A Techno-Economical Study Comparing the Bayer and Pedersen Processes for Alumina Production and Bauxite Residue Treatment

Camilla Sommerseth[1], Nils Henrik Eldrup[2] David Konlechner[3] and Casper van der Eijk[4]
1. Research Scientist
4. Senior Research Scientist, SINTEF Industry, Trondheim, Norway
2. Senior Advisor, SINTEF Industry, Porsgrunn, Norway
3. Owner, KON Chemical Solutions, Vienna, Austria
Corresponding author: camilla.sommerseth@sintef.no

Abstract

The objective of this paper is to investigate Mo i Rana as a possible site for the improved Pedersen process based on the results of the EU funded ENSUREAL project which investigated this process as an alternative to the Bayer process for producing alumina to the aluminium industry without producing bauxite residue deposits. A techno-economic study has been performed on several case studies: Keeping the Bayer process as it is today with a case study of a new-establishment of the Bayer process in Greece; Building the Pedersen process in its entirety in Mo i Rana; Building the Pedersen process for treating bauxite residue only; Building the Pedersen process connected to an existing Bayer refinery to avoid bauxite residue deposits and building a new Bayer process in Mo i Rana with and without the Pedersen process. The conclusion of the techno-economic study is very clear when it comes to revitalizing the Pedersen process: It is not economically feasible and cannot be recommended as a realistic competitor to the Bayer process. However, an economically feasible alternative is to treat the bauxite residue from the Bayer process, with the Pedersen process to access the iron and alumina raw materials present in the material that is now deposited. The techno-economic study performed in this work shows that this is an alternative that should be investigated further

Keywords: Techno-economic study, Bayer vs. Pedersen, Alumina production, Bauxite residue treatment, Valorising bauxite residue.

1. Introduction

The EU funded ENSUREAL project aimed at investigating a modification and optimisation of the Pedersen process to determine if it can be a true alternative to the currently dominating Bayer process for industrial production of aluminium oxide (also known as alumina or metallurgical/smelter grade alumina) from Bauxite. In the Bayer process a significant amount of the bauxite raw material is lost as a landfill called bauxite residue. This residue is highly alkaline and consists mainly of iron oxide but typically with 15-25 wt% alumina in addition. For every kg of alumina produced, approximately two kg of bauxite residue is generated with the feedstock today. Bauxite residue storage practices vary significantly; historically lagooning or even direct disposal were commonplace, however the industry is adopting more environmentally friendly practices such as dry stacking or farming. Nevertheless, the bauxite residue tailings present an environmental risk and historically major incidents have occurred with significant impacts on the surroundings and environment. The high content of Al_2O_3 in the bauxite residue represents a loss of raw material that could have been utilized with a more efficient process. In addition, there have been several severe incidents with bauxite residue lakes flooding towns, e.g., Hungary in 2010 killing several people and controversy regarding heavy rain claimed to be causing flooding of bauxite residue deposits in connection with the Alunorte plant in Brazil in 2018. Investigations after the incident, however, reported that no direct release/overflow occurred: the release was caused by some "not fully treated effluent" that ended up in the nearby Para River [1]. The major advantage of the Bayer process is that it produces alumina with a significantly lower energy consumption compared to the Pedersen process. However, from a circular economy perspective, where all raw materials should be utilized it makes sense to work towards reducing landfill materials.

Figure 1 shows a very general overview of the Bayer and the Pedersen processes. The most obvious difference between the two processes is the electric arc furnace which produces pig iron from the iron oxide in the bauxite. Pig iron is produced by carbothermic reduction when bauxite is smelted with burnt lime as the flux and coke as the reduction agent. A calcium aluminate slag is formed, and this is further treated by hydrometallurgy to extract alumina. The slag disintegrates during cooling and is then pulverized. The powder is then digested using sodium carbonate solution in the leaching phase, and the reactions are summarized in Equations (1)-(3) [2]. Figure 2 shows a more detailed flowsheet of the Pedersen process [3]. The process can also be performed using bauxite residue as raw material [4, 5].

$$CaO \cdot Al_2O_3(s) + Na_2CO_3(aq) \rightarrow Na_2O \cdot Al_2O_3(aq) + CaCO_3(s) \quad (1)$$
$$3CaO \cdot Al_2O_3(s) + 3Na_2CO_3(aq) \rightarrow 3Na_2O \cdot Al_2O_3(aq) + 3CaCO_3(s) \quad (2)$$
$$12CaO \cdot 7Al_2O_3(s) + 12Na_2CO_3(aq) \rightarrow 7Na_2O \cdot Al_2O_3(aq) + 12CaCO_3(s) + 10NaOH(aq) \quad (3)$$

In the classification step, grey mud is separated from the sodium aluminate solution. Grey mud is the non-soluble residue. The grey mud mainly consists of $CaCO_3$, but also some CaTi-oxides and SiO_2. The grey mud can possibly be used for cement production, in lime fertilizer production or be reused in the Pedersen process. In the precipitation step, CO_2 is used to precipitate gibbsite ($Al(OH)_3$) from the sodium aluminate solution. The sodium carbonate solution that is left in the solution is recycled into the leaching/digestion step. Gibbsite is further calcined to form smelter grade alumina, mainly comprising of transition alumina phases such as γ-Al_2O_3. The calcination step in the Pedersen process is identical to the calcination step in the Bayer process and is a well-established industrial technology.

In the present study several case studies have been investigated when it comes to techno-economic feasibility for handling of the bauxite residue issue to make alumina production more sustainable.

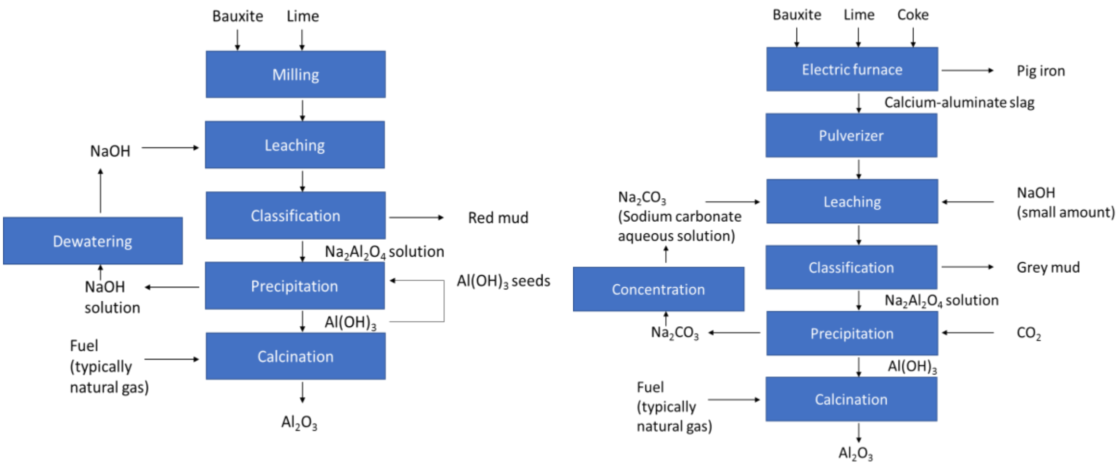

Figure 1. Overview of the Bayer process (left) and the Pedersen process (right). adapted from [2].

the result in this paper is very interesting concerning bauxite residue treatment and better utilization of the bauxite raw material without adding extra cost to the alumina manufacturers.

A fluctuating alumina price will always affect the business case for alumina producers, and the resulting alumina price in this report is perhaps a bit high in today's alumina market. However, the cost calculations in this report are based on very conservative assumptions and it is hence likely that the CAPEX and the OPEX costs are overestimated.

Acknowledgment

This project has received funding from the Norwegian Research Council under contract No. 309342, "Circular Alumina Production".

5. References

1. J.A. Berget, P. Magnussen, B.A. Malme, Internat Alunorte Task Force Report – 20180406, *Internal Hydro Report*, 2018.
2. J. Safarian, L. Kolbeinsen, Sustainability in Alumina Production from Bauxite, *2016 Sustainable Industrial Processing Summit and Exhibition*, *Starkey Intl. Symp. / Mineral Processing*, Hainan Island, China, 6th-10th November 2016, Vol. 5, 75-81, 2016.
3. M. Konlechner et al. ENSUREAL - Technology scale-up study - Deliverable 4.2, *Deliverable D4.2 report ENSUREAL*, 2021.
4. K.E. Ekstroem, et al "Recovery of Iron and Aluminum from Bauxite Residue by Carbothermic Reduction and Slag Leaching". J. Sustain. Metall. 7, 1314–1326 (2021).
5. A. Lazou et al., The Utilization of Bauxite Residue with a Calcite-Rich Bauxite Ore in the Pedersen Process for Iron and Alumina Extraction, *Metall Mater Trans B* 52 2021, 1255–1266.
6. C. Dalla et al., Life Cycle Cost Analysis, *Deliverable D6.4 report ENSUREAL*, 2022.