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Review Article

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Electrochemical dissolution of titanium under alternating current polarization to obtain its dioxide

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Abstract: The titanium electrode was polarized under the influence of alternating current (AC) at 50 Hz. The current density was varied between 100 and 5,000 A m^{-2}. Initially, the titanium electrode oxidized, and then, titanium oxides were reduced during the cathodic half-cycle of the AC. When the cathodic half-cycle changes to the anodic half-cycle, titanium is oxidized to the trivalent state: $Ti - 3\bar{e} \rightarrow Ti^{3+}$. The direction of the AC changes depending on its frequency, causing the processes occurring on the electrodes to be periodically repeated. The current efficiency of the titanium electrode dissolution depends on the sulfuric acid concentration and electrolyte concentration, reaching up to 63.4% under optimal conditions. Bipolar electrodes were used during AC electrolysis. It was found that the decrease in the mass of titanium electrodes increases almost linearly at first, from 400 to 1,600 A m^{-2}, and then more intensively within the current densities from 1,800 to 2,500 A m^{-2}. It was shown that when using a bipolar electrode, the total mass loss of the electrodes is 1.38 times greater than the total mass loss during polarization without a bipolar electrode. The composition of the titanium dioxide obtained as a result of electrolysis was identified using physico-chemical analysis methods.

Keywords: titanium, electrode, alternating current, polarization, sulfuric acid, titanium dioxide

1 Introduction

Titanium compounds are extensively utilized across various industries and engineering fields. Titanium dioxide, in particular, is frequently employed and is in high demand in the production of paper [1], as well as in the pharmaceutical [2,3], cosmetic [4,5], and textile industries [1,6].

Titanium dioxide nanoparticles are utilized in solar cells [7–11] and exhibit antibacterial activity [12].

The significant consumer demand for titanium for titanium dioxide necessitates that the methods for synthesizing this compound are both straightforward and cost-effective.

In industry, titanium dioxide is derived from natural raw materials, primarily ilmenite. The conventional for extracting titanium dioxide from ilmenite is intricate and involves multiple stages, consisting of various processes [13].

Since the objective of our research is the dissolution of metallic titanium, we will briefly address the challenges associated with this process.

Titanium metal, derived from titanium dioxide, is extensively utilized in various technological and industrial sectors due to its distinctive properties [14]. Furthermore, titanium plays a pivotal role in the production of numerous alloys [15,16]. Consequently, substantial quantities of titanium waste are generated in the form of shavings, rods, scrap, or pieces, which are customarily processed through remelting. However, this method only facilitates the recycling of 20–40% of the waste. Berkov et al. [17] propose a pre-treatment of the waste at room temperature using an aqueous solution comprising 5–16% sodium fluoride and 12–20% hydrochloric acid prior to remelting. While this approach potentially enhances processing, it introduces an additional step to the main operation, thereby increasing the complexity of the process.

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Despite the existence of several methods for processing titanium metal waste, a substantial proportion remains unrecycled. Currently, only less than 20% of titanium secondary resources can be recycled [18]. Given these circumstances, we deem it appropriate to explore the potential implementation of electrochemical methods for titanium waste processing. Electrochemical methods are grounded in the principles of standard electrode potentials.

We note that values of the standard potentials are considerably more negative than the standard potential of the hydrogen electrode, rendering titanium highly unstable from a thermodynamic perspective. Theoretically, titanium should displace hydrogen ions from water and dissolve in aqueous media. However, this phenomenon does not occur in practice. Titanium does not dissolve under anodic polarization even in solutions containing chloride ions [19–21]. It is resistant to both mineral acids in cold conditions and hot aqueous alkali solutions. The presence of oxide films on titanium surfaces [22,23] precludes its dissolution by chemical and electrochemical methods in aqueous solutions and synthesis of its compounds. Alternative approaches must be employed to facilitate the dissolution process of titanium.

The objective of our research is to develop an electrochemical method for the synthesis of titanium dioxide. In this study, we investigated for the first time the method of dissolving titanium and producing titanium dioxide through alternating current (AC) electrolysis using bipolar electrodes.

To meet this objective, we investigated the behavior of titanium under electrolysis with AC polarization at a frequency of 50 Hz, employing bipolar electrodes. We note that electrolysis with AC has several advantages. During electrolysis at an AC frequency of 50 Hz, the current direction reverses 50 times per second. The polarized electrode alternates between being a cathode and an anode; the cathode half-cycle is followed by the anode half-cycle, and vice versa. During the cathode half-cycle, the oxide film on the electrode is reduced. This is quickly followed by the anode half-cycle, during which metal dissolution occurs. This cyclical repetition prevents the production of a passivating oxide film. Moreover, these processes occur at room temperature, eliminating the need to heat the solution. The electrolysis process is simplified as it eliminates the need for rectifiers, with mains electricity supplied to the electrolyzer through a laboratory autotransformer, which also regulates the voltage. This results in time efficiency. It has been previously noted that titanium typically undergoes passivation in various mineral acids, including sulfuric acid. Sulfuric acid, however, is a cost-effective electrolyte commonly used in industrial processes. Consequently, our experiments focused on the polarization of titanium in sulfuric acid under the influence of industrial frequency AC. Our findings indicate that titanium dissolution occurs in sulfuric acid under the influence of AC frequency, meaning titanium passivation does not take place. Thus, we selected sulfuric acid as the electrolyte for our experiments, although the potential application of other mineral acids is not excluded.

Experiments were conducted using VT1-0 grade titanium, which is classified as technical titanium and does not contain alloying elements. The titanium content is notably high, ranging from 99.2 to 99.7%, with the remaining composition including iron, carbon, silicon, oxygen, and hydrogen. It is important to note that many products in Russia and Kazakhstan are manufactured from VT1-0 grade titanium. Therefore, we assume that the metallic waste generated during the production of these products, as well as the waste formed at the end of their life cycle, have a chemical composition consistent with VT1-0 grade titanium. Consequently, the impact of impurities on the electrolysis process was not studied. Our objective was to demonstrate the behavior of titanium during electrolysis under AC. Even if minor impurities of iron, carbon, silicon, or hydrogen are present in the resulting titanium dioxide, their quantities would be minimal (within the range of 0.8–0.3%) and would not significantly influence the operational properties of the product. If required, the resulting titanium dioxide can be purified to remove these impurities; however, this was not within the scope of our current study.

2 Materials and methods

Cyclic voltammograms (CVs) were obtained on an electrochemical workstation CS 120 Potentiostat (CorrTest Instruments, China) in a thermostatically controlled three-electrode cell (Model 663VA stand, Metrohm, Herisau, Switzerland) with separated electrode compartments. Data recording was carried out using the CS Studio5 program installed on an IdeaPad 5 laptop (manufactured in Slovakia for Lenovo, China). A titanium electrode (Ti, 99.70%, LD Didactic GmbH) served as the working electrode, and platinum wire was used as the auxiliary electrode. Before experiments, the electrodes were thoroughly cleaned with Matrix 1000 sanding paper followed by Mirka Finland 2000, degreased with alcohol, rinsed with distilled water, and polished with dense filter paper. A silver chloride electrode was used as the reference electrode.

CV measurements were carried out in the potential range from −1.0 to 2.5 V (in 1 M H_2SO_4) and from −0.5 to 2.0 V (in 5 M H_2SO_4), starting from 0 V. The potential was changed in the positive direction (anodic polarization) until reaching 2.0 or 2.5 V, and after changing the direction of polarization (cathodic polarization), the potential was decreased to reach the potential limit of −0.5 or −1.0 V. At that moment, the direction of polarization changed again. Scanning in the opposite direction to the cathodic–anodic polarization was also performed. The scan rate in our experiments was 100 mV s^{-1}.

The electrolysis was performed in a glass electrolyzer in aqueous solutions of H_2SO_4 (chemically pure, Sigma Tech LLC) using two titanium electrodes with the same surface area. Polarization was carried out by AC with an industrial frequency of 50 Hz. The current source was a TDGC29-2KVA laboratory autotransformer (Matrics Technology Inc), and the current value was measured with an ammeter E 538 (Etalon Instrument LLC). The titanium dissolution current efficiency at each electrode was calculated for the anodic half-cycle of the AC, taking into account the three-electron process (since titanium dissolves to produce trivalent ions). Additionally, electrolysis was carried out using bipolar titanium electrodes in an installation, the schematic diagram of which is shown in Figure 1. The setup consists of an electrolyzer (1), an electrolyte (2), a current source (3), two extreme monopolar electrodes (4^1, 4^3), one bipolar titanium electrode (4^2), and an ammeter (5). After electrolysis, the mass loss of the electrodes was determined by weighing them three times.

The influence of current density, electrolyte concentration, and temperature on the dissolution process (evaluated by mass loss of electrodes) of titanium electrodes was investigated. Electrolysis resulted in the production of a titanium (III) sulfate solution. Post-electrolysis, NH_4OH (analytical grade, JSC Kupavna-reactive, Russia) was added to this solution to precipitate titanium(III) hydroxide, which was subsequently settled and separated by filtration using a Buchner funnel. The precipitate was washed with hot water until the absence of ammonium and sulfate ions was determined, dried, and then calcined in a muffle furnace (SNOL 7.2/1100, Pagaminta Lietuvoje, Lithuania) at temperatures of 600–700°C.

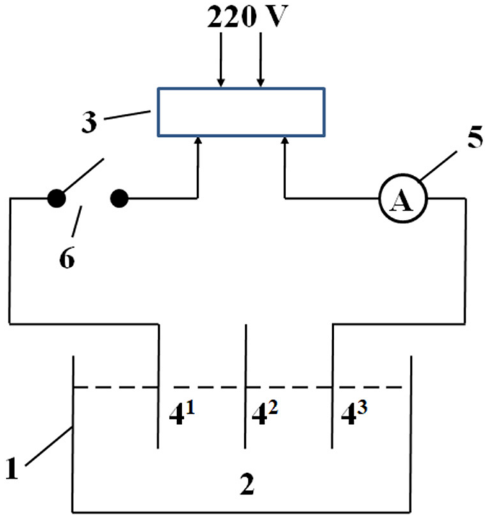


Figure 1: Schematic diagram of the installation for the dissolution of titanium electrodes with AC polarization, where 1 – electrolyzer, 2 – electrolyte, 3 – autotransformer, 4 – electrode, 5 – ammeter, and 6 – key.

The resulting precipitate was characterized by X-ray phase analysis using X-ray phase analysis using DRON-4-07 diffractometer (IC “Bourevestnik” JSC, Russia). Elemental analysis was performed with energy-dispersive X-ray fluorescence spectroscopy using an INCA Energy 450 system integrated with a scanning electron microscope (JSM-6610 LV, JEOL, Japan). The determination error for the elemental analysis is 0.01%.

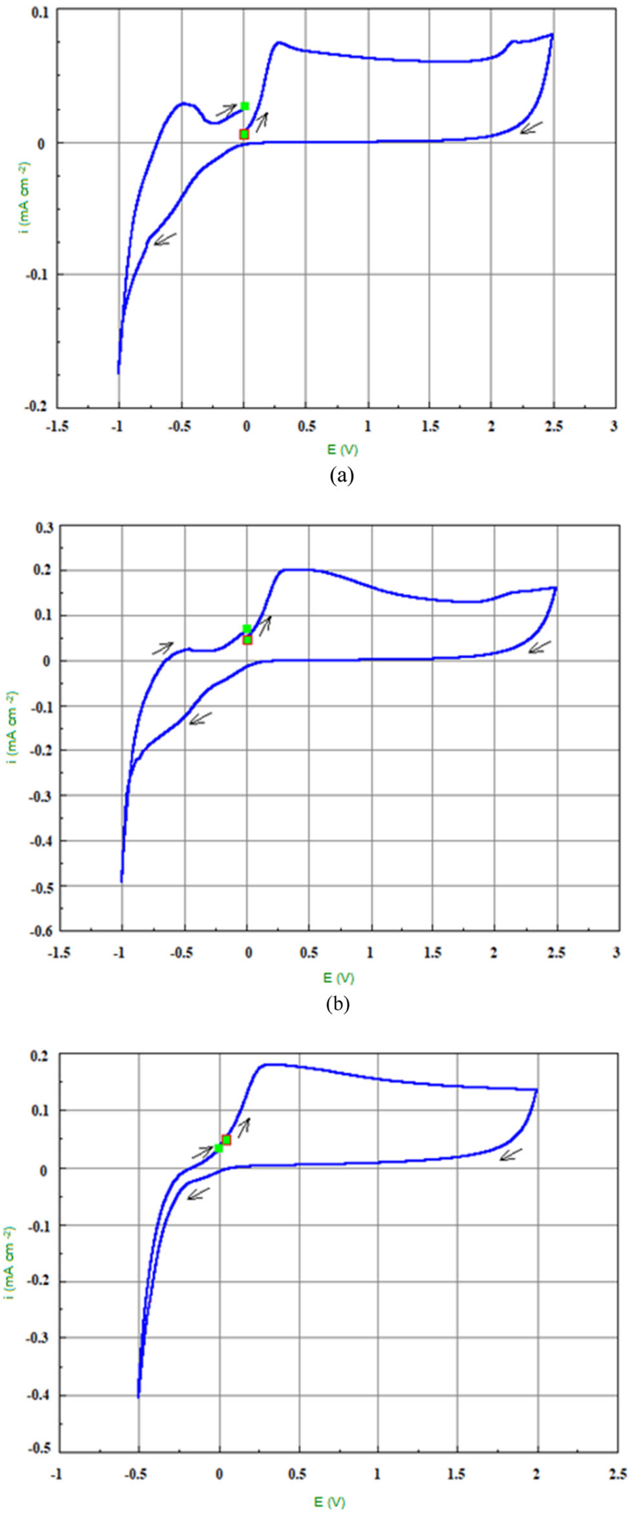
3 Results and discussion

The objective of our research is to investigate the dissolution process of titanium under the influence of AC and to produce its salt solutions, followed by the precipitation of titanium dioxide. In this regard, we initially decided to record CVs, which to some extent can simulate the processes occurring during AC electrolysis.

Figure 2 illustrates the CVs for titanium electrodes obtained in 1 and 5 M H_2SO_4 solutions. Upon anodic polarization, the potential is increased from 0 V to +2.5 V, revealing a discernible peak at approximately 0.3 V in the CV for the titanium electrode in 1 M H_2SO_4 at 25°C (Figure 2a). This peak is indicative of titanium oxidation and subsequent oxide film production, followed by titanium dissolution within the potential range of 0.3–2.5 V, occurring at a notably low rate in a transpassive state.

Conversely, the behavior of the titanium electrode in 1 M H_2SO_4 at an elevated temperature of 55°C exhibits minor variances (Figure 2b). Here, titanium dissolution initiates at 0.0 V, with transpassive dissolution spanning the potential range of 0.25–2.5 V (Figure 2b).

The CV measurements of the titanium electrode in 5 M sulfuric acid were executed within a narrower potential range from −0.5 to 2 V (Figure 2c), due to the substantially larger (more noticeable) peak current observed at higher electrolyte concentrations. Oxidation commences at −0.07 V, and the transpassive dissolution of the electrode can prolong significantly. Therefore, it is prudent to cease anodic oxidation and reverse the polarization direction. The fact is that in higher concentration sulfuric acid solution (5 mol l^{-1}), titanium oxidizes more vigorously during anodic polarization, and dissolution can proceed through the oxide film. However,



(a)

(b)

(c)

Figure 2: Cyclic anodic–cathodic voltammogram of titanium electrode: (a) $T = 25°C$, $V = 100\ mV\ s^{-1}$, 1 M H_2SO_4; (b) $T = 55°C$, $V = 100\ mV\ s^{-1}$, 1 M H_2SO_4; and (c) $T = 25°C$, $V = 100\ mV\ s^{-1}$, 5 M H_2SO_4.

continued anodic polarization results in increasing oxide film thickness, thwarting the desired objective. Upon reversing the current direction from anodic to cathodic, the oxide films are reduced, rendering the titanium surface active again. Subsequently, when the potential shifts toward negative values (cathodic polarization), minor waves can be observed on the voltammograms within the potential range of 0.02 to −1 V (Figure 2a and b) and 0 to −0.5 V (Figure 2c). These waves are associated with the reduction of titanium oxides as per reaction (4) and subsequent hydrogen release. We hypothesize that the reduction of titanium dioxide occurs; however, we cannot rule out its presence even after cathodic polarization. Nevertheless, the persistent presence of titanium dioxide impedes the reduction of titanium or hydrogen on its surface. In this instance, we are referring to direct current polarization, in which the passivation of titanium is unavoidable. The waves and peaks on the polarization curves indicate only partial modifications to the titanium surface, and thus, we cannot assert a complete reduction of the dioxide. Following the process of hydrogen release, the current direction changes once again, leading to anodic polarization. A peak corresponding to the oxidation of titanium hydrides (TiH_2) by reaction (2) is observed. In 5 M H_2SO_4, this peak becomes barely noticeable.

$$TiO_2 + 4H^+ + 4e^- \rightarrow Ti + 2H_2O, \tag{1}$$

$$TiH_2 \rightarrow Ti^{3+} + H_2 + 3e. \tag{2}$$

The production of TiH_2 on the titanium surface during cathodic polarization was also noted by Videm et al. [22]. In all cases, during anodic polarization, gas release, such as oxygen, is not observed.

From a comparison of the curves shown in Figure 2, it can be seen that an increase in the temperature of the solution and the concentration of sulfuric acid increases the height of the titanium oxidation peak. As shown in Figure 2a and c, the cathodic current density recorded for a titanium electrode in 5 M H_2SO_4 is significantly higher than that recorded for a titanium electrode in 1 M H_2SO_4.

Figure 3 presents a voltammogram recorded for the titanium electrode in 1 M H_2SO_4 during cathodic–anodic polarization. As seen in Figure 3 in the range of potentials 0 to −0.85 V, there is a slight reduction in the evolution of oxides and the release of hydrogen. When the direction of the current is reversed, the hydrides are oxidized (in the range of −0.07 to 0.0 V), and the oxidation of titanium begins at 0.0 V. This is followed by its transpassive dissolution. It is noticeable that the titanium oxidation potential shifts negatively by about 0.3 V. On this basis, it can be

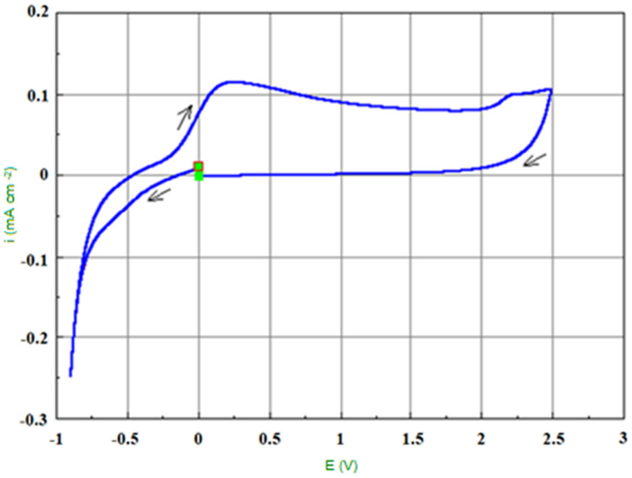


Figure 3: Cathodic–anodic voltammogram of titanium electrode recorded in 1 M H_2SO_4, V = 100 mV s^{-1}, T = 25°C.

concluded that polarization in the cathodic–anodic direction to a certain extent contributes to the preparation of the electrode surface, promoting its purification from oxides. After such treatment, titanium can dissolve more intensively during anodic polarization.

The scheme of the AC action can be represented as follows: in the cathodic half-cycle of AC on the titanium electrode, oxides are reduced (reaction (1)), and hydrogen is released (reaction (3)).

$$2H^+ + 2\bar{e} \rightarrow H_2. \qquad (3)$$

Further, almost instantly, the cathodic half-cycle is replaced by the anodic half-cycle, i.e., titanium becomes an anode, and is oxidized to the trivalent state (reaction (4)).

$$Ti - 3\bar{e} \rightarrow Ti^{3+} \quad E^o = -1.23V. \qquad (4)$$

In our opinion, an active effect on the titanium electrode surface can be carried out by conducting electrolysis under the action of AC. In this process, titanium dissolves according to the earlier described scheme. The results of electrolysis indicate that with an increase in the sulfuric acid concentration and the electrolyte temperature, the dissolution current efficiency of the titanium electrode rises (Tables 1 and 2).

Table 1: Dependence of the titanium dissolution current efficiency on the concentration of sulfuric acid at i = 700 A m^{-2}, τ = 0.5 h, T = 25°C

H_2SO_4 concentration, mol l^{-1}	1	2	3	4	5	6
Current efficiency, %	15.2	25.3	27.0	39.5	51.0	63.4

Table 2: Dependence of the titanium dissolution current efficiency on the electrolyte temperature in 3 M H_2SO_4, at i = 700 A m^{-2} and τ = 0.5 h

T (°C)	30	40	50	60	70	80
Current efficiency (%)	28.3	33.6	40.4	49.1	50.3	50.5

The subsequent part of the experiments focuses on electrolysis under the influence of AC of industrial frequency using bipolar electrodes. It is demonstrated for the first time that when titanium bipolar electrodes are polarized by AC, titanium dissolves according to reaction (4) in the anodic half-cycle. The progression of reaction (4), which involves the dissolution of titanium is visually noticeable as the solution turns purple, indicating the presence of titanium(III) ions. After electrolysis, titanium electrodes were weighed to determine the mass loss. Interestingly, a decrease in mass was also observed in electrodes that were not connected to a current source.

We explored the effect of current density on the mass loss of titanium electrodes. Table 3 illustrates that the decrease in the mass of monopolar and bipolar electrodes initially increases almost linearly (from 400 to 1,600 A m^{-2}), and then more intensively within the current densities from 1,800 to 2,500 A m^{-2}. Figure 4 graphically depicts the total mass loss of titanium electrodes when using a bipolar electrode compared to without a bipolar electrode. Calculations indicate that using a bipolar electrode results in a total mass loss of nearly 1.38 times greater than during polarization without a bipolar electrode. The mass loss was determined by weighing the electrodes on analytical scales at least three times, with a weighing error of no

Table 3: Dependence of the mass loss of titanium electrodes during AC polarization in sulfuric acid solutions on the current density: (a) using a bipolar titanium electrode: m_1, m_3 – mass loss of two extreme titanium electrodes; m_2 – mass loss of the bipolar electrode located in the middle; Δm – total mass loss during electrolysis with three electrodes; (b) without a bipolar electrode: m_1, m_2 – mass loss of two titanium electrodes; Δm – total mass loss of electrodes in electrolysis with two electrodes. C(H_2SO_4) = 150 g l^{-1}; τ = 1 h

Mass loss (g)	Current density (A m^{-2})					
	400	800	1,200	1,600	1,800	2,500
(a)						
m_1	0.0292	0.0726	0.1185	0.1694	0.175	0.4687
m_2	0.0172	0.0496	0.0846	0.1292	0.1464	0.2692
m_3	0.0306	0.0733	0.1258	0.1713	0.1733	0.4675
Δm	0.0770	0.1955	0.3289	0.4699	0.4947	1.2054
(b)						
m_1	0.0281	0.0724	0.1265	0.1698	0.1809	0.4474
m_2	0.0276	0.0735	0.1219	0.1694	0.1793	0.4457
Δm	0.0557	0.1459	0.2484	0.3392	0.3602	0.8931

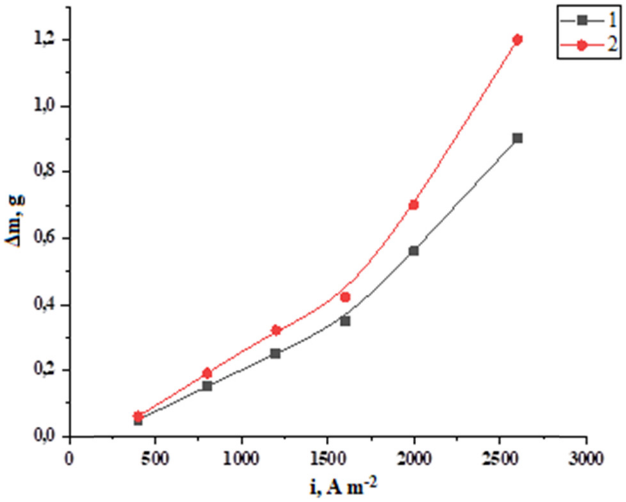


Figure 4: The dependence of the total mass loss (Δ*m*) of the electrodes during the polarization of titanium electrodes by AC of industrial frequency at $C(H_2SO_4)$ = 150 g l^{-1}; τ = 1 h; *T* = 25°C, where: 1 – electrolysis with two titanium electrodes; 2 – electrolysis with three titanium electrodes.

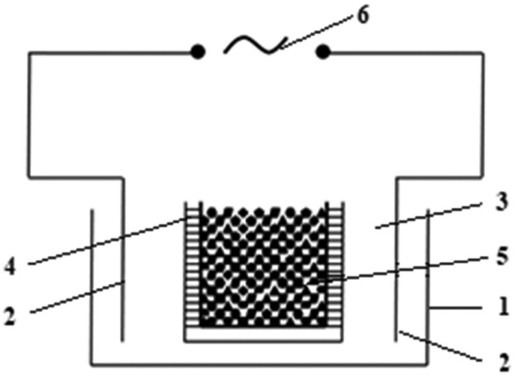


Figure 5: Electrolyzer with lump (titanium) bipolar electrodes: 1 – electrolyzer; 2 – extreme titanium electrodes; 3 – electrolyte; 4 – basket; 5 – lump titanium electrodes (bipolar); 6 – current source.

more than 3%. Notably, the mass loss values of the two extreme electrodes are quite close to each other and are detailed in Table 3.

Experimental data indicate that when exposed to industrial AC, the electrode situated between two monopolar electrodes functions as a bipolar electrode. Hence, we propose an electrolyzer design (Figure 5) comprising a plastic basket (4) with multiple small perforations placed between two titanium electrodes (2). This basket is packed with titanium pieces (5) and the electrolyzer is filled with a sulfuric acid solution of 150 g l^{-1} concentration. The external titanium electrodes are connected to an AC source (6) and undergo dissolution during the anodic half-cycle of the AC. Concurrently, the titanium pieces in the basket act as bipolar electrodes and also dissolve, with dissolution being notably intense. The titanium electrodes, notably, continue to dissolve even after the current is switched off, a process termed self-dissolution. It was observed that after 15–20 min of preliminary polarization with AC, the titanium spontaneously dissolves chemically, rendering the process energetically advantageous.

The solutions obtained after polarizing the titanium electrodes were utilized to produce titanium dioxide. Ammonium hydroxide was added to the titanium-containing solution to achieve a pH of 4.5, facilitating reaction (5) to produce titanium(III) hydroxide.

$$Ti_2(SO_4)_3 + 6NH_4OH \rightarrow 2Ti(OH)_3\downarrow + 3(NH_4)_2SO_4. \quad (5)$$

When the precipitate is slowly filtered, titanium (IV) hydroxide is produced (reaction (6)):

$$Ti(OH)_3 \xrightarrow{O_2} Ti(OH)_4. \quad (6)$$

The titanium(IV) hydroxide precipitate was washed to remove ammonium and sulfate ions, then dried and calcined at a temperature of 600–700°C in a muffle furnace (reaction (7)).

$$Ti(OH)_4 \xrightarrow{600-700^{\circ}C} TiO_2 + 2H_2O. \quad (7)$$

Based on the experimental data, we propose a technology for obtaining titanium dioxide from titanium metal waste such as scrap and shavings, which are byproducts of manufacturing processes. As illustrated in Figure 6, the proposed process begins by dissolving titanium metal in

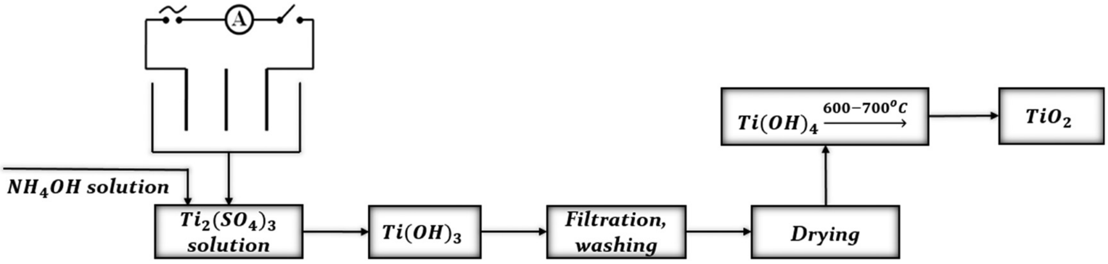


Figure 6: Principal process flow diagram for the production of titanium dioxide from titanium metal waste.

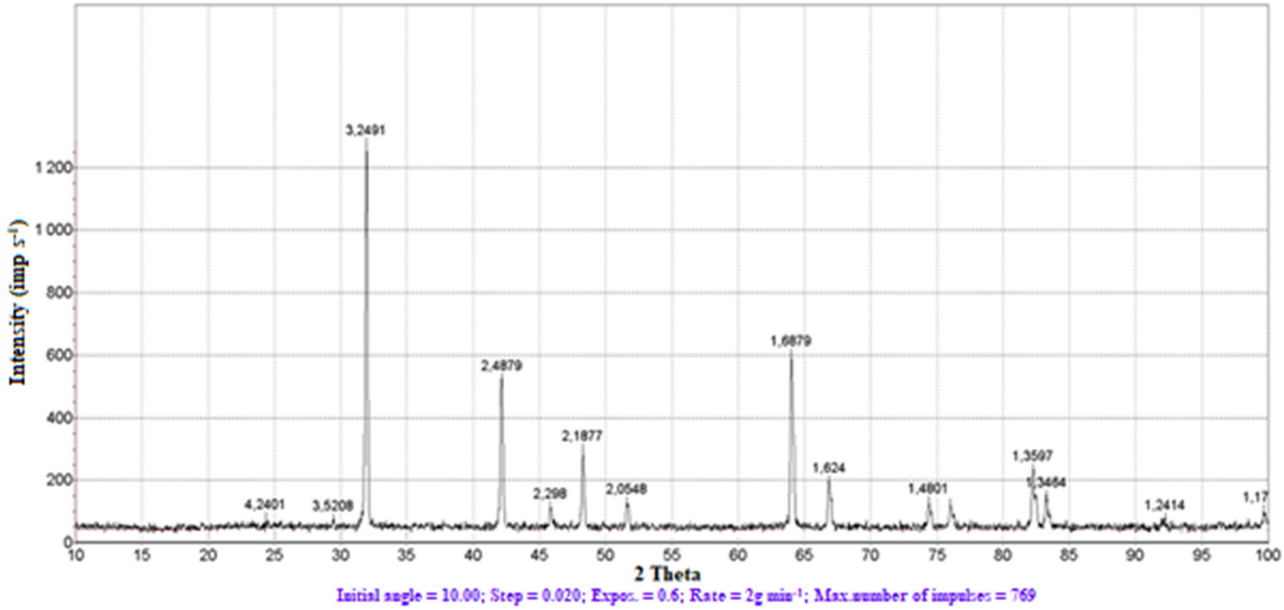


Figure 7: X-rays of titanium dioxide. Reflexes: 3.24; 2.48; 2.29; 2.18; 2.05; 1.68; 1.62; 1.48; 1.35; 1.34; 1.24; 1.17 Å – TiO_2 (ASTM 73-2224), 3.52 – TiO_2 (ASTM 1-562).

an electrolytic cell equipped with bipolar electrodes, using a sulfuric acid solution. The resultant solution, containing titanium(III) ions in the form of titanium(III) sulfate, is transferred to a container where ammonium hydroxide solution is added to precipitate titanium(III) hydroxide. This precipitate is then filtered and subsequently oxidized to titanium (IV) hydroxide. The washed precipitate, free of ammonium and sulfate ions, undergoes calcination in a furnace to obtain titanium dioxide (TiO_2).

The primary dissolution process of titanium metal exhibits a power consumption rate not exceeding 223.5 kW h t^{-1}. For comparative context, the power consumption rates for producing 1 ton of various metals are as follows: nickel (1,800–3,500 kW h), cadmium (1,300–2,000 kW h), silver (400–600 kW h), and zinc (3,200–3,300 kW h).

The resulting precipitate was identified by X-ray phase and elemental analysis as titanium dioxide. The X-ray phase analysis results (Figure 7) indicate the production of titanium dioxide in the anatase form (with all reflections corresponding to TiO_2). The elemental analysis results (Table 4) further confirm the production of titanium dioxide. Micrographs of titanium dioxide at various magnifications are presented in Figure 8. It is shown that titanium dioxide powders form amorphous particles agglomerated into various shapes. The average particle size of the agglomerates in this case ranges from approximately 0.2 to 0.5 µm.

Based on this research, a method for obtaining titanium dioxide was developed and is protected by a patent from the Republic of Kazakhstan and the Eurasian Patent Organization [24,25]. This developed method provides a foundation for the technology of obtaining titanium dioxide from various metal residues such as waste, scrap, shavings, or products at the end of their lifecycle.

Table 4: Elemental analysis of obtained product

Spectrum	Element composition (%)					
	O	**Al**	**Si**	**Ti**	**Fe**	**Total**
Spectrum 1	38.56	0.07	0.09	61.02	0.26	100.00
Spectrum 2	39.18	0.07	0.10	60.40	0.25	100.00
Spectrum 3	39.65	0.09	0.09	59.90	0.27	100.00
Average	39.13	0.08	0.09	60.44	0.26	100.00

Processing parameters: All elements are analyzed and normalized. All results are presented in weight %.

4 Conclusions

For the first time, we propose a fundamentally new technology for producing titanium dioxide from metal waste, comprising the following stages:

(1) Polarizing metallic titanium waste with industrial AC (50 Hz) in a sulfuric acid solution to obtain titanium(III) sulfate solution.

(2) Alkalizing the titanium(III) sulfate solution with ammonium hydroxide to pH = 4.5, precipitating titanium(III) hydroxide.

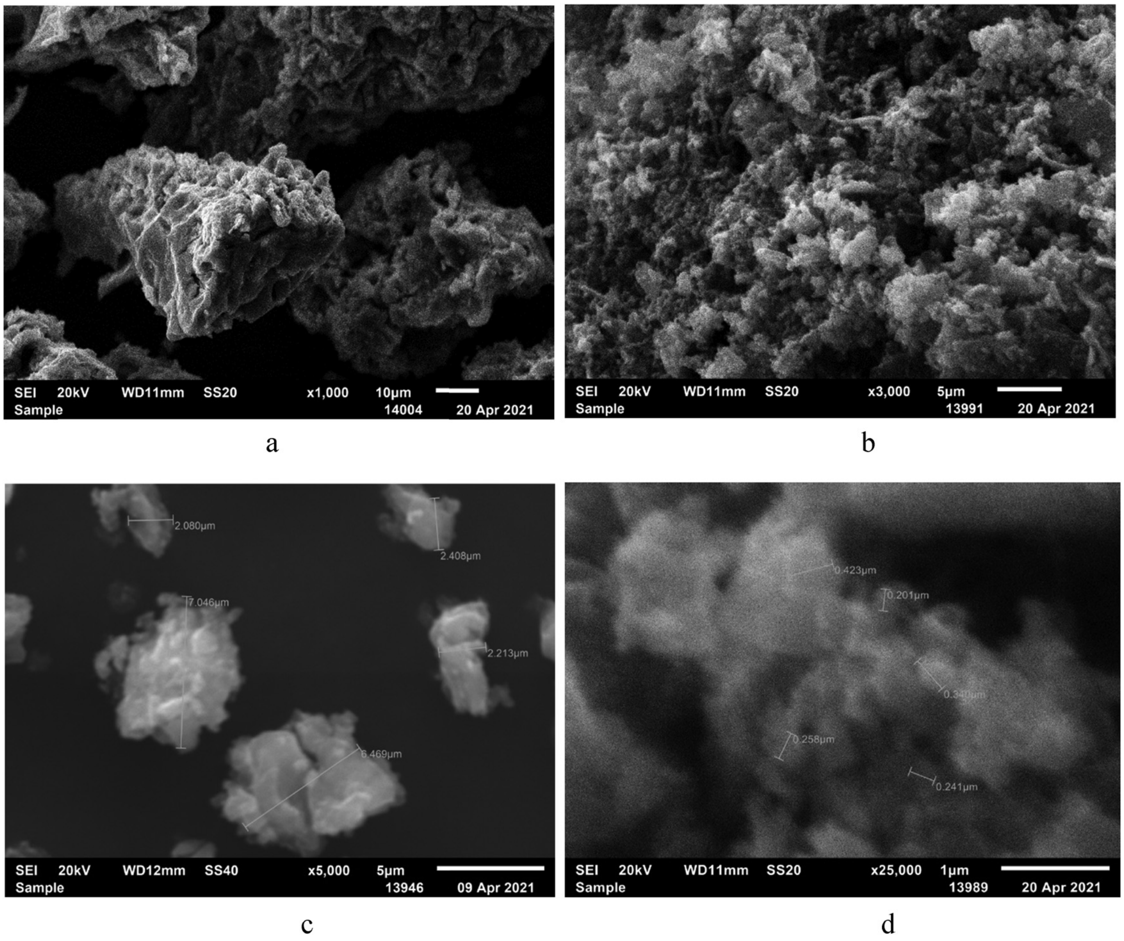


Figure 8: Micrographs of titanium dioxide obtained at different magnifications: (a) 1,000×; (b) 3,000×; (c) 5,000×; and (d) 25,000×.

(3) Separating the titanium(III) hydroxide precipitate by filtration and washing away sulfate and ammonium ions.
(4) Drying and calcining the titanium(III) hydroxide precipitate in a muffle furnace at 600–700°C.
(5) Obtaining the final product is titanium dioxide (TiO_2).

Titanium is a unique metal with the ability to resist dissolution under normal conditions in aqueous acid solutions and during electrolysis with direct current. This study demonstrates that titanium can be dissolved following preliminary polarization by AC. Due to the extensive industrial use of titanium, significant amounts of titanium waste accumulate in the environment in forms such as pieces, shavings, rods, and end-of-life products. Currently, there are no efficient methods for processing such titanium metal waste. Therefore, the method of dissolving titanium and obtaining titanium dioxide via AC electrolysis using bipolar electrodes holds practical significance. The theoretical findings contribute valuable insights to the electrochemistry of titanium. Additionally, these results can be applied to obtain other titanium compounds. The titanium dioxide obtained, characterized by unique properties, can be utilized for various applications. Numerous materials in the scientific and technical literature detail the applications of titanium dioxide. Furthermore, we aim to employ titanium dioxide as a suspension electrode in the electrochemical reduction of various anions, such as selenate and tellurate ions.

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Conflict of interest: The authors declare no conflict of interest.

Ethical approval: The conducted research is not related to either human or animal use.

Data availability statement: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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