Treatment of bauxite residues - acidic leaching (first part)

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Abstract:

Introduction/purpose: Bauxite residue as a waste product from the aluminium industry produced through the Bayer process is mainly composed of iron oxide, titanium oxide, silicon oxide and undissolved alumina together with a wide range of other oxides and a minor content of rare earth elements, gallium, vanadium and scandium, which vary according to the country of origin of the bauxite. The extraction of valuable elements from bauxite residues and the minimisation of bauxite residues during different treatments are an open research field.

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Methods: Different hydrometallurgical and pyrometallurgical methods were used for the treatment of bauxite residues. In this study, the results of the hydrometallurgical treatment of bauxite residue from Alumina Zvornik using sulfuric acid and hydrochloric acid will be shown in order to study the change of the mineralogical composition. Leaching efficiency will be calculated using the ICP OES analysis. The XRD-Analysis was used for the characterization of the initial material and solid residues studying the change of the mineralogical phases.

Results: Leaching of bauxite residues with sulphuric and hydrochloric acid leads partially to the change of mineralogical structure and the transfer of elements into a liquid phase. Natural precipitation of iron is observed over time. Silica gel formation is confirmed during leaching of bauxite residues with hydrochloric acid.

Conclusion: A new research strategy for treating bauxite residue is needed in order to ensure a complete change of the initial minearlogical structure and the most efficient transfer of metals into a liquid phase.

Key words: bauxite residues, aluminium, hydrometallurgy, acid, recycling, rare earth elements.

Introduction

The Bayer process is a traditional industrial method for the production of alumina from bauxite ore. The chemical quality of precipitated aluminum hydroxide, and consequently the final alumina product in the Bayer process directly depends on the level of impurities in a refinery's Bayer liquor. Under optimal reaction parameters (temperature and time), it is possible to remove iron, zinc and copper from the Bayer liquor using a precipitation agent such as calcium hydroxide with an efficiency of more than 90%, in such a way that the treated solution is still economically usable in the following stages of processing while obtaining different types of aluminum trihydrate. (Damjanović et al, 2020)

In Europe, alumina refineries operate in Bosnia and Herzegovina (Alumina, Zvornik), France, Hungary, Germany, Greece, Ireland (AAL), Romania (ALUM), Spain and Ukraine, while significant BR deposits from refineries that have stopped their operations (legacy sites) exist in former Yugoslavia (Podgorica, Kidricevo, Mostar, Obrovac), Italy, France (RT), Germany, Hungary and other countries. The current BR production level in the EU is 6.8 million tonnes per year while the cumulative stockpiled level is a staggering >250 million tonnes (dry matter).

The mineralogical structure of bauxite residue, where nearly 80 % consists of three of these phases: cancrinite, sodalite and hematite, is shown in Table 1. (Castaldi et al, 2008)

Table 1 – Typical mineralogical structure of bauxite residue (in wt. -%)
Таблица 1 – Типичный минералогический состав бокситового шлама (в процентном соотношении)
Табела 1 – Типична минералска структура боксitних остатака (у тежинским процентима)

Cancrinite [$Na_6Ca_{1.5}Al_6Si_6O_{24}(CO_3)_{1.6}$]:	29.0-33.0
Sodalite [$Na_8(Cl,OH)_2Al_6Si_6O_{24}$]:	16.0-24.0
Hematite [Fe_2O_3]:	27.0-29.0
Boehmite [AlO(OH)]:	5.0-6.0
Gibbsite [$Al(OH)_3$]:	4.0-5.0
Anatase [TiO_2]:	5.0
Andradite [Ca-Fe-Al-Si oxides]:	4.0
Quartz [SiO_2]:	2.0

Bauxite residues contain scandium and gallium (Approx. 50-150 ppm) and up to an order of magnitude higher for elements such as: vanadium and rare earths elements (0.05-0.5 %). Since 1991, MYTILINEOS, Greece, has been doing pioneering research on BR handling and reuse, focusing initially on massive low value applications such as use as a raw material for geopolymer bricks, cement clinker production, iron production, bricks and tile production, soil remediation (vegetation), extraction of rare earth elements, and road substrate.

Due to the generation of large amounts of bauxite residue (red mud), an alternative method, called the Pedersen Process was considered in order to prevent bauxite residue generation (Lazou et al, 2020). In the conventional Pedersen Process, iron in bauxite is separated in the form of pig iron through a carbothermic smelting-reduction step which has a carbon dioxide emission similar to that during conventional iron production. In order to eliminate the carbon dioxide emission of this step, the focus of their work was to reduce the iron oxides of bauxite ore by hydrogen gas prior to smelting and minimizing the use of solid carbon materials for the reduction. Calcination and reduction of bauxite ore by hydrogen was studied by the thermogravimetry method supported by the microstructural and phase analysis confirming that the reduction of hematite to magnetite and magnetite to iron starts at temperatures below 560 °C with a slow rate and is faster at higher temperatures. At higher temperatures, i.e., 860, 960, and 1060 °C, the formation of hercynite ($FeAl_2O_4$) retards the complete reduction to metallic iron.

The possibilities to recover rare earths from bauxite residues, which commonly contain only low concentrations of rare-earth elements, but are available in very large volumes and could provide significant amounts of rare earths to European countries are the main research subject of the European funded projects (EURARE; REMOVAL, SCALE, REDMUD) in the last ten years. The extraction rate of the rare earth recovery from these industrial waste streams is a part of a comprehensive, zero-waste, “product-centric” valorisation scheme, in which applications are found for the residual fractions that are obtained after removal of not only the rare earths but also other critical metals such as scandium, vanadium and gallium and especially the base elements: aluminium, titanium and iron (Binnemans et al, 2015).

Unfortunately, the extraction of aluminium, iron and titanium from bauxite residue under acid leaching is limited due to an insufficient amount of acidic solution from leaching caused by the polymerization of silica (Rivera et al, 2017). Kinetic studies have demonstrated that, at constant temperatures, silica dissolution increases with increasing acid concentrations, but it decreases when the temperature is increased and the acid concentration is reduced. This is due to the enhancement in the solubility of monomeric silicic acid formed during acidic leaching. The control mechanisms of silica dissolution have been described according to the shrinking core model by a chemical reaction stage, i.e., silica polymerization, followed by a diffusion stage, because of the silica gel adsorbed on the surface of the particles that limits the metal extraction. The recovery of iron, titanium, aluminium, and rare earth elements from bauxite residues preventing silica gel formation was performed using the dry digestion process with sulphuric acid and hydrogen peroxide (Alkan et al, 2018). The operational parameters were investigated and the addition of 2.5M hydrogen peroxide into 2.5M sulfuric acid was decided to be the best leaching condition to have favored quartz formation with a suppressed rhomboclase precipitation. Since the leaching reactions are mainly controlled by diffusion, no significant increase in the efficiencies was observed after 30 minutes of leaching. While Si gel was not formed in the oxidative environment, high titanium extraction from bauxite residue was only achieved when hydrogen peroxide was introduced into the acidic solution.

The combined pyrometallurgical and hydrometallurgical treatment of bauxite residue for the recovery of valuable metals included firstly carbothermic reduction (Xakalashe & Friedrich, 2018). The reductive smelting of bauxite residue uses coke as the reductant between 1500 and 1550°C and acidic to basic fluxes to low temperature smelting and the production of conditioned slag. Additional conditioning of bauxite residue with basic oxygen furnace slag and bottom ash as fluxing agents in the smelting process was performed in order to recover the valuable metals with the exclusive use of the secondary resources as slag formers (Lucas et al, 2018). The final products based on aluminium, titanium, rare earth elements and scandium were obtained after a hydrometallurgical treatment using leaching, filtration, and precipitation (Yagmurlu et al, 2019).

The aim of this work is to offer the first information about the characterisation of bauxite residue from Alumina, Zvornik, and study its behaviour after a hydrometallurgical treatment using hydrochloric and sulphuric acid under the atmospheric pressure in the absence of hydrogen peroxide!

Methods

The mineralogical characterization of the samples was carried out using the X-ray diffraction technique – XRD. After the measurement, we processed the spectral images of the sample with the help of Difrac software, EVA v 4.2.2. The obtained values d (2θ), which are characteristic for each mineralogical phase, were compared with the literature data in the existing database, and thus we identified the present crystal phases.

The sample preparation was performed in single steps. The samples needed to be prepared so that their granulation was about 50μm, so that a flat-surface pallet could be made in polyethylene molds. In most samples, it was difficult to fulfill this condition due to the hardness of the samples that could not be prepared in the crucible. Regardless of the difficulties, making a pallet that did not have a flat surface was successful. The operational conditions are present in Table 2:

Table 2 – Operational data for the XRD-measurement
Таблица 2 – Оперативные данные для рентгеноструктурного анализа
Табела 2 – Операциони подаци коришћени за рендгеноструктурну анализу

Device	Model	Producer	Current	Voltage	Time per step		Range **2θ**	step
XRD	Endeavor D8	Bruker	40mA	35KV	40mA		10-90	0.5

In order to determine the elements in the ppm range, the samples are measured on the ICP-OES device, using an optical emission technique that uses inductive-coupled plasma as a source. This technique is intended for analysing trace elements and requires translating the sample into an acidic solution. The sample preparation was performed using ISO

6607-1985 method. The method involves the destruction of the sample with three concentrated acids (sulfuric, nitric and hydrochloric) at the beginning, and the treatment of the precipitate with hydrofluoric acid to translate residual elements (except SiO_2) into a solution. After this preparation, a complete dissolution was expected. Total dissolution was confirmed during the treatment of solid residue obtained in the leaching experiments at 90°C.

Material

Due to its properties such as high alkalinity, bauxite residue can be used as an input material in various neutralization processes. Three different types of bauxite residue were compared, as shown in Table 3.

Table 3 – Chemical Composition of BR (Lucas et al, 2021)
Таблица 3 – Химический состав бокситового шлама (Lucas et al, 2021)
Табела 3 – Хемијски састав бокситних остатака (Lucas et al, 2021)

Percent (%)	Fe_2O_3	Al_2O_3	CaO	SiO_2	TiO_2	Na_2O	Cr_2O_3	Sc (ppm)
Germany	35.3	15.7	6.7	14.0	11.4	8.9	0.2	86
Greece	44.0	23.0	10.2	5.5	5.6	1.8	0.3	122
Zvornik	49.3	12.0	8.2	10.5	4.6	2.5	0.13	76

This table shows that the bauxite residue from Zvornik, Bosnia and Herzegovina contains mostly iron oxide. The Greek bauxite residue contains more scandium, aluminium oxide, and chromium oxide but smaller content of sodium oxide than the German and Zvornik ones. The bauxite residue from Germany is highly alkaline due to the presence of sodium hydroxide from the Bayer process. Bauxite residue was provided from Alumina Ltd, Zvornik, Bosnia and Herzegovina, as the starting raw material. The Alumina factory has been in the continuous production mode since October 6, 1978, and continuously processes bauxite and produces alumina, hydrates, zeolites, and other related aluminosilicate products. The Alumina company currently has about 1500 employees, which is about 25 % of all employees in Zvornik. Alumina owns a red mud disposal site located about 5 km from the factory. The transportation of the red mud suspension from the factory to the landfill is carried out by suitable pumps. The area of the red sludge landfill is about 1 km^2, as shown in Figure 1.

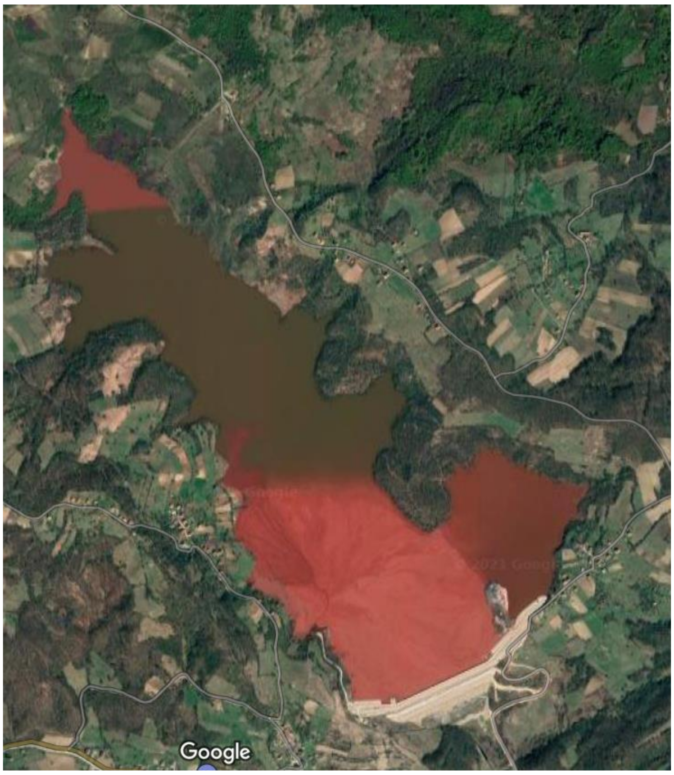

Figure 1 – Area of the accumulated bauxite residue in Zvornik, Bosnia and Herzegovina
Рис. 1 – Площадь скопления бокситового шлама в г.Зворник, Босния и Герцеговина
Слика 1 – Површина акумулисаног бокситног остатка у Зворнику, Босна и Херцеговина

During the operation of the Alumina Ltd. company, about 19.4 x 106 m^3 of red mud suspension was disposed of. Depending on the quality of bauxite, the amount of completely dry red mud typically ranges from 0.8 to 2 tons of tailings per ton of alumina produced. The Alumina Ltd. company from Zvornik uses bauxite with a silicon dioxide modulus between 8.5 and 12. Accordingly, the amount of red mud that is separated and disposed of at the landfill is about 1.0 - 1.2 tons per ton of Al_2O_3 produced, or approximately 400,000 t / per year. The installed technical-technological equipment at the clearing plant is of a continuous (uninterrupted) nature, where there are five installed autoclave batteries of 11-12 interconnected autoclaves in series (each autoclave has 50 m^3).

The bauxite residue from alumina was filtrated, washed and dried at 105 °C for 24 h.The chemical composition of bauxite residue is shown in Table 4.

Table 4 – Chemical composition of BR, Zvornik
Таблица 4 – Химический состав бокситового шлама в г.Зворник
Табела 4 – Хемијски састав бокситних остатака у Зворнику

Compounds	%	Compounds	%
Ignition loss at 1000°C	8,32	Ga_2O_3	0,225
SiO_2	10,52	CuO	0,007
Fe_2O_3	49,29	K_2O	0,159
Na_2O	2,45	Tl_2O_3	0,088
TiO_2	4,59	MnO	0,145
CaO	8,23	MgO	0,627
Al_2O_3	12,03	NiO	0,034
Ag_2O	0,001	PbO	0,019
BaO	0,014	P_2O_5	0,930
Cr_2O_3	0,133	ZnO	0,016
Sc_2O_3	0,011	V_2O_5	0,135
Co_2O_3	0,012	SrO	0,075

One additional elemental ICP -OES analysis was performed in order to establish the content of rare earth elements (REE) presented in Table 5:

Table 5 – Content of rare earth elements in BR, Zvornik
Таблица 5 – Содержание редкоземельных элементов бокситового шлама в г. Зворник
Табела 5 – Садржај елемената ретких земаља у бокситним остацима у Зворнику

Content	Pr	Sc	Y	La	Ce	Nd	Sm	Tb	total
ppm	12	76	133	114	250	96	11	8	700

As shown in Figure 2, the XRD-analysis found the following phases: hematite, perovskite, cancrinite, cancrinite, ilmenite, calcite, diaspore, gibbsite, and hydrogarnet. Iron is available in the hematite and ilmenite structures. Titanium is present in perovskite and ilmenite structures, while aluminum is available in the structures of cancrinite, diaspore, boehmite, gibbsite, and hydrogarnet.

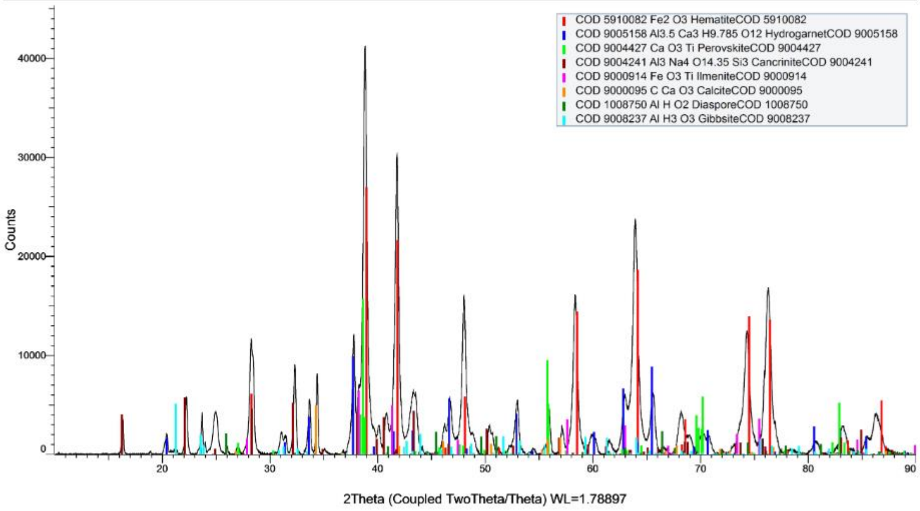

Figure 2 – XRD-analysis of BR from Zvornik
Рис. 2 – Рентгеноструктурный анализ бокситового шлама в г. Зворник
Слика 2 – Рендгеноструктурна анализа бокситног остатка из Зворника

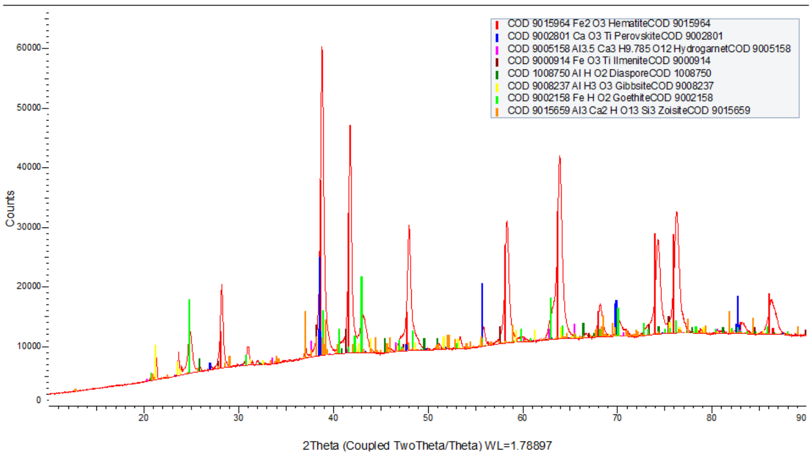

Figure 3 – XRD-analysis of solid residue after leaching with 1mol/L hydrochloric acid at 90 °C for 2 hours
Рис. 3 – Рентгеноструктурный анализ твердого шлама после выщелачивания 1 моль/л соляной кислоты при 90°C в течение 2 часов
Слика 3 – Рендгеноструктурна анализа чврстог остатка после лужења 1 Mol/L хлороводоничном киселином на 90°C, у трајању од два сата

Experimental

The first experiments were performed in order to study the change of the mineralogical structure during leaching experiments. The leaching was performed using 1mol/l hydrochloric acid and 1mol/L sulfuric acid at 90 °C with a solid/liquid ratio 1:10 and a mixing rate of 200 rpm for 2 hours. The obtained XRD-analysis results are shown in Figures 3 and 4.

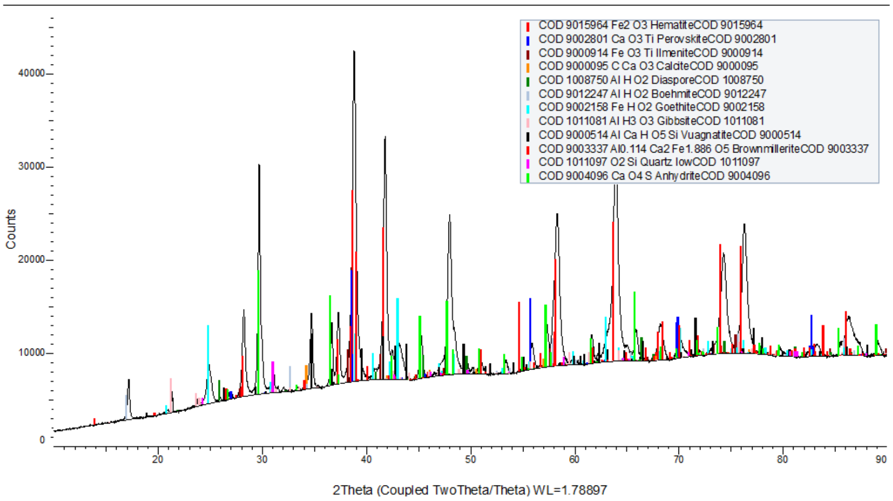

Figure 4 – XRD-analysis of solid residue after leaching with 1mol/L sulphuric acid at 90 °C for 2 hours
Рис. 4 – Рентгеноструктурный анализ твердого шлама после выщелачивания 1 моль/л серной кислоты при 90°C в течение 2 часов
Слика 4 – Рендгеноструктурна анализа чврстог остатка после лужења 1 Mol/L сумпорном киселином на 90°C, у трајању од два сата

The comparative analysis of the obtained XRD-analysis results is presented in Table 6.

The analysis of the initial bauxite residue in Figure 2 has shown that Fe is present in the hematite and ilmenite structure, Ti in perovskite and ilmenite and Al in cancrinite, diaspore, boehmite, gibbsite and hydrogarnet. Direct leaching of BR (as shown in Figs. 3 and 4) confirms that the mineral structure is not only changed, but also some new compounds are found such as vuagnitit, brownmillerite, anhydrite ($CaSO_4$), as shown int Figure 3. The addition of sulphuric acid leads to the formation of unsoluble calcium sulphate.

Table 6 – Comparative analysis of the mineralogical phases
Таблица 6 – Сравнительный анализ минералогических фаз
Табела 6 – Упоредна анализа минералошких фаза

Material	Process	Mineral	Phase composition
Red mud (Bauxite residue)	Bayer (autoclave) T=150°C t=2 hours addition of NaOH	Hematite Perovskite Cancrinite Ilmenite Calcite Diaspore Gibbsite Hydrogarnet	Fe_2O_3 $CaTiO_3$ $Al_3Si_3Na_4O_{14.35}$ $FeTiO_3$ $CaCO_3$ AlOOH $Al(OH)_3$ $Al_{3.5}Ca_3H_{9.875}O_{12}$
Solid residue after a leaching of BR with hydrochloric acid	Leaching of BR using 1 mol/L HCl, 90 °C, 120 min	Hematite Perovskite Hydrogarnet Diaspore Gibbsite Goethite Zoisite	Fe_2O_3 $CaTiO_3$ $Al_{3.5}Ca_3H_{9.875}O_{12}$ AlOOH $Al(OH)_3$ FeOOH $Ca_2Al_3(SiO_4)(Si_2O_7)O(OH)$
Solid residue after a leaching of BR with sulfuric acid	Leaching of BR using 1 mol/L H_2SO_4, 90 °C, 120 min	Hematite Perovskite Ilmenite Calcite Diaspore Boehmite Goethite Gibsite Vuagnatit Brownmillerite Quartz Anhydrite	Fe_2O_3 $CaTiO_3$ $FeTiO_3$ $CaCO_3$ α-AlOOH Υ-AlOOH FeOOH $Al(OH)_3$ $CaAlSiO_4(OH)$ $Ca_2(Al,Fe)_2O_5$ SiO_2 $CaSO_4$

The analysis of the obtained solution with the calculated leaching efficiencies is shown in Table 7:

Table 7 – Chemical composition of the obtained solution and the calculated leaching efficiency
Таблица 7 – Химический состав полученного раствора и рассчитанная эффективность выщелачивания
Табела 7 – Хемијски састав добијеног раствора и израчуната ефикасност лужења

Elements from solutions are presented as compounds	Leaching with 1M HCl (90°C, 2hours, s/L: 1/10)		Leaching with 1M H_2SO_4 (90°C, 2hours, s/L: 1/10)	
	Content (mg/L)	Leaching Efficiency (%)	Content (mg/L)	Leaching Efficiency (%)
Al_2O_3	7190	59.76	7292	60.61
SiO_2	2351	22.34	1369	13.01
P_2O_5	84.7	9.10	128.1	13.76
V_2O_5	8.8	6.51	41.4	30.66
SrO	12.6	16.8	7.9	10.53
Ga_2O_3	10,9	4.84	22.4	9.95
K_2O	46.2	29.05	56.4	35.47
Y_2O_3	16.3	9.65	13.6	8.05
NiO	4.44	13.08	9.1	26.76
Cr_2O_3	15.3	11.50	19.1	14.36
MnO	11.2	7.7	15.2	10.45
Ce_2O_3	13.3	4.54	4.0	1.37
Sc_2O_3	4.98	45.27	5.82	52.90
PbO	5.27	27.73	4.4	23.16
Fe_2O_3	718	1.46	1096	2.23
TiO_2	233	5.07	441	9.60

For aluminum, the maximum leaching efficiency was about 60 % for both used acids. The small leaching efficiency has confirmed that the leaching time of 2 hours was not enough to ensure complete leaching efficiency. Leaching efficiency from scandium is maximal for critical metals (52.90 %), but not sufficient.

Therefore, the increased concentration of solution, reaction temperature, and duration of process in the presence of hydrogen peroxide will be considered in order to increase leaching efficiency. The formation of silica gel is confirmed in a study of the leaching process with sulfuric acid under the atmospheric pressure, as shown in Figure 5:

Figure 5 – Formation of silica gel after sulfuric acid leaching at 90°C
Рис. 5 – Образование силикагеля после сернокислотного выщелачивания при 90°C
Слика 5 – Формирање силика гела након растварања сумпорном киселином на 90°C

Natural precipitation of iron from the obtained solution has been confirmed after leaching with hydrochloric acid, as shown in Figure 6!

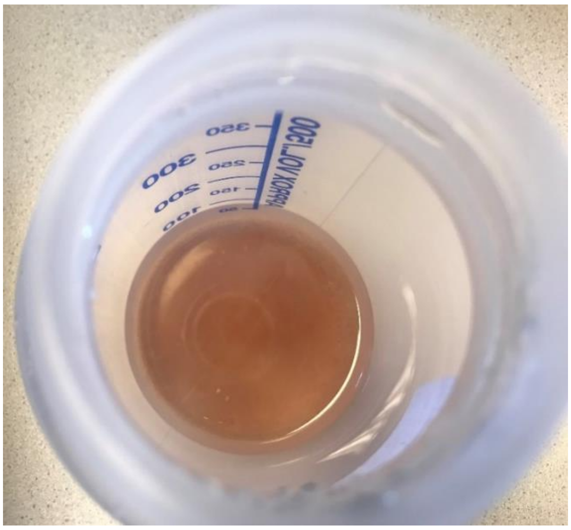

Figure 6 – Natural precipitation of iron after hydrochloric acid leaching at 90°C
Рис. 6 – Естественное осаждение железа после солянокислотного выщелачивания при 90°C
Слика 6 – Природно таложење железа након растварања хлороводоничном киселином на 90°C

The formation of silica gel and the natural precipitation of iron can be prevented through the dry digestion process in the presence of hydrogen peroxide, as mentioned in the literature review. The performed experiments of acidic leaching confirmed some difficulties related to a direct leaching process. Therefore, highly efficient technology is proposed to improve leaching efficiency of valuable metals. The pyrometallurgical method can ensure destroying the mineralogical structure of bauxite residue forming a more suitable slag structure for better leaching using different acids. A combined pyrometallurgical and hydrometallurgical method for the treatment of bauxite residue will be reported in the future in order to improve a direct leaching process.

Conclusion

The hydrometallurgical treatment of bauxite residue with 1mol/l hydrochloric acid and 1mol/L sulphuric acid at 90°C for 2 hours leads to a maximum leaching efficiency of aluminium about 60 %, 53 % of scandium and a minimum efficiency of other valuble elements, respectively. The analysis of the changes in the mineralogial structure has revaled that small changes are possible during the hydrometallurgical treatment. A new research strategy for the treatment of bauxite residue is needed in order to ensure a full change of the initial mineralogical structure and the most efficient transfer of metals from bauxite residues to a liquid phase. The formation of unsoluble calcium sulphate is found during leaching with sulphuric acid. The silica gel formation and the natural precipitation of iron from the solution are some difficulties that can be prevented using dry digestion. The following step is an improvement of a direct leaching process using a pyrometallurgical method such as hydrogen plasma reduction.

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Обработка бокситового шлама − кислотное выщелачивание (первая часть)

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РУБРИКА ГРНТИ: 61.13.21 Химические процессы
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: Бокситовый шлам, являющийся побочным продуктом алюминиевой промышленности, получаемый по способу Байера, в основном состоит из оксида железа, оксида титана, оксида кремния и нерастворимого оксида алюминия, а также широкого спектра других оксидов и незначительного содержания редкоземельных элементов, галлия, ванадия и скандия. Извлечение ценных элементов из бокситового шлама и минимизация его образования в ходе обработки являются недостаточно исследованной областью.

Методы: В обработке бокситового шлама использовались различные гидрометаллургические и пирометаллургические методы. В данном исследовании представлены результаты гидрометаллургической обработки бокситового шлама из глинозема Зворник с использованием серной и соляной кислот с целью изучения изменения минералогического состава. Эффективность выщелачивания рассчитана на основании анализа ICP OES. Рентгеноструктурный анализ был использован в изучении свойств исходного материала и твердого шлама и в изучении изменений минералогических фаз.

Результаты: Выщелачивание бокситового шлама серной и соляной кислотой частично приводит к изменению минералогической структуры и преобразованию элементов в жидкую фазу. С течением времени наблюдается естественное осаждение железа в состоянии покоя. Подтверждено образование силикагеля в процессе выщелачивания бокситового шлама соляной кислотой.

Выводы: В области обработки бокситового шлама необходимо разработать новую исследовательскую стратегию с целью обеспечения полного изменения исходной минералогической структуры и наиболее эффективного преобразования металлов в жидкую фазу.

Ключевые слова: бокситовый шлам, алюминий, гидрометаллургия, кислота, рециклирование, редкоземельные элементы.

Третирање бокситних остатака – лужење (први део)

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ОБЛАСТ: хемијске технологије
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Остатак од лужења боксита је отпадни продукат из индустрије алуминијума настао у Бајеровом процесу састављен од оксида железа, титана, силицијума и нераствореног алуминијум-оксида са широким спектром других оксида и минималним садржајем елемената ретких земаља, галијума, ванадијума и скандијума, који се мења сагласно земљи из које потиче. Екстракција вредних елемената из бокситног остатка и минимизација бокситног остатка кроз различите третмане су отворено истраживачко поље.

Методе: Различите хидрометалуршке и пирометалуршке методе коришћене су за третирање бокситних остатака. У раду су приказани резултати хидрометалуршког третмана коришћењем сумпорне и хлороводоничне киселине како би се проучиле промене минералског састава. Ефикасност лужења биће израчуната коришћењем ИЦП ОЕС анализе. Рендгеноструктурна анализа коришћена је за карактеризацију почетног материјала и чврстог остатка проучавајући промене минералошких фаза.

Резултати: Растварање бокситног остатка сумпорном и хлороводоничном киселином води делимично до промене минералске структуре и трансфера елемената у течну фазу. Природна преципитација железа присутна је током стајања. Формирање силика гела потврђено је током растварања бокситних остатака хлороводничном киселином.

Закључак: Нова истраживачка стратегија неопходна је за третирање бокситног остатка како би се обезбедила потпуна промена минералошке структуре и много ефикаснији пренос метала у течну фазу.

Кључне речи: бокситни остатак, алуминијум, хидрометалургија, киселина, рециклирање, елементи ретких земаља.

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