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Environmental assessment of Rare Earths recovery method from bauxite residues

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ABSTRACT – Bauxite residue is highly alkaline and very fine-grained by-product of the Bayer process with an increasing annual production of about 150 million tonnes. The management and safe disposal of bauxite residue are therefore a major issue for bauxite and alumina industries affecting the production cost. This study focuses on the environmental assessment of an innovative integrated process for the recovery of Rare Earth Elements and Scandium from bauxite residue in the framework of the European research project REEScue. The aim is to identify hot spots and provide a quantified assessment of the environmental impacts of the new technologies and final materials.

Keywords: Rare Earth Elements, Critical Metals, Bauxite Residues, Secondary Raw Material, Life Cycle Assessment

Introduction

Aluminium is important in various sections of industry and the economy. Bauxite is the basic raw material processed and converted to alumina for aluminium and industrial alumina production [1]. The Bayer process is the method utilised for this transformation. One of the challenges facing the Bayer process is the need of treatment and disposal of bauxite residues (BR) commonly known as red mud (RM).

BR is the major waste material produced during alumina production following the Bayer process. It is derived from the process of caustic digestion of crushed bauxite at elevated temperatures. BR is characterized by tiny particle size and high alkaline value [2]. These properties make the disposal of RM a very challenging process as it leads to serious environmental issues and affects production cost.

Depending on the quality of the bauxite processed, 1.0 to 1.8 tons of bauxite residues are generated per tonne of alumina produced, on average [3, 4]. The annual production

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of BR is about 150 million tonnes. BR is rich in minerals and metals of high economical interest. Typically, BR material contains mainly CaO, Al_2O_3, Fe_2O_3, SiO_2, TiO_2, Na_2O, V_2O_5 and Rare Earth Oxides (REO). The exact composition is related to the bauxite ore sources and production processes [1]. The exploitation of BR as a low-cost secondary raw material and metal resource could be a solution for BR reduction and would enter the waste again in the economic cycle [5]. The content of the single elements is not very high; hence the total amount of resource is huge leading to considerable amounts of recovered elements.

One approach is tapping BR as a source of scandium as it accounts for more than 90% of rare earth elements (REEs) with economic value present in BR [1], and other REEs. According to a policy brief of the EU-funded SCALE project, it is estimated that extracting the REE from the Aluminium of Greece's annual BR production can meet the needs of approximately 10% of the of Europe's demand [6]. Innovative extraction and separation technologies are suggested to tackle the weaknesses and risks resulting from the existing methods utilised.

In the framework of the REEScue project, two processes are developed; i) the direct acid leaching of BR with the addition of oxidative agents and, ii) the hydrothermal conversion of hematite to magnetite, magnetic separation of magnetite and the production of a non-magnetic fraction rich in basic metals and REEs, leaching of metals from the non-magnetic fraction.

The aim of this study is to assess the expected environmental impact and the sustainability of the developed processes, and to detect the hotspots that requires taking action, in terms of energy efficiency and environmental impacts. The implementation of the Life Cycle Assessment (LCA) is the main tool for reaching this objective.

EXPERIMENTAL

Bauxite Residues Treatment Processes

Two process options are evaluated for the extraction of scandium and REEs from BR. The two processes are the direct leaching of bauxite residues process and the hydrothermal transformation process.

Direct leaching of Bauxite Residues

Leaching is a primary process in hydrometallurgy for recovery of the desired elements, applied mainly when there is low concentration. It is a mass transfer operation in which constitutes of the solid material are released into a contacting water phase with the contribution of different solvents [7]. The selection of the solvent for operating the leaching process is of great importance. The solvent affects the extraction efficiency, the purity of desired elements recovery, and the concentration of REEs in the leachate.

In this case there is examined the direct acid leaching of the BR, i) using solution with higher acid concentrations, and ii) adding oxidative agents.

Hydrothermal transformation process

Hydrothermal transformation for the exploitation of BR is a novel approach. This process is a sequence of different sub-processes. At first the hematite is transformed

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magnetite implementing hydrothermal conversion. Hydrothermal treatment, is a treatment method which generates a reaction of material with high temperature and high-pressure steam, with the contribution of alkaline media. In this case, the red mud is processed with the hydrothermal treatment for hematite to be transformed into magnetite to enhance its magnetization character [8]. BR treatment takes place in autoclave combined with Fe source. To reduce hematite to magnetite high temperature, reaching 250°C and, alkaline conditions are required.

The magnetic separation follows and then the leaching process. Magnetic separation, follows. The magnetite and the non-magnetic materials are separated, taking advantage of their magnetic properties. The non-magnetic fraction is rich in basic metals and REEs. From this procedure an iron-rich concentrate and a residue are produced. Leaching of the metals from the non-magnetic fraction produced and collected as residues is the final step. The residues generated from the magnetic separation phase are processed with the use of acid agents, as hydrogen chloride (HCl), to dilute the REEs. Both direct leaching and hydrothermal transformation processes are followed by the recovery of REEs from the leaching solutions using ionic resins.

Life Cycle Assessment

Methodology

LCA is a well-established, internationally recognized and standardised methodology for assessing the environmental impacts and detecting the environmental hotspots of a production process that require taking action in order to optimise it. According to ISO14040 (ISO, 2006), an LCA consists of the following steps: i) definition of goal and scope, ii) life cycle inventory (LCI), iii) life cycle impact assessment (LCIA) and iv) interpretation of the results [9, 10].

Goal and Scope

The goal of this study is to assess and evaluate the expected environmental impacts and to identify the points with the highest environmental burden. The life cycle phases of the input and output material flows, the energy flows, the wastes and emissions generated are under consideration.

The functional unit (FU), is part of the scope definition and provides the reference for the normalisation of all the flows. In the present study the FU defined is 1kg of BR used.

System Boundary

Two different models are designed corresponding to the different cases examined. The first model concerns the direct leaching of the BR. All inputs (BR, electricity, water, solvents, acids, etc.), and outputs (recovered material, solid waste residues, recovered liquids, etc.), are included within the system boundaries.

The second model concerns the hydrothermal transformation. This model is investigated in three different phases; i) the hydrothermal transformation, ii) the magnetic separation and, iii) the leaching of the non-magnetic fraction. All inputs (BR,

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electricity, water, solvents, etc.), and outputs (recovered material, solid residues, recovered liquids, etc.) corresponding to each of phase, are included within the system boundaries.

Life Cycle Inventory

The LCI realised for the implementation of this environmental assessment is based on the data acquired from the use cases implemented and the literature review. Information concerning the inputs and outputs entering and exiting the system boundaries, for the assessment of BR treatment will be collected and evaluated. The information acquired will be evaluated in terms of accuracy, coherence and consistency.

The material treated (BR), the solvents used for the treatment, the energy required for processes' implementation and the water used are some of the inputs. In the other hand, the product produced or extracted, the solid and liquid wastes generated, the emissions ejected, etc. comprise the output flows.

Life Cycle Impact Assessment

LCIA uses the results of the LCI modelling analysis and the impact factors defined for the quantification of the environmental impacts of the processes. The mass of the environmental impact is connected with the FU.

Results and Discussion

Results

BR results in the large amounts of waste produced in industrial level affecting the Aluminium production industries in terms of production cost and environmental impact. Every new method and technique suggested is assessed and evaluated to better understand their feasibility and environmental performance.

For the extraction of Scandium from BR the model 1 uses combination of processes, namely: i) leaching with mineral acid (LMA), ii) Purification with selective ion recovery and ion exchange, iii) Purification with solvent extraction, iv) antisolvent crystallization and v) calcination, the greenhouse gas (GHG) value totals at 0.1-0.12 kg CO_2-eq. per kg of BR treated [11]. The LMA counts for the largest share of the impact accounted, ~93% of the total impact, approximately 0.093-0.11 kg CO_2-eq per kg of BR treated. The elevated amount of acid required for the process and the energy consumption, accounts for more than 80% of the total impact resulting from the analysis. Besides, the theoretical maximum avoided burden for extracting scandium oxide from 1kg is estimated at 1.13 kg CO_2-eq when comparing with the landfilling of BR.

Model 2 includes: i) the hydrothermal treatment, ii) the magnetic separation and, iii) the leaching of the non-magnetic fraction. In both hydrothermal treatment and magnetic separation, the energy consumption is responsible for the environmental impact of the two processes. The GHG value of these processes is 3.44 kg CO_2-eq. per kg of BR treated. The non-magnetic fraction that will be leached to recover the RRE, is approximately 20% of the BR treated. The GHG value for leaching process is approximately 0.022-0.026 kg CO_2-eq. per kg of BR treated. The GHG value of for this model totals at 3.462-3.466 kg CO_2-eq. per kg of BR treated.

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Discussion

The bauxite processing to Aluminium production results in BR after the Bayer plant processing. The BR is an important factor impacting on the function of an Aluminium industry and having significant environmental risks.

From the moment slurry bauxite exits the washers within the Bayer plant until the place of bauxite residues in the disposal area, transport, dewatering, disposal, recovery and discharge take place. Additionally, this combined with the huge amounts of BR generated from the industry and the space needed for their disposal rise the need for introducing new better methods for BR management.

Further treatment of BR and extraction of economically important elements is a solution for both industry viability and environmental sustainability. In this study, two new methods are presented and evaluated for their efficiency and sustainability, the direct leaching of BR and the hydrothermal transformation process. As occurring from other BR treatment methods for extracting RRE, numerous sub-processes are conducted. Each sub-process and the system as a whole must be evaluated to better understand their impact and make any necessary improvements implementing LCA.

Conclusions

In this study, it is described the methodology followed for the LCA implementation on two new methods for BR treatment and Scandium extraction. The acid leaching process is the one with the most environmental burden due to the amount of acid used and the energy consumption need. However, the extraction of Scandium from BR remains a better solution than disposing the BR combined with directly extracting Sc from ore mines.

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