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Extraction of titanium from Ti-doped seaside magnetite concentrate in HCl media

Introduction

Today, the developing industry and technology with the rapidly increasing population have led to the search for alternative ways to reach the essential raw materials, to discover new raw material sources, and to source the raw materials used (Barksdale 1966). The decreasing of high-grade ore deposits and the increasing consumption revealed the need for the use of low-grade ore deposits (Rötzer and Schmidt 2018; Spooren et al. 2020). Although traditional methods were used successfully in beneficiation from high-grade ores, low-grade deposits started to be used in recent times because of the depletion of rich deposits (Spooren et al. 2020). Pyrometallurgical (i.e. traditional) methods bring high costs and environmental pollution in operating low-grade and/or complex ore deposits, and recovery costs and environmentally friendly systems are applied with developing hydrometallurgical methods (Spooren et al. 2020; Binnemans and Jones 2017).

The main sources of metallic titanium and titanium compounds are rutile that has 50–97% TiO_2 content and ilmenite minerals with 30–50% Fe and 40–65% TiO_2 contents

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(Hamor 1986; Zhang et al. 2011). Ilmenite, which contains 40–65% TiO_2, approximately 91% of the world's demand for titanium (Das et al. 2013). However, the decreasing of high-grade ores (Sarker et al. 2006), and the traditional methods (e.g. smelting at high temperatures such as pyrometallurgy, reduction, converter, fire treatment, etc.) polluted the environment with radioactive problems because of the inability of the obtained metal in covering the processing costs, all attention was focused on ore deposits that have low grade titanium resources (Zhong et al. 2014). Various studies were conducted in the past to develop the use of Ti-containing magnetite concentrates from these ore deposits. Some new pyrometallurgical and hydrometallurgical techniques were developed in these studies (Hu et al. 2017; Sun et al. 2015) that not only cause environmental pollution, but also cause Fe-Ti resources to become waste. For this reason, applications of environmentally friendly methods increased to recover precious metals extensively and efficiently (V, Ti, and Fe) from titanium-containing magnetite concentrates (Luo et al. 2021).

There are considerable amounts of Ti-doped seaside magnetite reserves throughout Turkish coastlines. Ti-doped seaside magnetite ore consists of ilmenite ($FeTiO_3$) and magnetite (Fe_3O_4) phases that include dissolved ilmenite in its crystal structure (Zhong et al. 2014). The ore bed in the coastline is rich in magnetite, hematite, rutile, ilmenite, ilmenomagnetite, and titanomagnetite content, and Ti-SMC is obtained by separating SiO_2, which is a gangue mineral, and with the magnetic separation method. Ti-SMC is a high potential reserve in terms of Ti, Fe, Al, and Mg content with its magnetite content of ≥90%. This reserve, which has potential in terms of Ti-Fe content, must be evaluated with innovative (economic and environmentally friendly) methods.

In this study, it was emphasized that Ti-SMC, which is a potential reserve for titanium, is a source to contribute to the economy and industry of the country. In this context, the dissolution behavior of titanium was examined by applying innovative, economical, and environmentally friendly agitation acid leaching under atmospheric conditions, aside from traditional production metallurgy methods, which are not economical and which cause environmental pollution, for the production of Ti or Ti compounds from Ti-SMC sources.

1. Materials and methods

1.1. Materials and analyses

The Ti-SMC sample that was taken from the Turkey/Black Sea Region coastline placer-type deposit and concentrated with Ti-SM wet magnetic separation method was used in experimental studies. The quantitative mineralogical and elemental analysis of the Ti-SMC sample was made by using the X-ray diffraction (XRD) and inductively coupled plasma atomic emission spectroscopy (ICP-AES), respectively. The mineralogical composition of the Ti-SMC sample is given in Figure 1, and its chemical composition is given in Table 1.

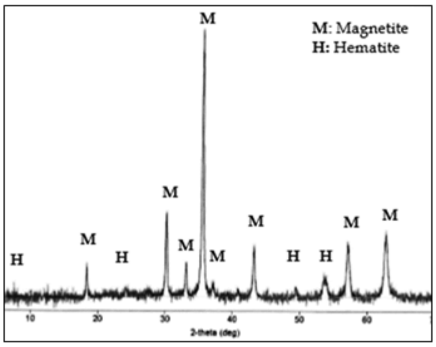

Fig. 1. XRD pattern of raw Ti-SMC

Rys. 1. Dyfraktogram XRD próbki Ti-SMC

Table 1. Chemical composition of Ti-SMC

Tabela 1. Skład chemiczny Ti-SMC

Element	Mg	Al	Ti	Fe	V
%	1.02	1.44	4.05	50.17	0.28

When the XRD pattern given in Figure 1. was examined, it was found that the major minerals of the sample were hematite and magnetite. Also, an iron oxide mineral that contained a small amount of goethite (FeO·OH) was detected. Titanium content was determined with the mineralogical optic microscope, and it was found that it also had ilmenite ($FeTiO_3$) and rutile (TiO_2) (Figure 2). In the cross-section images given in Figure 2, the sample consists of abundantly-concentrated ore and very little gangue minerals, with grain sizes of minimum-maximum 0.005–0.3 mm, and dominant grain sizes of 0.02–0.2 mm. In this sample, the main ore mineral consists of iron oxide minerals, dominantly magnetite ($FeO{\cdot}Fe_2O_3$), and less hematite (Fe_2O_3), and goethite (FeO·OH). In the images, small ilmenite ($FeTiO_3$) and rutile (TiO_2) amounts were also detected as Ti-containing ore minerals. Small amounts of chromite ($FeCr_2O_4$), psilomelane group manganese oxide minerals, and trace amounts of sphalerite (ZnS) were also detected in the sample. The small number of gangue minerals consisted of pyroxene, olivine, amphibole, epidote, and sphenes. Sphene, which is a gang mineral, may contain some titan in its structure $CaTiO(SiO_4)$. Also in the sample, the magnetites existed both as pure magnetites and as partially transformed into hematite as a result of martitization. Magnetite parts had pinkish, and hematite parts had a pale blue color. Martitization samples of magnetite (M+H) and hematite (H+M) were also detected. Ilmenite and rutile containing titanium were not found as free independent minerals in the sample.

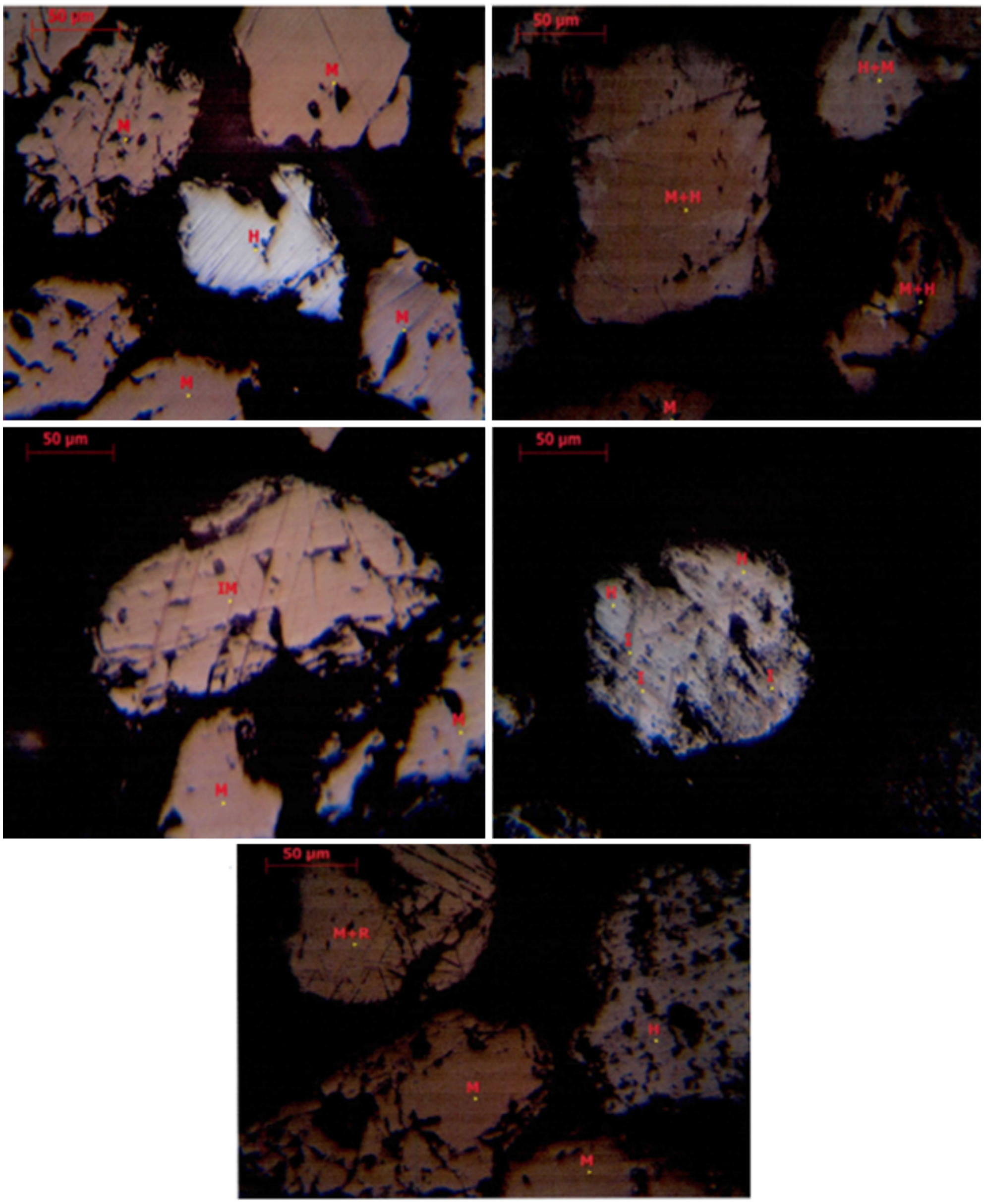

Fig. 2. Mineralogical analyses of Ti-SMC by optic microscope
rutiles in the form of dark needles in magnetite (M+R), free magnetites (M),
mineral completely martitized into hematite (H), thin ilmenite lamellae (I), ilmenomagnetite mineral (IM),
martitization with dominant hematite (H+M)

Rys. 2. Analizy mineralogiczne Ti-SMC pod mikroskopem optycznym
rutyl w postaci ciemnych igieł w magnetycie (M+R), magnetyt wolny (M),
minerał całkowicie zmartytyzowany do hematytu (H), cienkie lamele ilmenitu (I),
minerał ilmenitowo-magnetytowy (IM), martytyzacja z dominującym hematytem (H+M)

These are generally found in magnetite and hematites as thin lamellae, and as residues that have a grain size of less than 10 microns in small amounts.

Merck-quality HCl (37%, d:1.19 g/cm^3) and de-ionized water were employed in the experimental studies conducted on the concentrated sample with hydrometallurgical methods. HCl was used as the acid source of the solution that was used to dissolve the Ti-SMC sample in leaching experiments. De-ionized water was used for the experiment to adjust the solution concentration, for washing before/after the filtration, and to clean the reaction container and all other equipment used in the experiments. All Ti% extraction calculations were determined with the atomic adsorption spectrometry (AAS) analysis after the leaching processes.

1.2. Leaching methods

Physical water was removed at 105°C for 24 hours and 10 g of Ti-SMC that was stored in vacuum containers were used in leaching experiments. The Ti-SMC was grinded for 5 seconds with a pulverizer in the moisture-free sample given in Figure 2 to release the locked ilmenite and rutile grains (i.e. locked minerals) and to increase the leaching efficiency. Olanipekun (1999) examined the effects of grain size on leaching efficiency in his study in which he applied HCl leaching to ilmenite ore and found that small grain size increased the titanium recovery yield (Olanipekun 1999). El-Hazek et al. (2007) emphasized that the particle size reduction process increased the dissolution efficiency of ilmenite since the surface area that was exposed to HCl also increased (El-Hazek et al. 2007). As seen in Figure 3, leaching experiments were done in an 800 ml Pyrex reaction container that was placed in a water bath. The agitation was performed with the help of an external propeller during leaching. The mixing speed was kept constant at 160 rpm with an accuracy of ±5 rpm to ensure that all Ti-SMC particles were suspended and to avoid sticking to the wall of the reaction container with the effect of centrifugal force (Uzun Kart 2021; Uzun et al. 2016).

HCl is widely used in studies that examine Ti recovery from Ti-containing raw materials with leaching (El-Hazek et al. 2007; Mahmoud et al. 2004; Li et al. 2008; Klojzy-Karczmarczyk and Mazurek 2021). For this study, in which Ti extraction from Ti-SMC sample was examined, and when the literature data were reviewed, the dissolution kinetics of ilmenite ($FeTiO_3$) in HCl yielded more positive results than in H_2SO_4 (Sasikumar et al. 2007). Also, HCl leaching was applied to ilmenite concentrate in the Altair and Ortech-Argex processes in the literature (Zhang et al. 2011; Verhulst et al. 2002). In this study, HCl was preferred as the acid source that was employed in the leaching process with its technical advantages, e.g. high efficiency, leaching kinetics, easy regeneration, and recovery (Sarker et al. 2006). When the studies in the literature were reviewed, the dissolution behavior of Ti was investigated by leaching ilmenite at variable parameters with HCl (Jackson and Wadsworth 1976; Van Dyk et al. 2002; Tsuchida 1982; Hussein and Kolta 1976). For this reason, in the scope of the present study, atmospheric acid leaching was performed for the Ti-SMC samples subjected to HCl leaching by making use of the atmospheric acid leaching studies reported in the literature for ilmenite ($FeTiO_3$) minerals at different leaching temperatures (25–50–75––90°C), acid concentrations (8–10–12 N), and leaching duration of 30–60–120–240 minutes. By considering the 1/40 solid/liquid ratio (w/v) determined with the preliminary experiments, a 10 g Ti-SMC sample was leached in a 400 ml solution.

Table 2. Leaching of Ti-SMC experimental parameters, results, and calculations

Tabela 2. Wyniki i obliczenia parametrów ługowania Ti-SMC

Leaching Temperature (°C)	Leaching Time (min.)	HCl Concentration (N)	Weight of Feed (g)	Weight of Leach Residue (g)	Weight of dissolute feed (g)	Dissolute Feed (%)	Ti Extraciton (%)
25	30	8	5.0008	2.8963	2.1045	42.08	34.52
	60		5.0005	2.8909	2.1096	42.19	35.21
	120		5.0002	2.4058	2.5944	51.89	42.25
	240		5.0005	1.8623	3.1382	62.76	53.69
	30	10	5.0003	2.8307	2.1696	43.39	37.78
	60		5.0009	1.6064	3.3945	67.88	56.38
	120		5.0008	1.2455	3.7553	75.09	64.10
	240		10.0008	1.7998	8.201	82.00	68.50
	30	12	5.0003	1.2630	3.7373	74.74	64.15
	60		5.0003	0.7621	4.2382	84.76	76.36
	120		5.0004	0.7427	4.2577	85.15	74.83
	240		10.0001	1.3283	8.6718	86.72	74.82
50	30	8	5.0005	2.4073	2.5932	51.86	49.29
	60		5.0001	1.8508	3.1493	62.98	53.32
	120		5.0002	1.7923	3.2079	64.16	53.61
	240		5.0003	1.8206	3.1797	63.59	55.79
	30	10	5.0009	1.1508	3.8501	76.99	65.07
	60		5.0001	1.1070	3.8931	77.86	67.02
	120		5.0007	0.7483	4.2524	85.04	73.94
	240		5.0005	0.5475	4.4530	89.05	82.00
	30	12	5.0000	0.5779	4.4221	88.44	80.02
	60		10.0005	1.1431	8.8574	88.57	80.65
	120		10.0006	1.0873	8.9133	89.13	82.29
	240		10.0005	1.0784	8.9221	89.22	81.92

Leaching Temperature (°C)	Leaching Time (min.)	HCl Concentration (N)	Weight of Feed (g)	Weight of Leach Residue (g)	Weight of dissolute feed (g)	Dissolute Feed (%)	Ti Extraciton (%)
75	30	8	10.0000	1.4639	8.5361	85.36	72.96
	60		10.0000	1.1080	8.8920	88.92	81.11
	120		10.0007	1.0635	8.9372	89.37	83.56
	240		10.0001	1.0413	8.9588	89.59	83.26
	30	10	10.0002	1.0259	8.9743	89.74	83.68
	60		10.0008	0.9840	9.0168	90.16	85.64
	120		10.0005	1.0081	8.9924	89.92	83.93
	240		10.0000	1.0043	8.9957	89.96	85.22
	30	12	10.0003	1.0434	8.9569	89.57	84.51
	60		10.0008	0.9766	9.0242	90.23	85.61
	120		10.0003	1.0016	8.9987	89.98	84.89
	240		10.0000	0.9967	9.0033	90.03	85.84
95	30	8	5.0004	0.6070	4.3934	87.86	80.41
	60		5.0002	0.5335	4.4667	89.33	81.91
	120		5.0008	0.4621	4.5387	90.76	84.00
	240		10.0007	0.9989	9.0018	90.01	86.31
	30	10	10.0002	1.0076	8.9926	89.92	85.25
	60		10.0008	0.9876	9.0132	90.12	86.12
	120		10.0000	1.0051	8.9949	89.95	86.82
	240		10.0008	0.9756	9.0252	90.24	87.86
	30	12	10.0001	0.9840	9.0161	90.16	86.69
	60		10.0005	0.9507	9.0498	90.49	87.10
	120		10.0002	0.9543	9.0459	90.46	86.89
	240		10.0006	0.8969	9.1037	91.03	87.63

After completing the leaching experiments, solid/liquid separation was performed with a vacuum filter, and insoluble solid waste (leach residue) and pregnant solution were obtained. After completing the filtration process, the leach residue was washed with de-ionized water. The pregnant solution that was separated from its insoluble solid was kept in the volumetric flask, and the solid waste was dried at 65°C for 24 hours and the moisture removed completely. The solid waste obtained after drying was weighed, and the Ti% extraction values were determined with the AAS analysis.

Fig. 3. Experimental procedure

Rys. 3. Aparatura doświadczalna

2. Results and discussion

The hydrochloric acid leaching experiments of Ti-SMC sample under atmospheric conditions were carried out at different leaching temperatures (25, 50, 75, 95°C), at different leaching times (30–60–120–240 minutes), and at different acid concentrations (8–10–12 N). $FeTiO_3$ dissolves according to the chemical reaction that can be represented by the following equation (Equation 1) (Jabit and Senanayake 2018).

$$FeTiO_3 + HCl \rightarrow Fe^{2+} + TiO_2+ + 2H_2O \quad (1)$$

The Ti% values recovered as a result of the leaching experiments, experimental measurements, and weighing, and the experimental parameters are given in Table 2. The effects of each variable parameters on leaching were examined separately in the experimental series under the specified conditions, and the optimization of these conditions was made. Optimum conditions obtained in all leaching experiments were determined as; 10 g Ti-SMC sample at 1/40 (w/v) solid/liquid ratio determined as a result of preliminary experiments, in 400 ml solution, leaching temperature as 50°C, the acid concentration of 10 N, and the leaching time of 480 min. As a result of the leaching experiments done under these conditions, 92% Ti extraction was obtained. After the optimization, the XRD pattern of the leaching residue is given in Figure 4.

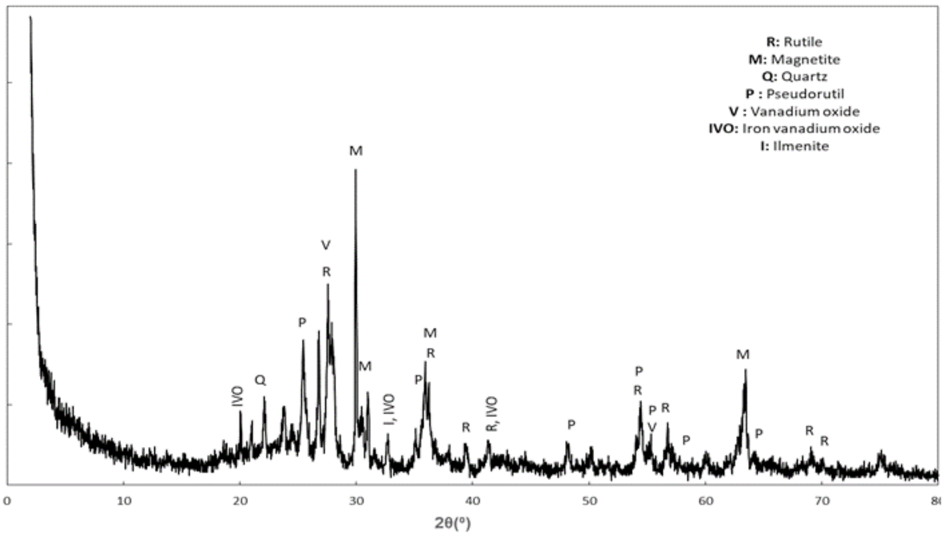

Fig. 4. XRD pattern of leach residue at optimum leaching conditions (50°C, 10 N HCl, 480 m)

Rys. 4. Dyfraktogram XRD pozostałości po ługowaniu w optymalnych warunkach ługowania (50°C, 10 N HCl, 480 min)

When the XRD pattern of the leaching residue was examined after leaching Ti-SMC under optimum conditions, it was found that iron was in the form of magnetite in 29 and 30 2θ (ref. code: 01-075-0449) (Fe_3O_4), and in the form of pseudorutile ($Fe_2Ti_3O_9$) at 25, 35, 48, 54, 55, 57, 64 2θ (ref. code: 00-029-1494). Also, ilmenite ($FeTiO_3$), which was insoluble after leaching at 32 2θ (ref. code: 01-075-1210), and rutile minerals (TiO_2) 27, 35, 39, 41, 54, 56, 69, 70 2θ'da (ref. code: 01-087-0710), which formed with the dissolution of ilmenite according to Equation 1. or which already existed in the structure, were also observed (Das et al. 2013). The vanadium in the crystal structure of Ti-SMC did not dissolve in leaching and was in the form of iron vanadium oxide ($FeVO_4$) at 20, 32, 41 2θ (ref. code: 00-030-0667), and vanadium oxide at 55 2θ (ref. code: 01-076-0678). It was reported in the literature that more titanium can be recovered from the leaching residue that contains high rutile and pseudorutile with Becher and chlorination process (Das et al. 2013; Minkler and Baroch 1981).

2.1. Effects of HCl concentration

In the experiments in which the effects of acid concentration were examined, the leaching times were 30, 60, 120 and 240 minutes, the temperature was kept constant at 25, 50, 75, and 95°C, and the solution acid concentration was changed into 8, 10 and 12 N. The results, extraction values, and calculations of the leaching experiments under these conditions are given in Table 2; and the dissolution behavior trends are given in Figure 5a, b, c, d. Hussein et al. (1976) and Jackson and Wadsworth (1976) found that the rate of dissolution of ilmenite depends on the acid concentration. When the leaching temperature value is kept constant at 25°C (a), the effect of the solution acid concentration against the leaching time and titanium extraction values also increased proportionally with increased acid concentration, as seen in Figure 5(a). This proportional increase continued at 50°C (b). The titanium recovery of the 10 N acid concentration reached maximum value when compared to the other acid concentrations with increased leaching time at this temperature.

The titanium extraction value continued to increase slightly with the increase in acid concentration at leaching temperatures of 75°C (c) and 95°C (d). It is seen in Figure 5d that the effect of the leaching time starts to decrease as the temperature increase continues at high values. The highest titanium extraction (88%) was obtained in 240-minute leaching time in the experiment in which the acid concentration was 10N and the temperature was 95°C. With leaching experiments where the temperature was kept constant, the idea that dissolution accelerates as the acid concentration increases at 25°C (i.e. Ti% extraction of 12 N > 10 N > 8 N) continued at 50°C; however, 10N titanium extraction efficiency reached higher values than 12 N (Ti% extraction) with increased leaching time (Ti% extraction of 10 N > 12 N > 8 N). It was found that the effects of acid concentration decreased with increasing leaching time at 95°C (Ti% extraction of 10 N > 12 N > 8 N).

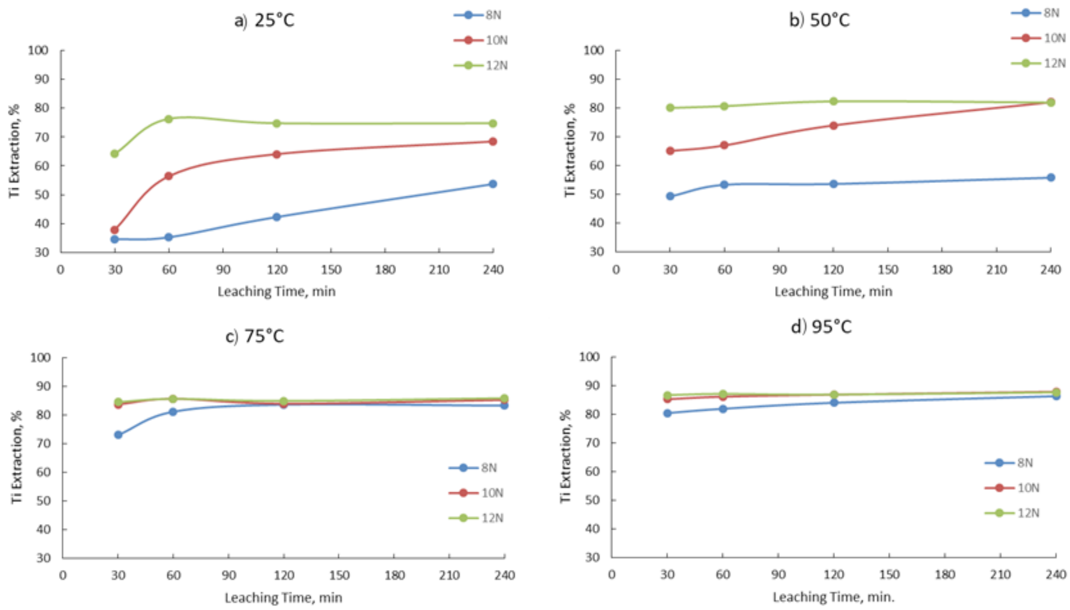

Fig. 5. The effect of solution acid concentrations on leaching at 25°C (a), 50°C (b), 75°C (c) and 95°C (d)

Rys. 5. Wpływ stężenia kwasu w roztworach na ługowanie w temperaturze 25°C (a), 50°C (b), 75°C (c) i 95°C (d)

2.2. Effects of leaching time

The experiments that examine the effects of the leaching times were conducted at acid concentrations of 8 N, 10 N, 12 N, at temperatures of 25, 50, 75, 95°C, and at 30, 60, 120, and 240 minutes. Titanium extraction values, which are the results of these leaching experiments under these conditions, are given in Table 2; and the dissolution behavior trend lines are given in Figure 6a, b, c. As seen in Figure 6a, titanium extraction showed the same behavior in all leaching times, which emphasized that the leaching time did not differ according to the temperature at 8 N acid concentration. There seems to be a direct relationship between increasing leaching times and titanium extraction. However, high acid concentrations and high temperatures can decrease the effects of leaching times. The highest titanium extraction in 30 min leaching time was 87% at 12 N and 95°C. The highest titanium extraction in 60 min leaching time was 87% at 12 N and 95°C. The highest titanium extraction in 120 min leaching time was 87% at 12 N and 95°C. The highest titanium extraction at 240 min leaching time was 88% at 10 N and 95°C.

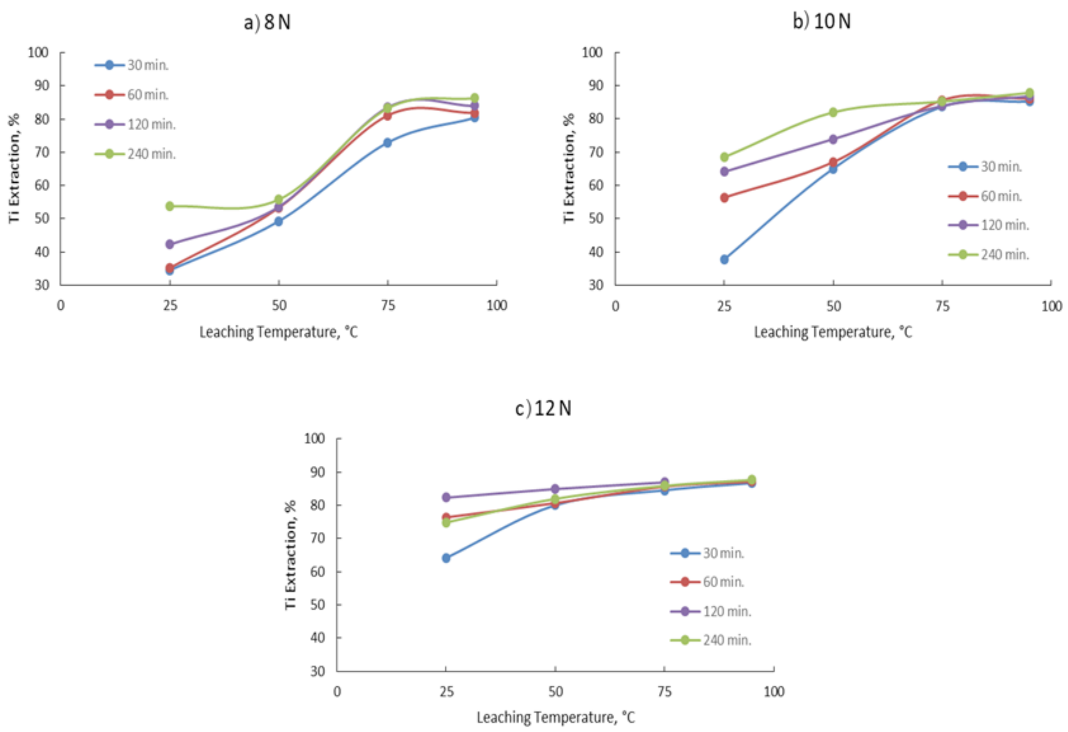

Fig. 6. Effects of leaching time at 8 N HCl (a), 10 N HCl (b), and 12 N HCl (c)

Rys. 6. Wpływ czasu ługowania 8 N HCl (a), 10 N HCl (b) i 12 N HCl (c)

2.3. Effects of leaching temperature

In the experiments in which the effects of leaching temperatures were examined, leaching times were changed as 30, 60, 120, and 240 minutes, acid concentrations as 8, 10 and 12 N, and leaching temperatures as 25, 50, 75, and 95°C. The titanium extraction values, which are the results of the leaching experiments under these conditions, are given in Table 2, and the dissolution behavior trend lines are given in Figure 7a, b, c. The effects of the temperature in time by keeping the solution acid concentration constant at 8 N HCl are shown in Figure 7a.

As seen in the figure, there is a directly proportional increase in the titanium extraction values as the temperature rises from 25 to 95°C (Das et al. 2013). In the experiments performed under these conditions, it was found that the titanium extraction achieved at the lowest time, acid concentration, and temperature (30 minutes, 8 N, and 25°C) was 35%. Under these conditions, the highest titanium extraction value of 80% was reached by increasing the temperature to 95°C. It was observed in the experimental series that examined the effects of the leaching temperatures on the dissolution behavior of titanium that the titanium extraction increased with increased temperature (Verhulst et al. 2002). El-Hazek et al. (2007) emphasized that the dissolution rate of ilmenite increases with increasing temperatures.

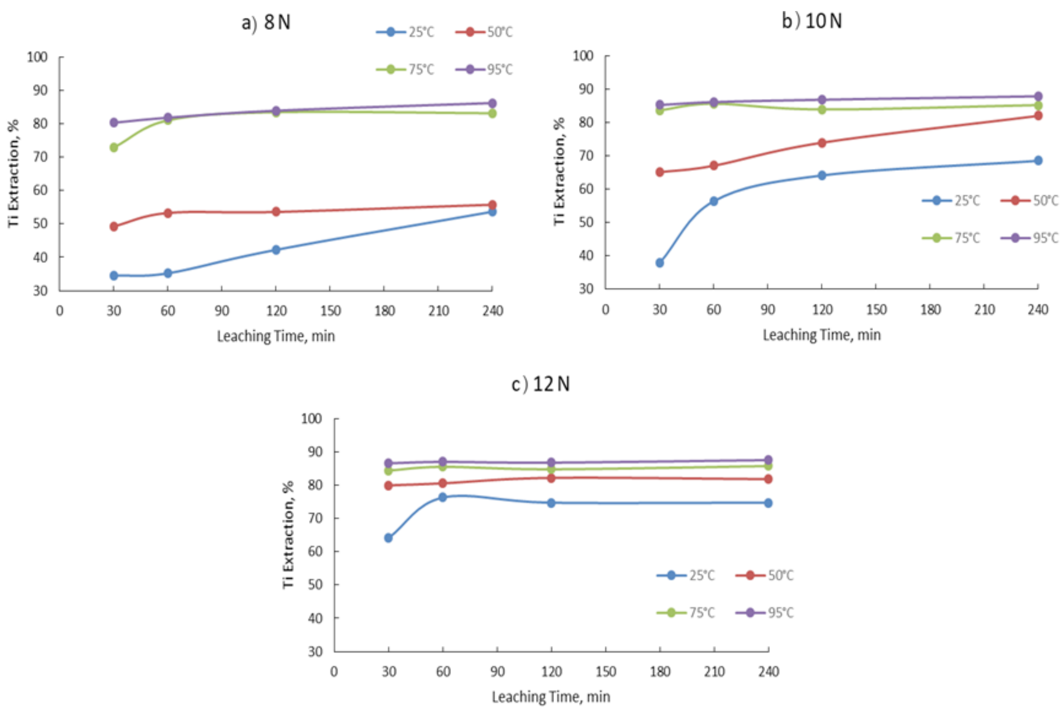

Fig. 7. Effects of leaching temperature on leaching at 8 N (a), 10 N (b), and 12 N (c)

Rys. 7. Wpływ temperatury na proces ługowania 8 N (a), 10 N (b) i 12 N (c)

The highest titanium extraction values were obtained as 75% at 25°C, 82% at 50°C, 86% at 75°C, and 87% at 95°C in the scope of this study (El-Hazek et al. 2007).

When a brief summary calculation is made from an economic point of view for industrial profitability of the process for certain optimal parameters, i.e. HCl concentration and consumption. The introduction of this element will enable the optimization of the industrial enrichment process, the results are given in Table 3 and 4.

Table 3. Optimum parameters, reserve and production calculations

Tabela 3. Optymalne parametry, rezerwy i obliczenia produkcyjne

Run of Mine	15 years
Total reserve of Ti-SMC	150 000 ton/annually
Ti Grade of Ti-SMC	6%
Solid/liquid ratio of extraction leaching	1/4 weight/volume
Recovery of Ti Extraction	92%
Optimum HCl concentration	10 N (80%)

Table 4. Economical calculations and general cost analysis without CAPEX

Tabela 4. Kalkulacje ekonomiczne i ogólna analiza kosztów bez CAPEX

Total amount of Ti in the Ti-SMC	9 000 ton/annually
Total amount of extracted Ti with leaching	8 280 ton/annually
Total HCl solution consumption	28 800 Liter/annually
Total solid HCl consumption	77 837 ton/annually
OPEX of HCl consumption	8 M $/annually
Total TiO_2 production from extracted Ti by leaching	48 000 ton/annually
Price of TiO_2	3 500 $/ton
Total annual return of TiO_2 sales	168 M $/annually

Conclusions

In this study, a placer-type Ti-doped seaside magnetite concentrate consisting of 4–6% Ti, 50–52% Fe, 1–2% Al, and 1–2% Mg content, 93.90% magnetite, and 6.10% hematite, which is found on the coast of Turkey/Black Sea region was used. The Ti-SMC was milled, and the locked minerals were liberated. Atmospheric agitation HCl leaching experiments were applied at 25–50–75–90°C temperatures, 8–10–12 N HCl concentrations, and for 30–60–120–240 minutes (1/40 w/v) to determine the dissolution behavior of Ti-SMC.

In the experiments in which the effects of acid concentration, leaching time and leaching temperatures were examined.

As a conclusion;

- When the effects of the variable parameters on titanium extraction were examined separately, the increased leaching time increased the titanium extraction value; however, the effect of the leaching time disappeared when the temperature increase continued at high acid concentrations and at high temperatures.
- It was observed that the effect of the solution acid concentration decreased with increasing leaching time, and 10 N titanium extraction value reached higher values compared to 12 N with the increase of leaching time at 50°C.
- As a result of the dissolution kinetic series experiments, it was considered that an increase in titanium extractions might be obtained with increased temperature and acid concentrations where the effect of the leaching time was detected. In this respect, atmospheric agitation acid leaching experiments were done on Ti-SMC at 50°C, 10 N acid concentration, and in 480 minutes leaching time, and 92% Ti recovery was obtained. These conditions were accepted as optimum.

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EXTRACTION OF TITANIUM FROM Ti-DOPED SEASIDE MAGNETITE CONCENTRATE IN HCl MEDIA

Keywords

Ti-doped seaside magnetite concentrate, atmospheric HCl leaching, titanium extraction

Abstract

The purpose of the present study was to extract high added value titanium from Ti-doped Seaside Magnetite Concentrated (Ti-SMC), which has a high potential reserve for Ti-Fe with 4–6% Ti, 50–52% Fe, 1–2% Al, and 1–2% Mg content by applying innovative, economical, environmentally friendly methods. Agitaion HCl leaching was applied to the Ti-SMC sample at different leaching temperatures (25–50–75–90°C), at acid concentrations (8–10–12 N), and leaching times (30–60–120–240 min) in atmospheric conditions. After the leaching experiments under the indicated conditions, the optimization of the leaching experiments was determined with Ti% recovery that dissoluted by elemental analysis, and the titanium recovery values reached the maximum value with increased leaching time at 50°C and 10 N HCl acid concentration; and 65% Ti was recovered in 30 minutes, 67% in 60 minutes, 74% in 120 minutes, and 82% Ti in 240 minutes. For Ti-SMC, leaching was carried out at 50°C leaching temperature and at 10 N acid concentration for 480 minutes, and a 92% Ti extraction value was achieved. According to the extraction results of all leaching experiments, the leaching temperature of 50°C, the acid concentration of 10 N, and the leaching time of 480 minutes were determined as the optimum conditions. In this study, it was emphasized that this resource is a potential reserve, which has not been used as a source before, with 92% Ti extraction with atmospheric acid leaching, which is an environmentally friendly method, consuming less energy than Ti-SMC, which is difficult and expensive to extract with traditional methods.

EKSTRAKCJA TYTANU Z NADMORSKIEGO KONCENTRATU MAGNETYTU DOMIESZKOWANEGO TYTANEM W ŚRODOWISKU HCl

Słowa kluczowe

nadmorski koncentrat magnetytu zawierający Ti,
ługowanie w warunkach atmosferycznych HCl, ekstrakcja tytanu

Streszczenie

Celem badań była ekstrakcja tytanu z nadmorskiego koncentratu magnetytu (Ti-SMC – *Ti-doped Seaside Magnetite Concentrated*), charakteryzującego się znacznym potencjałem rudy Ti-Fe zawierającej 4–6% Ti, 50–52% Fe, 1–2% Al oraz 1–2% Mg, dzięki zastosowaniu innowacyjnych, ekonomicznych i przyjaznych dla środowiska metod ługowania. Ługowanie kwasem solnym HCl z mieszaniem zastosowano do próbek Ti-SMC w różnych temperaturach ługowania (25–50–75–90°C), przy stężeniach kwasu (8–10–12 N) i czasach ługowania (30–60–120–240 min) w warunkach atmosfe-

rycznych. Następnie dokonano optymalizacji eksperymentów ługowania z odzyskiem Ti%. Maksymalne wartości odzysku tytanu wystąpiły przy zwiększonym czasie ługowania w temperaturze 50°C i stężeniu kwasu solnego HCl 10 N; 65% Ti odzyskano w ciągu 30 min, 67% – w 60 minut, 74% – w 120 minut, a 82% – w 240 minut. W przypadku Ti-SMC ługowanie prowadzono w temperaturze 50°C i przy stężeniu kwasu 10 N przez 480 minut i otrzymano wartość ekstrakcji 92% Ti. Zgodnie z wynikami ekstrakcji we wszystkich eksperymentach ługowania jako optymalne warunki określono: temperaturę ługowania 50°C, stężenie kwasu 10 N i czas ługowania 480 minut. W pracy podkreślono, że surowiec ten stanowi potencjalną rezerwą, wcześniej niewykorzystywaną. Ekstrakcja 92% Ti z ługowaniem kwasem solnym w warunkach atmosferycznych jest metodą przyjazną dla środowiska, zużywającą mniej energii niż Ti-SMC, która jest trudna i droga do ekstrakcji tradycyjnymi metodami.