A Cradle-to-Gate Life Cycle Assessment of Pre-baked Carbon Anode Production; A Case Study in Quebec

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Abstract

The carbon anode, which is an important raw material in the production of aluminium, is conventionally produced by mixing granular calcined petroleum coke (CPC) and coal-tar pitch (CTP), which acts as a binder. The mixture is compacted and then baked to produce carbon anodes. With the continued rise in the global demand for aluminium, the demand for carbon anode is expected to increase significantly. The aluminium industry is exploring methods to lower its carbon footprint on the path to achieving net zero greenhouse gas emissions by 2050. One potential approach involves using biomass-based binders instead of CTP-based binders. While this technology is in its early stages and not yet in industrial production, it still generates emissions despite using biomass as a raw material. The current study, which supports the ongoing global efforts to mitigate industrial processes' environmental impact, delves into the comprehensive life cycle assessment (LCA) of CTP-based carbon anode production. By utilizing the LCA methodologies, the results of this study will serve as a baseline for comparison with the potential impacts of bio-pitch-based anodes. A baseline process tree, which represents a cradle-to-gate life cycle inventory process system, has been built to produce 1 t of CTP-based anode and assess its environmental impacts in Quebec. The study utilized the ReCiPe midpoint (H) environmental impact method for the assessment. The results from the study show that CTP and CPC have the major environmental impacts in all environmental impact categories. CTP and CPC accounted for about 69.5 % of the climate change emissions, and 82.7 % of the emissions from human toxicity. The two sensitivity analyses proved that an increase in the total mass of CTP within the accepted range of the mixing ratio from the industry causes a consistent increase in the total emissions in each environmental impact category.

Keywords: Aluminium, Coal-tar pitch, Carbon anode, Cradle-to-gate, Life cycle assessment.

1. Introduction

In Canada, and particularly in the province of Quebec, aluminium production is among the major industries. Globally, Canada is the fifth-largest aluminium producer and the second-largest aluminium exporter, with aluminium constituting 2 % of Canadian exports. Countrywide, nine smelters (eight in Quebec and one in British Columbia) are operated by three major aluminium producers (Rio Tinto, Alcoa, and Alouette). The total annual production was 3.1 Mt in 2021, 90 % of which was produced in Quebec [1]. Based on assessments by the International Energy Agency (IEA), it was predicted that by the end of 2050, the demand for aluminium in various industrial applications will increase between 2.6 and 3.5 times [2]. The emissions from aluminium production have made the aluminium industry currently responsible for 2 % of global greenhouse gas (GHG) emissions, i.e., about 1.1 Gt CO_2 equiv. annually [3]. According to the International Energy Agency report, several countries have pledged to maximize their efforts to fight against atmospheric emissions. The main target is to reach net zero GHG emissions by 2050 and provide an equitable means for the world to limit the global temperature rise to 1.5 °C [4]. To achieve this target, all industries have been edged to play their part in the effort to achieve net zero GHG emissions by 2050 [5].

The aluminium industry is exploring methods to lower its carbon footprint toward achieving net zero greenhouse gas emissions by 2050 [6]. Some researchers are studying how carbon capture [7] and inert anodes [8] can be incorporated into aluminium production to help achieve this aim. Another potential approach involves using biomass-based binders instead of coal-tar pitch-based binders for anode production. This technology, being investigated by some researchers [9-13], is in its initial stages and not yet in industrial production. Before this technology can be accepted and used in industrial production, the potential environmental benefits, including CO_2 and PAH emissions reduction, as well as the environmental impacts of using this new technology should be studied in comparison with the existing technology. This can be achieved using life cycle assessment (LCA) to analyze the impacts of raw materials acquisition and processes utilized in the production of carbon anode.

The pre-baked anodes used in aluminium production are produced from a recipe of calcined petroleum coke, anode butts, and coal-tar pitch [14], which serves as a binder. The calcined petroleum coke and the CTP are fossil-based materials, and their consumption emits about 1.5 t CO_2 eq./t Al produced [15, 16]. The calcination of petroleum coke and the distillation of coal tar to produce the coal-tar pitch also release CO_2. CTP transportation, storage at the site, and anode paste processing release polycyclic aromatic hydrocarbons (PAHs), although most are captured on-site in the paste plant [17]. Again, during the baking of the carbon anodes, which is part of the production process, the coal-tar pitch releases PAHs, but most of these PAHs are combusted in the furnace and other subsequent scrubbing processes also remove some of the released PAHs [18, 19]. These PAH substances are assumed to be carcinogenic to humans and potentially hazardous to the environment [20-22].

The current study delves into the comprehensive LCA of CTP-based carbon anode production. The LCA approach has been used by several researchers to assess the emissions and impacts of primary aluminium production [23–26] and one study has reported the CO_2 emitted by the Alouette smelter in Quebec, including data on the production of CPC and CTP and on the manufacture of anodes [27]. The International Aluminium Institute (IAI), as part of their inventory data for the production of aluminium, reported the CO_2 emissions and 5 other impact categories for the anode production process in Canadian smelters [28]. However, none of the studies described above have included the human toxicity impact category in their LCA. In the case of bio-binders, it is important to quantify those impacts since the reduction of PAH emissions is one potential incentive to use those materials. The current study therefore focuses on CO_2 emissions and human health impacts from the production of CTP-based carbon anodes in Quebec. As part of the study, a baseline process tree has been built to produce 1 t of CTP-based anode. The baseline represents a cradle-to-gate life cycle inventory process system, that covers the entire life cycle, from the extraction of raw materials to the production of the pre-baked anode. Input and output data were supplemented with background data from the Ecoinvent version 3.10 database. The impact factors were quantified with ReCiPe midpoint (H) method. This will guide future studies to determine the potential benefits of using bio-pitch for anode production.

2. Life Cycle Analysis (LCA)

Life cycle assessment (LCA) is a systematic method for evaluating the impacts associated with a product or process life, from its early stages to its end-of-life stage. It can assess all input material and energy inputs of a process as well as the waste released to the environment [19]. It is concerned with the environmental impacts of a series of industrial operations or a system. LCA has a wide range of uses, including marketing, developing new products and processes, developing policies,

2.4.1- CO_2 Emission

Calculated from equation (A2) with the quantity of natural gas needed for the mixing and forming process. The estimated quantity of natural gas used in this process in this study is 0.2 m^3.
ECO_2 = 0.36 kg CO2/t baked anode.

Other emissions which include PAH, SO_2, and Particulate matter are taken from the IAI anode and paste emission contributions, which are included in their aluminium production inventory report [28].

3.0- Sensitivity Analysis Elementary Flow Calculations

All elementary flow related to the two sensitivity analyses are calculated using the same approach for the initial analysis calculation above with the specified quantities used in this study.

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