18H10T) under alternating current polarization with frequency of 50 Hz in sulfuric acid solution. The impact of the current density (200-1200 A/m<sup>2</sup>) in a stainless steel electrode, the current density (20-120 kA/m<sup>2</sup>) in a titanium electrode, a concentration of sulfuric acid solution (0,25-1,5 M), an electrolysis duration (0,25-1,5 hours) and an alternating current frequency (50-250 Hz) on the electrical dissolution of an alloy based on iron-chromium were investigated. The preliminary studies have shown that alloys do not practically dissolve under the polarization of two stainless steel electrodes by the alternating current. And, when one of the stainless steel electrodes is replaced by a titanium wire, the alloy dissolves intensively with the formation of Fe<sup>2+</sup>, Fe<sup>3+</sup>, Cr<sup>3+</sup> and Cr<sup>6+</sup> ions. This can be explained by the valve property of the titanium electrode. Under the direct current polarization, the alloy dissolution at a very low current efficiency was observed (12.7% for general iron ions, 3.9% for general chromium ions). As the current density in the stainless steel electrode increased up to 400 A/m<sup>2</sup>, the dissolution rate of the alloy reached a maximum value (84% for general iron ions and 17% for general chromium ions). The optimum current density of the titanium electrode was detected; at a density of 60 kA/m<sup>2</sup>, 54% of the current efficiency is formed by iron ions while 15% by the total chromium ions. At a sulfuric acid concentration of 0.5 M, the stainless steel electrode dissolution showed the maximum value. It has been established that, as the duration of electrolysis and the frequency of alternating current increase, the current efficiency of the stainless steel electrode dissolution decreases.

**Key words:** stainless steel, alternating current, sulfuric acid, iron, chromium, electrolyte.

Stainless steel (SS) has become one of the most widely used materials in the engineering industry. This steel is used in the heavy and light industry since the beginning of the electronics industry [1]. The difference between SS and other raw materials is its long-term use with its corrosion resistance property. About 90% of the stainless steel is recycled in their last use. Even after ten years of their usage, stainless steel items do not lose their properties after undergoing corrosion. However, many methods used in SS production require complicated and special equipment and high-temperature processing [2,3]. It can be assumed that the rational use of electrochemical methods for the production of SS wastes can be the solution of these problems. The application of electrochemical method allows to process the alloy in a simple mode and to obtain its compounds.

Due to the structure, stainless steel is divided into martensite, martensite-ferrite and austenitic -ferrite. Martensite steel contains 12-17% chromium, 0.15% carbon and vanadium, tungsten, molybdenum and nickel in small quantities. Martenite steel has high viscosity, but it is quickly transferred from a viscous state to a fragile state at some temperatures. Martensite ferritic steel contains 13-18% chromium, 0.15% carbon and additional elements as titanium, nickel and silicon. Such steels do not corrode in the atmosphere and have a mechanical property in a weak acidic media. Austenitic ferrite steels are characterized by a high content of chromium (18-22%) and nickel (4-6%) and by their durability and corrosion resistance properties [4].

SS consists of other elements than carbon and iron that produce different strength properties. Such elements are called impurity elements. Steel containing chromium the mass fraction of which varies from 12% to 30% is specially designed for special aggressive environments. In various acidic media, the chromium shows passive properties and is also resistant to pitting corrosion. The main disadvantage of the steel containing chromium is its fragility. Nickel is added to stainless steel to eliminate such defects [5].

Although details on the physical and chemical properties of stainless steel are provided in literatures, its electrochemical properties have not been fully studied. Many studies are aimed at investigating the corrosion properties of SS [6-10]. I.M. Zamametdinov, a Russian scientist, studied the corrosion resistance of powder-like SS in the presence of sodium chloride and nitric acid electrolyte. Investigating the corrosion rate of powder-like alloy of various grades in nitric oxide, he defined the low corrosion quality of steel H17H2 [6]. In work [7], the electrochemical behaviour of type 321 SS was studied in sulfide ions containing chlorinated aqueous media with by drawing cyclic potentiodynamic curves. It was established, that the main factors influencing on the pitting corrosion of SS 321 are the concentrations of  $\text{Cl}^-$  ions, the pH solution and temperature. In the studies of K.V. Rybalka and others, electrochemical behaviour of SS was investigated by Electrochemical Impedance and Rotating Disc electrode method [8]. The corrosion current was estimated and the steel passivation mechanism in the given electrolyte was presented. In next study [9], the natural and induced passivation properties of duplex SS in alkaline media were considered. In work [10], the electrochemical equilibrium of type SS 12X18H10T was studied and indirect influence of titanium, chromium, magnesium and silicon on the chemical and electrochemical equilibrium of stainless steel was determined. Though the corrosion properties of stainless steel in aggressive environments have been described in detail, its dissolving processes by the electrochemical method have not been studied. However, electrochemical properties of iron and chromium as a separate element have been investigated [11-16]. In this regard, the investigation the electrochemical properties of stainless steel in an acidic media and development a rational method for its processing are of great importance.

In the present work, the electrochemical dissolution of the stainless steel electrode polarized by alternating current in sulfuric acidic media was studied. A 100 ml thermostatic glass electrolysis device was used to study the electrochemical dissolution of stainless steel electrodes. Our preliminary study results showed that by polarization of two SS electrodes with alternating current in the acidic media the alloy dissolved at a very low current efficiency (CE). The results of previous studies have shown the dissolution of two iron and two chromium electrodes with high current efficiency by their polarization with alternating current in sulfuric acidic solution [11-13]. When one of the stainless steel electrodes is replaced with a titanium wire, an intense dissolution of the alloy by forming  $\text{Fe}^{2+}$ ,  $\text{Fe}^{3+}$ ,  $\text{Cr}^{3+}$ ,  $\text{Cr}^{6+}$  ions was observed.

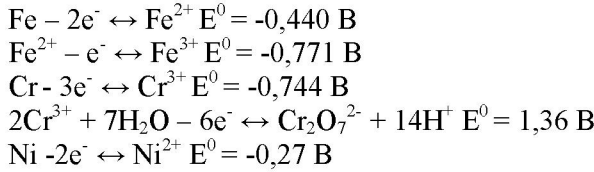
Stainless steel of austenite 12X18H10T was used as a working electrode for the study. Its elemental composition is shown in Table 1 below. This alloy mainly consists of iron (63,83%) and contains a large amount of chromium (18,79%) and a small amount of nickel (9,2%).

Table 1 - Elemental composition of stainless steel electrode

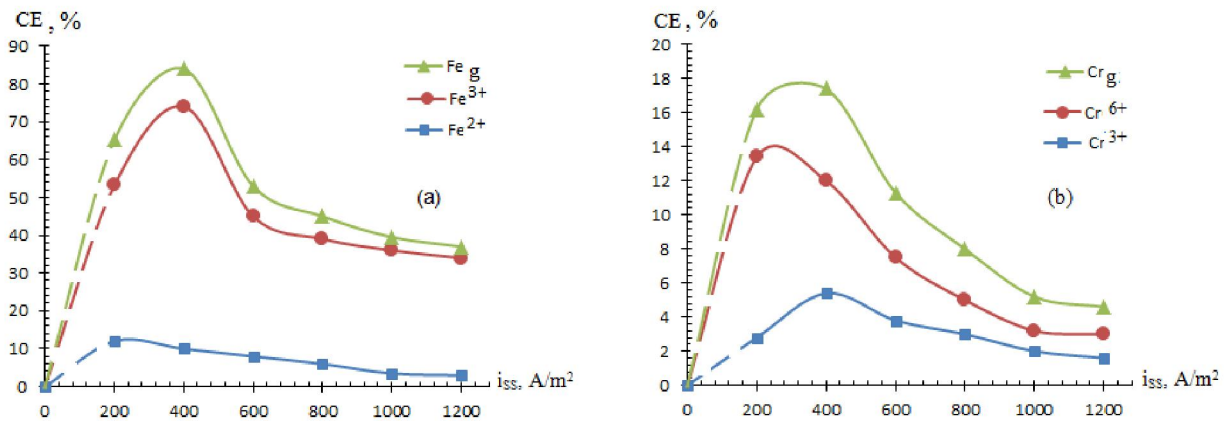
C	O	Al	Si	S	Ti	Cr	Mn	Fe	Ni	Cu
4,45	0,94	0,04	0,51	0,05	0,24	18,79	1,72	63,83	9,21	0,22

After the electrolysis,  $\text{Fe}^{2+}$  ions in the electrolyte composition was detected by the permanganometric titration, while  $\text{Fe}^{3+}$  ion by the complex ionometric titration [17]. A photometric method was used for the analysis of chromium (VI) and its total ions. To determine the chromium (III) ions, the total amount of chromium ions was determined by adding ammonium sulfate and silver nitrate to  $\text{Cr}^{3+}$  ions contained in the electrolyte and oxidizing it till  $\text{Cr}^{6+}$  ions. The mass of chromium (III) ions was calculated by removing the mass of chromium (VI) ions from the total mass of chromium ions [18]. Since the mass of nickel was very low in the alloy, its detection in the electrolyte composition was impossible. This is due to the positive value of its standard potentials relatively to iron and chromium.

The following reactions may take place in the anodic half-period by polarization stainless steel electrode by alternative current with a titanium electrode [19]:

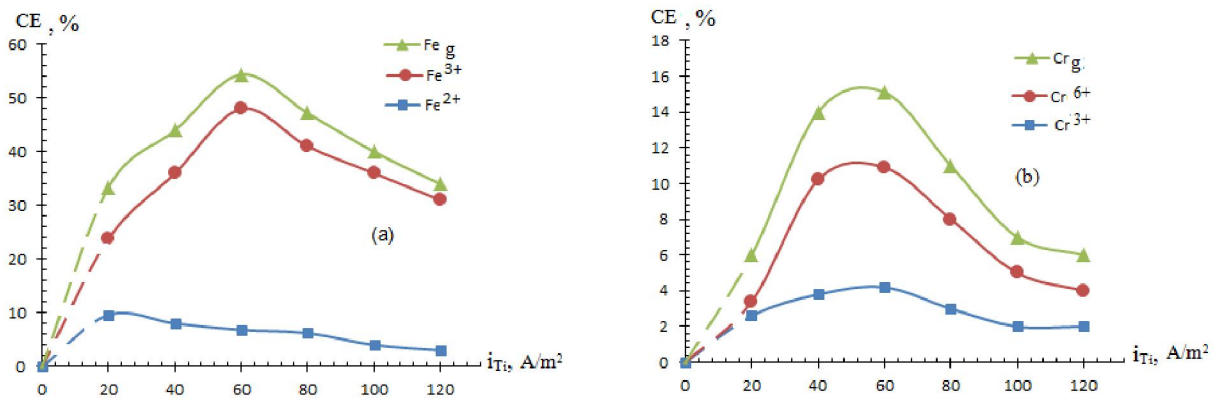


In the electrochemical dissolving process of the alloy on the basis of Fe-Cr in the acidic media, the effect of the current density in the steel electrode was investigated from 200 A/m<sup>2</sup> to 1200 A/m<sup>2</sup> (Figure 1). During the experimental work, when the value of the current density in the SS electrode was increased from 200 A/m<sup>2</sup> to 400 A/m<sup>2</sup>, the CE of the alloy dissolution increased from 65.2% to 84% for iron ions and 15% for total chromium ions. As the current density value was increased further, a decrease in the current efficiency was observed. This is due to the increase in the rate of additional reactions by increasing the current density.



$i_{\text{Ti}}=60 \text{ kA/m}^2$ ,  $[\text{H}_2\text{SO}_4]=0.5 \text{ M}$ ,  $t=0.5 \text{ h}$ ,  $v=50 \text{ Hz}$ ,  $t=20^0\text{C}$

Figure 1 - Effect of the current density in the stainless steel electrode on the current efficiency of the alloy dissolution: (a) is the iron ions, (b) is the chromium ions



$i_{\text{ss}}=400 \text{ kA/m}^2$ ,  $[\text{H}_2\text{SO}_4]=0.5\text{M}$ ,  $t=0.5 \text{ hour}$ ,  $v=50 \text{ Hz}$ ,  $t=20^0\text{C}$

Figure 2. Effect of the current density in the titanium electrode on the current efficiency of the stainless steel electrode dissolution: (a) is iron ions, (b) is chromium ions

The impact of the current density in the titanium electrode on the dissolution process of the stainless steel electrode is illustrated in Figure 2. An increase of the current density when increasing the current density value from 40 kA/m<sup>2</sup> to 60 kA/m<sup>2</sup> can be explained by the appearance of an oxide layer with "valve" properties on the titanium electrode surface in the anodic half-period [20]. A further increase of the current density in the titanium electrode has led to a reduction in the current efficiency of the steel

electrode dissolution since the surface structure of the oxide layer in the titanium electrode changes and becomes loose due to the increase in current density and its current correction properties reduce.

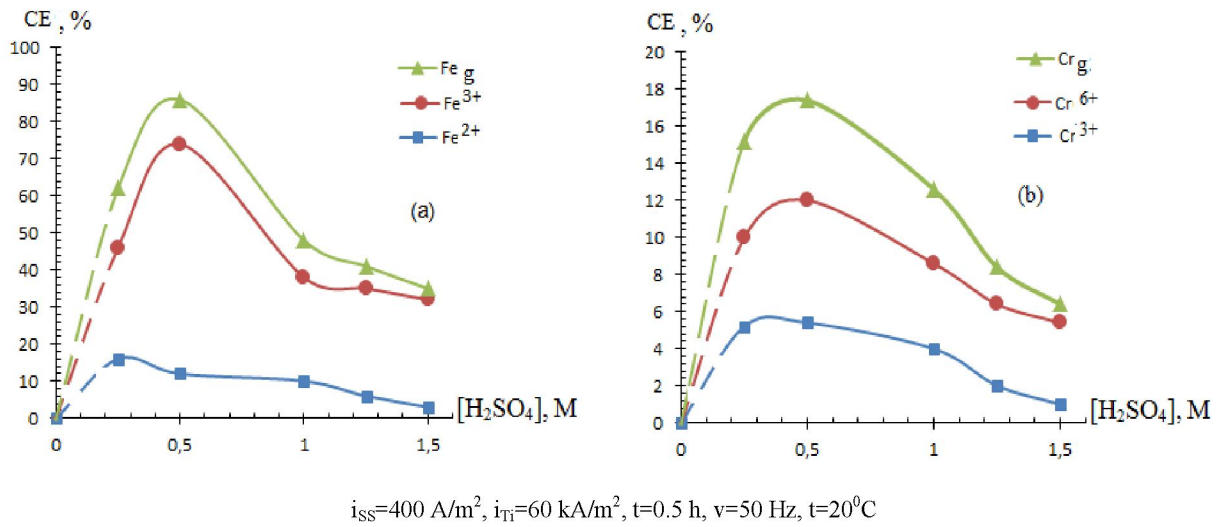


Figure 3 - Effect of the sulfuric acid concentration on the current efficiency of stainless steel electrode dissolution: (a) is iron ions, (b) is chromium ions

The effect of sulfuric acid concentration on the CE of the SS electrode dissolution polarized by the alternating current was studied from 0.5 to 1.5 M (Figure 3). According to the research results, the current efficiency of the stainless steel electrode dissolution increased to 0.5 M. Further, a decrease in the CE was observed when the acid concentration was increased. This can be explained by the fact that as electrolyte concentration increases, the ionic motion slow down, as the sulfate ions increase, the anode partial release of oxygen increases, and the SS electrode passivate.

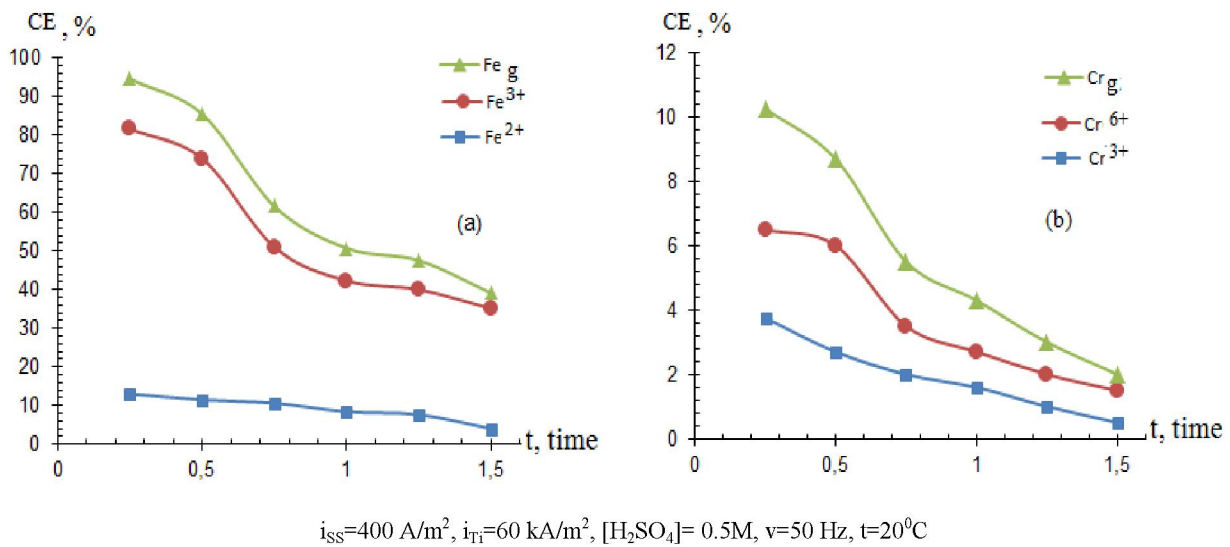
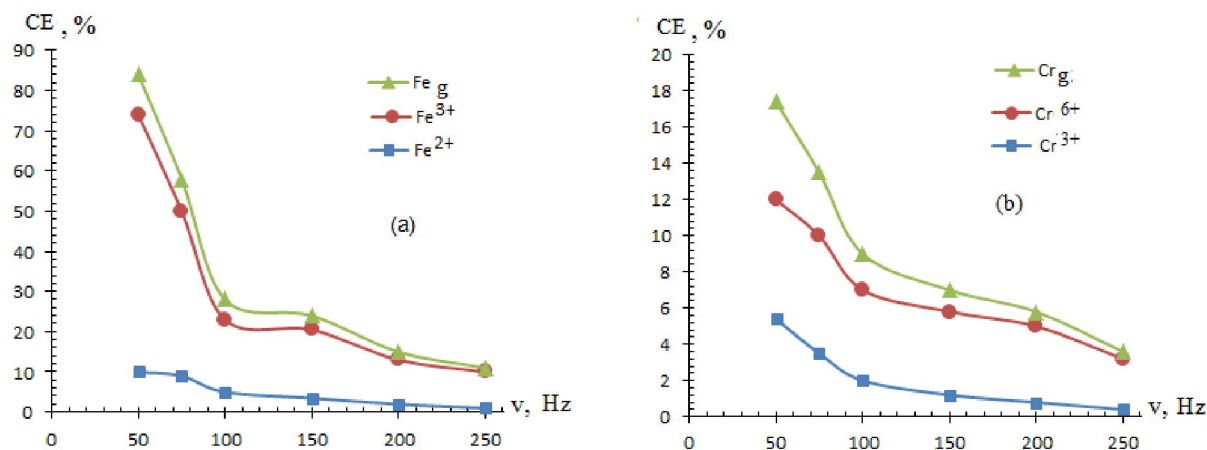


Figure 4 - Effect of the electrolysis duration on the current efficiency of stainless steel electrode dissolution: (a) is the iron ions, (b) is the chromium ions

The impact of electrolysis duration on the current efficiency of the stainless steel electrode dissolution is shown in Figure 4. The more the electrolysis duration increases, the more the current off of the steel electrode dissolution decreases. As the electrolysis duration increased, a gradual passivation of electrodes with iron and chromium products with poorly soluble electrolysis products was observed.



$i_{ss}=400 \text{ A/m}^2$ ,  $i_{Ti}=60 \text{ kA/m}^2$ ,  $[\text{H}_2\text{SO}_4]=0.5\text{M}$ ,  $t=0.5 \text{ hour}$ ,  $t=20^\circ\text{C}$

Figure 5 - Effect of alternating current frequencies on the current flow of the stainless steel electrode dissolution: (a) is the iron ions, (b) is the chromium ions.

A decrease in the chromium ions formation and in the CE of stainless steel electrode dissolution due to the increase in the alternating current frequency can be seen in Figure 5. This can be explained by the incapability of alloy to provide the time required for direct oxidation of iron and chromium ions since the periods rapidly change in high current frequencies.

Thus, the effects of the basic electrochemical parameters on the stainless steel electrode dissolution polarized by the alternating current with the frequency of 50 Hz in the sulfuric acidic media were studied and the iron and chromium ions dissolution with high CE was detected. As a result, the effective conditions of the alloy dissolution were established:  $i_{Ti} = 60 \text{ kA/m}^2$ ,  $i_s = 400 \text{ A/m}^2$ ,  $[\text{H}_2\text{SO}_4] = 0.5 \text{ M}$ ,  $t = 20^\circ\text{C}$ ,  $v = 50 \text{ Hz}$ . The fact that the CE of the formation of iron (II), iron (III) and chromium (III), chromium (IV) ions in the sulfuric acid solution was 10%, 74% and 5.4%, 12% respectively under these effective conditions was shown for the first time.

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### АЙНЫМАЛЫ ТОКПЕН ПОЛЯРИЗАЦИЯЛАНҒАН ТОТ БАСПАЙТЫН БОЛАТТЫҢ ЕРУІ

**Аннотация.** Ұсынылған жұмыста күкірт қышқылы ерітіндісінде жиілігі 50 Гц айнымалы токпен поляризацияланған тот баспайтын болат (12X18H10T) электродының еруі зерттелінді. Темір-хром негізіндегі құйманың электрохимиялық еруінің ток бойынша шығымына тот баспайтын болат электродындағы ток тығыздығының (200-1200 А/м<sup>2</sup>), титан электродындағы ток тығыздығының (20-120 кА/м<sup>2</sup>), күкірт қышқылы ерітіндісі концентрациясының (0,25-1,5 М), электролиз ұзақтығының (0,25-1,5 сағ) және айнымалы ток жиілігінің (50-250 Гц) әсерлері зерттелді. Алдын-ала зерттеу жұмыстары айнымалы токпен поляризацияланған екі тот баспайтын болат электродтарының нашар еритіндігін көрсетті. Ал, тот баспайтын болат электродының бірін титан сыммен алмастырғанда, құйманың Fe<sup>2+</sup>, Fe<sup>3+</sup>, Cr<sup>3+</sup>, Cr<sup>6+</sup> иондарын түзе қарқынды еритіндігі анықталды. Мұны титан электродының вентильдік қасиет көрсетуімен түсіндіруге болады. Тұрақты токпен поляризацияланғанда құйманың анағұрлым төмен ТШ еритіндігі байқалды (жалпы темір иондары үшін 12,7%, жалпы хром иондары үшін 3,9%). Айнымалы токпен поляризацияланған тот баспайтын болат электродындағы ток тығыздығын 400 А/м<sup>2</sup> дейін жоғарылатқанда құйманың еруінің ток бойынша шығымы максималды мәнді көрсетті (жалпы темір иондары үшін 84%, ал жалпы хром иондары үшін 17%). Титан электродындағы ток тығыздығының оңтайлы жағдайы анықталып, 60 кА/м<sup>2</sup> ток тығыздығында темір иондарының түзілуінің ТШ 54%, ал жалпы хром иондары бойынша 15% құрады. Тот баспайтын болат электродының еруінің ток бойынша шығымы күкірт қышқылының концентрациясы 0,5 М кезінде максималды мәнді көрсетті. Электролиз ұзақтығының және айнымалы ток

жилігінің әсерінен тот баспайтын болат электродының еруінің ток бойынша шығымы төмендейтіндігі анықталды.

**Түйін сөздер:** тот баспайтын болат, айнымалы ток, күкірт қышқылы, темір, хром, электролит.

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### **РАСТВОРЕНИЕ НЕРЖАВЕЮЩЕЙ СТАЛИ ПРИ ПОЛЯРИЗАЦИИ ПЕРЕМЕННЫМ ТОКОМ**

**Аннотация.** В данной работе исследовано растворение нержавеющей стальной (12X18H10T) электрода при поляризации переменным током с частотой 50 Гц в растворе серной кислоты. Исследовано влияние плотности тока на нержавеющей стальном электроде (200-1200 А/м<sup>2</sup>), плотности тока на титановом электроде (20-120 кА/м<sup>2</sup>), концентрации серной кислоты (0,25-1,5 М), продолжительности электролиза (0,25-1,5 часа) и частоты переменного тока (50-250 Гц) на электрорастворение сплава на основе железо-хром. Предварительные исследования показали, что при поляризации двух электродов из нержавеющей стали переменным током сплавы практически не растворяются. А при замене одного из электродов из нержавеющей стали на титановую проволоку сплав интенсивно растворяется с образованием ионов Fe<sup>2+</sup>, Fe<sup>3+</sup>, Cr<sup>3+</sup>, Cr<sup>6+</sup>. Это можно объяснить вентильным свойством титанового электрода. При поляризации постоянным током наблюдалась более низкая ВТ растворения сплава (12,7% для ионов общего железа, 3,9% для ионов общего хрома). При увеличении плотности тока на электроде из нержавеющей стали до 400 А/м<sup>2</sup>, скорость растворения сплава достигла максимальное значение (84% для ионов общего железа и 17% для ионов общего хрома). Оптимальная плотность тока титанового электрода установлена при плотности 60 кА/м<sup>2</sup> с ВТ 54% образования ионов общего железа и 15% ионов общего хрома. При концентрации серной кислоты 0,5 М ВТ растворения нержавеющей стальной электрода показал максимальное значение. Установлено, что при увеличении продолжительности электролиза и частоты переменного тока ВТ растворения электрода из нержавеющей стали уменьшается.

**Ключевые слова:** нержавеющая сталь, переменный ток, серная кислота, железо, хром, электролит.