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Review of measures for improved energy efficiency in production-related processes in the aluminium industry – From electrolysis to recycling

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ABSTRACT

The aluminium industry is facing a challenge in meeting the goal of halved greenhouse gas emissions by 2050, while the demand for aluminium is estimated to increase 2–3 times by the same year. Energy efficiency will play an important part in achieving the goal. The paper's aim was to investigate possible production-related energy efficiency measures in the aluminium industry. Mining of bauxite and production of alumina from bauxite are not included in the study. In total, 52 measures were identified through a literature review. Electrolysis in primary aluminium production, recycling and general measures constituted the majority of the 52 measures. This can be explained by the high energy intensity of electrolysis, the relatively wide applicability of the general measures and the fact that all aluminium passes through either electrolysis or recycling. Electrolysis shows a higher number of emerging/novel measures compared to the other processes, which can also be explained by its high energy intensity. Processing aluminium with extrusion, rolling, casting (shape-casting and casting of ingots, slabs and billets), heat treatment and anodising will also benefit from energy efficiency. However, these processes showed relatively fewer measures, which might be explained by the fact that to some extent, these processes are not as energy demanding compared, for example, to electrolysis. In many cases, the presented measures can be combined, which implies that the best practice should be to combine the measures. There may also be a future prospect of achieving carbon-neutral and coal-independent electrolysis. Secondary aluminium production will be increasingly important for meeting the increasing demand for aluminium with respect to environmental and economic concerns and strengthened competitiveness. Focusing on increased production capacity, recovery yields and energy efficiency in secondary production will be pivotal. Further research and development will be required for those measures designated as novel or emerging.

1. Introduction

The aluminium industry is facing a challenge. The global demand for aluminium is estimated to increase 2–3 times by the year 2050 [1,2]. At the same time, the industry's total GHG emissions are targeted to be cut in half by the same year [1,2]. This implies that the GHG emissions per produced ton of aluminium need to be reduced by at least 75% [1]. Energy efficiency cannot meet all of this reduction on its own [2], but it will play a part in achieving the goal.

The production of aluminium is an energy- and CO_2-intensive process [2]. The refining of bauxite (aluminium ore) to alumina (aluminium oxide) and the reduction of alumina to metallic aluminium are the two most energy- and CO_2-intensive processes in the production of aluminium products [2].

A lot of research has been conducted in regard to aluminium production in general. However, the majority of this research has not studied energy efficiency measures but rather has focused on production-related factors. In some scientific articles, energy efficiency issues are mentioned, but the main focus is on other things, e.g. development of a technology or computational model. Energy efficiency falls into the background in these articles. The reference documents for best available technology (BAT) from the European Commission (see e.g. [3–5]) have a main focus on environmental aspects and present only a few measures for reduced energy demand. Kermeli et al. [6] review 22 efficiency measures in aluminium production. However, they focus just on primary production, including alumina refining, aluminium electrolysis, anode production and ingot casting, and do not include measures for the subsequent processing into finished products or recycling. They also focus on currently available measures and do not present any innovative measures for future energy reductions. BCS [7] has a main focus on electrolysis and process heating operations and only provides a brief description of future prospects in other main production processes when it comes to energy efficiency. This implies that there is a lack of scientific reviews studying energy efficiency for

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Nomenclature

ACD	Anode-cathode distance
GHG	Greenhouse gas
Onsite energy demand	Energy used within the facility, excluding energy needed for generation/production and transmission/transportation of the electricity and fuel used
PFC	Perfluorocarbons, a group of powerful GHGs
Tacit energy demand	Combination of the onsite energy demand, the process energy needed for production and transportation/transmission of the energy sources and the inherent energy in the fuels used as materials

the entire aluminium industry as well as studying energy efficiency measures that are under development and not currently available.

Therefore, the aim of this paper is to review the findings of published papers on energy efficiency measures[1] in the aluminium industry. The paper is limited to electrolysis of aluminium oxide (alumina) to aluminium, secondary aluminium production (recycling) and the most common production processes for processing of aluminium. Mining of bauxite and production of alumina from bauxite are not included in the review. The paper will include measures that are currently available and innovative measures that are under development. However, the paper does not claim to present an exhaustive description of all possible measures but will focus on energy efficiency measures specific to the aluminium industry. This means that the article will mainly focus on the production-related processes.

Fig. 1 shows a schematic supply chain for the production of aluminium products. The production processes within the dotted lines are studied in this paper. In addition, the surface treatment process called anodic oxidation and heat treatment are also included in the review, but they are not shown in Fig. 1.

2. Literature search and classification

The work in this review can be divided into two parts: (1) an unsystematic part and (2) a systematic part. The first part was characterised by probing with a wide range of search strings based on keywords related to the topic. Some of the references found gave inspiration for further search strings. In some cases, literature from the reference lists of the references found were included in the review. The starting point was the European Commission's reference documents for BAT. In particular, the documents regarding non-ferrous metals industries [3], the smitheries and foundries industry [4] and surface treatment of metals and plastics [5] were used. These documents presented a number of efficiency measures and gave some understanding of the field that was helpful for the continued work with the review.

In the second part, a more systematic search for literature was performed. Fig. 2 shows a graphical representation of the search process, the search strings used and their results. The words were searched for in titles, keywords and abstracts in the database Scopus. The searches were first limited to the past ten years (2007–2016) and to references written in English or Swedish. The searches were further limited to sources that seemed relevant by reading the titles and abstracts and to sources available in full text through the Linköping University library. Finally, these sources were read through, and the ones containing relevant information were included in the review.

In some cases, relevant energy efficiency measures were identified through the above search process, but the sources did not provide sufficient information about the measures. In these cases, further searches for information were conducted for those specific measures. In this case, the search strings used were based on the name or description of the measures. The searches were mainly conducted in the Scopus database, but in some cases, Google Scholar and Linköping University library's UniSearch (based on EBSCOhost) were also used.

In total, 111 scientific references and 6 references from organisations and companies were included in the review. Ninety of the scientific references were found in the second part of the search process, but it is worth noting that some were found in the first part as well.

3. Aluminium industry

This chapter will provide a basic understanding of the production processes studied in this article. Some of the processes are illustrated below, but illustrations for the other processes can be found in e.g. [138].

3.1. Electrolysis and alloying

Primary aluminium is produced from aluminium oxide (alumina), and the major process for achieving this is the electrolytic process called the Hall-Héroult process [8]. An electrical reduction line is formed by connecting several electrolysis cells in series [3]. Fig. 3 shows a schematic drawing of an electrolysis cell.

The carbon anodes are continuously consumed during the electrolysis as the carbon combines with the oxygen in the alumina to form carbon dioxide and carbon monoxide [3]. A part of the energy needed for the cell operation is supplied by the carbon anodes [7]. The cathode is not consumed but deteriorates over time and has to be replaced after four to eight years, because of cracking, swelling and erosion [3].

Søderberg and prebaked are the two main types of electrolytic cells [3]. The Søderberg cells use a continuous anode, which is regenerated through the addition of carbon material at the top and is baked in-situ [3]. Prebaked cells use multiple anodes, which are manufactured in separate anode plants and need to be changed when approximately 80% is consumed [3]. In a modern cell, the anode needs to be changed after about four weeks [7]. As of 2013, there are only prebaked cells of the point feeder type (PFPB) in operation in Europe [3]. Fig. 3 shows a PFPB cell.

The world average energy use for only the electrolysis cell is 13.4 kWh/kg Al produced [10]. If rectifiers and other cell auxiliaries, such as pollution control equipment, are included, the world average rises to 14.2 kWh/kg [10]. The energy cost can amount to as much as 50% of the production costs in the electrolysis [3].

Holding furnaces of either an induction or reverberatory type are used for storing the molten aluminium from the electrolysis and for adding alloying metals and additions to refine the grain of the metal [3]. Primary aluminium sites melt internal and bought scrap, which should be free from substances such as paint, plastics and oil [3]. The scrap is either melted separately before adding molten metal or is added to molten metal [3].

3.2. Recycling and alloying

Scrap melting is used to produce secondary aluminium. There is a variety of raw materials and hence a variety of furnaces used for melting the aluminium [3].

The first step is to sort the raw materials into wrought alloys and cast alloys [3]. Reverberatory furnaces are used for remelting the majority of wrought alloy scrap [3]. Rotary drum furnaces (sometimes tiltable) are mostly used for remelting cast alloys [3]. Sorting the scrap into specific alloy types for production of the desired alloys is done to minimise reprocessing [3]. The type and composition of the raw materials and the required product quality are major factors determining suitable treatment processes, furnace type and other process steps [3].

[1] In this paper, an energy efficiency measure is defined as a technical measure that reduces the energy demand for producing one unit of product, e.g. one ton of aluminium. This implies that even if the measure reduces the energy need for producing one unit of product, the total energy demand can increase if the total production increases.