ECOTOXICITY OF RESIDUES FROM THE LEACHING PROCESS OF BAUXITE RESIDUE FOR SCANDIUM PRODUCTION

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Abstract

Scandium may be produced from bauxite residue through a series of technological steps. The first step – leaching – is one of the most crucial ones regarding the amount and characteristics of generated residues. We compared four different technology alternatives towards ecotoxicity of the generated solid residues. These alternatives were: 1. ionic liquid leaching; 2. mineral acid leaching at high temperature; 3. mineral acid leaching at ambient temperature; 4. mechanochemical leaching with mineral acid. The results showed that the ecotoxicity of the residues from the various technologies increased in the following order: ionic liquid leaching < high temperature mineral acid leaching < ambient temperature mineral acid leaching < mechanochemical mineral acid leaching.

Introduction

Scandium production from bauxite residues (BR) includes several technological steps[1]. The first step, leaching of the targeted element(s) from the BR generates the highest amount of residue, so it is crucial to analyse these from an ecotoxicological point of view. The technology alternatives are: 1. ionic liquid leaching; 2. mineral acid leaching at high temperature; 3. mineral acid leaching at ambient temperature; 4. mechanochemical leaching with mineral acid.

Materials and methods

Samples originated from the laboratory experiments performed within the SCALE project by different partners (Table 1). From the solid samples, both solid (whole soil tests) and 1:10 aqueous extracts (shaken for 24 h at 300 rpm, filtered) were tested. Chemical analysis of the extracts was carried out by inductively coupled plasma-mass spectrometry (ICP-MS 7'500cx / 8800, Agilent Technologies). The ecotoxicity test battery applying testorganisms from three trophic levels included: *Aliivibrio fischeri* (bacteria) bioluminescence inhibition test[2], *Sinapis alba* (plant) root and shoot elongation test[2], *Daphnia magna* (crustacean) immobilization test[3]. Effective Concentrations (EC_{20}, concentration causing 20% inhibition) were calculated from the inhibition % (compared to the control) of a sample dilution series. The EC was expressed as x-fold dilution of the initial sample. EC_{20} values can be regarded as the lowest dilution that have a significant toxic impact[4]. We considered median EC_{20} values from all tests as the threshold dilution with tolerable toxic effect.

Table 1. Samples from various leaching procedures of the bauxite residue carried out in the SCALE project

Sample name	Leaching technology
BR	Bauxite Residue (Greek)
LIL SR	Leaching with Ionic Liquids, Solid Residue (HbetTf2N [betainium bistrifluoromethylsulfonylimide] by Iolitec Ltd.) sample by NTUA LabMet*
HTLMA SR	High Temperature Leaching with Mineral Acid, Solid Residue (4M H_2SO_4, 95 °C, 2 h, 400 rpm, S:L=1:5, washed, dried) sample by NTUA LabMet
ATLMA SR	Ambient Temperature Leaching with Mineral Acid, Solid Residue[5] (2M H_2SO_4, 1 h, 550 rpm, S:L=1:10) sample by NTUA ChemLab**
LMC SR	Mechanochemical Leaching, Solid Residue (3M H_2SO_4, 1 h milling, S:L=1:5) sample by Fraunhofer-Gesellschaft

*NTUA LabMet: School of Mining and Metallurgical Engineering, National Technical University of Athens, Greece
**NTUA ChemLab: School of Chemical Engineering, National Technical University of Athens, Greece

Results and discussion

Results of the ecotoxicity tests are presented in Table 2. BR showed slight acute aquatic toxicity (detected with *D. magna,* no effect measured by *A. fischeri* and *S. alba*), in accordance with previous results detecting no acute toxicity of BR sediment for marine environment[6]. The *S. alba* direct contact test indicated 8 times dilution as the threshold for acceptable toxicity. This was in accordance with previous results showing that more than 10 w/w% BR in soil may be significantly toxic to *S. alba*[7].

The residue from leaching with ionic liquid was not toxic to the applied testorganisms (20% inhibition was not reached by the lowest measured dilution), only a slight toxicity was detected with the direct contact plant test (3 times dilution needed to reach the acceptable toxicity). The residue from the high temperature mineral acid leaching was also less toxic than the BR itself. These results may be attributed to the washing step introduced after leaching of the residues.

The residue from ambient temperature mineral acid leaching was more toxic than the BR, with higher EC_{20} values in all test organisms. Residue from mechanochemical leaching had the highest acute and chronic toxicity to the aquatic environment. However, the direct contact plant test showed only a slight toxicity with similar EC_{20} values to the LIL technology residue. In the latter case milling was applied to enhance the leaching of the targeted element, and smaller sized particles may have contributed to higher aquatic toxicity by affecting the testorganisms negatively.
The toxicity order of the residues was in accordance with the chemical analytical data. The metal amount (e.g. Al, Ti, Fe, Cr, Co, Ni) in the water extracts of the residues was proportional with their toxicity.

Table 2. EC_{20} values for the residues generated in the BR leaching technology alternatives

Test-organism	Test duration	Sample	Acute / chronic	**BR**	**LIL SW**	**HTLMA SW**	**ATLMA SW**	**LMC SW**
				EC_{20} (dilution)*				
A. fischeri	30 min	Extract	Acute	<5x	<5x	<5x	6x	11x
	60 min			<5x	<5x	<5x	10x	16x
D. magna	48 h			30x	<2x	<2x	32x	106x
	72 h			30x	<2x	<2x	33x	106x
S. alba	72 h shoot			<1x	<1x	3x	15x	26x
	72 h root			<1x	<1x	3x	19x	27x
Median				**5x**	**<2x**	**3x**	**17x**	**26x**
A. fischeri	120 min		Chronic	<5x	<5x	<5x	30x	159x
	180 min			87x	<5x	<5x	80x	154x
Median				**46x**	**<5x**	**5x**	**55x**	**157x**
S. alba	72 h shoot	Solid	Acute	13x	2x	12x	15x	4x
	72 h root			3x	4x	N.D.	19x	2x
Median				**8x**	**3x**	**12x**	**17x**	**3x**

*The lowest dilution measured was 5x for *A. fischeri*, 2x for *D. magna*, *S. alba* solid sample and 1x for *S. alba* liquid sample due to the test setup or limited amount of sample.

Conclusions

Based on the ecotoxicity of the residues generated from the various BR leaching technology alternatives, we can rank the technologies. From an ecotoxicity point of view the order of the technology alternatives (from less toxic to the most toxic) in the first step of BR treatment within the SCALE technology line is the following: ionic liquid leaching < high temperature mineral acid leaching < ambient temperature mineral acid leaching < mechanochemical mineral acid leaching. The washing step applied in case of the two less toxic samples, may have influenced the ecotoxicity results and thus may also decrease the adverse effect of mechanochemically leached residues in practise.

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