Exploring cleaner routes of Alumina Production: Thermodynamic Simulation of Pedersen Process and CO_2 Capture Integration via Calcium Looping

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Abstract

Alumina industry stands out as a significant contributor to mineral scarcity because of the generation of bauxite residue during its production process. This study explores an alternative route to produce alumina: the Pedersen process. A thermodynamic simulation and an energy optimization are implemented to avoid bauxite residues and reach the goal of zero CO_2 emissions.

Introduction

Aluminium stands currently as one of the most demanded metals. Alumina (Al_2O_3) is its essential precursor and it is obtained from bauxite ore through the Bayer process. This process faces two significant drawbacks. First, the generation of bauxite residue, a highly alkaline muddy residue that entails substantial environmental and health risks [1]. The second one is the high energy demand of the process, for which fossil fuels are used, emitting significant amounts of CO_2. Alternative routes to produce alumina are being explored to address these challenges.

One of these routes is the Pedersen process, which was industrially applied in Norway until 1969, when it was discontinued because of economic reasons [2]. This process has regained interest in recent years because of its environmental advantages. Its main peculiarity is the use of an electric arc furnace to remove the iron present in bauxite by smelting-reduction before extracting alumina. Thus, reduced iron can be commercialized as pig iron and bauxite residue generation is minimized. A basic flowsheet of the process is shown in Figure 1. Other features include the use of $CaCO_3$ and CO_2 as raw materials.

CO_2 capture technologies have gained much interest thanks to their contribution to mitigating global warming. Among them, calcium looping (CaL) is one of the most promising technologies due to their relatively low energy penalty [3]. CaL technology consists of putting flue gases containing CO_2 through a carbonation-calcination cycle. Calcium oxide (CaO) is used as a sorbent, producing calcium carbonate, which is later decomposed to isolate CO_2. A simple CaL layout is shown in Figure 2.

Accordingly, the goal of this work is to carry out a simulation of the complete Pedersen process based on thermodynamics and bibliographic references. In addition, the integration of a CaL plant is analyzed in the same simulation environment, with the aim of providing a source of CO_2 for the Pedersen process and quantifying the penalty of the CO_2 avoided.

Methods

A thermodynamic model of a Pedersen process plant was developed in Aspen Plus V12.1 software. The plant was sized to treat nearly 1.5 million tonnes of bauxite per year and the composition of the bauxite employed in the study was 80.1%wt $Al(OH)_3$, 15.7%wt Fe_2O_3, 2.7%wt SiO_2 and 1.5%wt TiO_2. The model comprehended the production of pig iron, grey mud and alumina from bauxite, using natural gas as energy source.

Next, a CaL configuration was integrated into the simulation. Basis of the integration consisted of carrying out a purge of CaO sorbent at the CaL calciner to avoid its deactivation. Purged CaO was then used in the bauxite dehydration unit, decreasing accordingly the necessities of fresh $CaCO_3$ of the Pedersen plant.

Results

Results of both simulations indicate that 0.473 tonnes of alumina and 0.116 tonnes of pig iron are produced per tonne of bauxite. Composition of alumina is >99.9%wt, with traces of sodium and silicon oxides.

Composition of pig iron is 94.3%wt Fe, 4.5% C and 1.2% Si, making it suitable for commercialization.

As regards to energy demand, results show that energy consumption of Pedersen process stands at 13.62 GJ per tonne of alumina produced, surpassing the average consumption of Bayer process (≈10.22 GJ/tonne). However, considering that the average energy demand of pig iron production is 17 GJ/tonne, the state-of-the-art production of 1 tonne of alumina and 0.245 tonnes of pig iron requires 15.16 GJ. Hence, it is shown that co-production of alumina and pig iron via Pedersen process can mitigate the energy consumption of both industries. Results of the integration of the CaL plant are shown in Table 1.

Tabla 1. Energy performance of diverse CaL models.

	Energy Demand (GJ/tonne Al_2O_3)	Energy penalty (GJ/tonne CO_2 avoided)
Single Plant	13.62	-
2.6% Purge ratio	20.29	7.94
33.3% Purge ratio	16.32	3.20
50.0% Purge ratio	15.01	1.65

It is shown that high CaO purge ratios entail lesser energy penalties and better energy performances. A greater grade of substitution of $CaCO_3$-CaO in the bauxite dehydration unit of the Pedersen plant results crucial to decrease both CO_2 looping in the system and the thermal energy required to capture that CO_2.

Conclusions

Throughout this study, Pedersen process was investigated. Results show that its energy intensity is relatively lower than the state-of-the-art alumina and pig iron production industries. This energy intensity stands at 13.62 GJ per tonne of alumina produced in a single Pedersen plant and 15.01-20.29 GJ if a CO_2 capture plant via calcium-looping technology is integrated.

Additionally, the avoidance of bauxite residue generation can make this technology more attractive and efficient in the use of mineral resources. Therefore, considering environmental benefits of CO_2 avoidance, more studies should be carried out, to optimize experimental conditions and gain understanding of the process, as well as to analyze environmental and economic aspects of both layouts.

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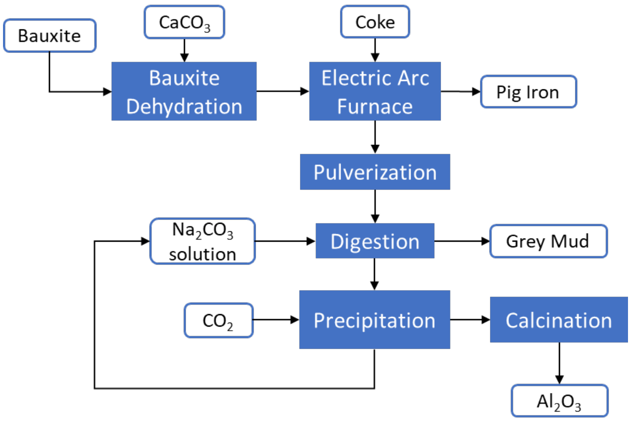

Figure 1: Simplified flowsheet of Pedersen process.

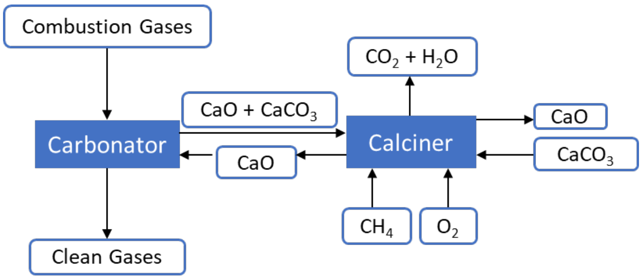

Figure 2: Simplified flowsheet of CaL technology