Heat Exchanger Prototype for Alumina Preheating in Aluminium Reduction Cells

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Abstract

The process temperature of an aluminium reduction cell is around 960 °C, thus all supplied raw materials need to achieve this temperature. The most relevant of the materials in terms of mass flow is alumina, which consumes around 0.56 kWh/kg Al in order to achieve the reaction temperature. Recovering some of the energy lost to heat up the alumina is a way to reduce cell specific energy consumption.
In our paper from 2018 a heat exchanger was presented that is designed to preheat the alumina by using the heat of the gases generated by the reduction process. In this article, the results obtained by a prototype built to prove the concept of the proposed heat exchanger are presented. The prototype was constructed in real scale. It uses a natural gas burner as heat source to simulate the off-gas received from the process. As predicted by the models, the alumina was heated up from an ambient temperature to around 500 °C as it passed through the device in a steady flow rate similar to the necessary flow to feed a real electrolysis cell.

Keywords: Aluminium electrolysis cells; energy consumption; alumina preheat; energy recovery, heat exchanger.

1. Introduction

The reduction of the energy consumption in the aluminium electrolysis process has been a subject of many research works in the industry. This occurs because electric energy is a scarce and expensive resource, and its consumption reduction is a decisive factor in the profitability of an aluminium smelter. Some examples of energy recovery in the smelting process studied in the past can be found in the recommended literature [1–10]. Furthermore, heat recovery by external fluids with heat exchangers [1–5] has been employed. The heated fluid recovers energy that is useful in other applications such as decreasing the off-gas temperature before the GTC [2]. In other works, the energy is recovered to preheat raw materials. For example, the preheating of anodes is a desirable use of energy recovery because it potentially improves the process in many aspects [6]. This has been tried in the industry as presented in papers [6] as well as in patents [9].

Alumina preheat could also improve the process, decreasing energy specific consumption while improving the alumina mixing in the bath. Devices for alumina preheat trials can be found in literature. For example, US patent 3,006,825 presents an alumina feeder wherein the alumina is preheated by the burners' off-gas in Soderberg cells whereby the gases pass through an alumina fluidized bed [11]. Further work presents a feeder (US patent 3,371,026) that is claimed to have the ability to preheat the alumina before feeding [12].

In 2017, CAETE Engenharia presented a design of a heat exchanger for alumina preheat [14], using the off gas produced inside the cell cavity. In the referenced work, a novel concept of the heat exchanger was presented and numerical simulations were employed in order to assess the potential energy recovery efficiency and also to estimate the final possible preheat temperature of the alumina feed into the bath. As described with more detail in the paper, preheating the alumina has the potential to improve the electrolysis process thermal efficiency through many aspects, as is summarized below:

a) Reduction in energy consumption to increase the alumina temperature from ambient to process temperature.
b) Dissolution of preheated alumina is easier than cold alumina.
c) When feeding preheated alumina, the cell superheat can be lowered and therefore, heat losses through the sidewalls can be decreased.
d) The heat exchanger device proposed is accompanied with localized pot suction. This potentially reduces the top heat loss because the under-hood space would present lower temperature, thereby reducing both convection and radiation heat losses.

All the above-mentioned combined effects have the potential to reduce the specific energy consumption by 1.2 – 1.5 kWh/kg Al. Hereby the estimation considers that alumina can be fed at 550 °C, the CE can be increased by 1 % and the superheat can be lowered by 5 °C. In this work, a real test prototype of the heat exchanger is presented.

2. Heat Exchanger Design

As presented in the earlier work [14], the heat exchanger design for use in real cells was shown and its most relevant parts and features are explained in Figure 1. The heat exchanger is embedded into the alumina hopper (2) and the alumina feeding is activated by a pneumatic cylinder (3). Alumina passes through the alumina heating chamber (4) reaching the dosing device (6). A crust breaker (5) is necessary to guarantee the crust opening stability. When the pneumatic cylinder acts, the alumina falls into the discharging chute (7). A gas collection cap (8) is placed over the anode cover (9). It presents a vertical sliding degree of freedom allowing for the anode height variation during the anode life. The gas collection cap presents a controllable false air inlet (12) and the hot gases evolving from anodes (10) and bath (11) are collected and directed in counter flow with regard to the alumina flow. The gases leave the heat exchanger at the top where a draft control valve combined with temperature sensor (1) is used to control the off-gas temperature and mass flow.

temperatures that leave the heat exchanger during the experiment. It reached around 500 °C on average. In the experiment, the system was still transient at the end of feeding, due to the insufficient alumina available to continue the experiment up to a stationary condition. It is estimated by modelling, that around 45 min of continuous experiment would be required to achieve steady state, instead of the 15 min continuous feeding available.

Figure 9. Bulk temperature inspection in the alumina deposit, after the alumina flow ended in the experiment.

5. Conclusions

The experiment using the prototype has confirmed the heat recovery potential of the heat exchanger and the results are in good agreement with the predicted values from previous numerical models. Alumina discharge temperature reached the predicted temperature level of 500 °C.

The experiment has also shown that the pseudo steady state of alumina flow is in reality a sequence of intermittent slidings of alumina particle packs, which is very characteristic of a granular flow. The thermal steady state condition of the heat exchanger was not achieved during the 15 minutes of process. The model shows that it takes 45 minutes but the current setup is not providing sufficient process time allowed the achievement of thermal steady state. However, if this can be achieved in future experiments then the alumina discharge temperature could be even higher.

6. References

1. Geir Wedde and Anders Sorhuus, Waste heat recovery from industrial smelting exhaust gas, *TMS International Smelting Technology Symposium* 2012, 31-38.
2. Anders Sorhuus and Geir Wedde, Pot gas heat recovery and emission control, *TMS Light Metals* 2009, 281-286.
3. Hadi Fanisalek, Mohsen Bashiri and Reza Kamali, Waste heat recovery trial from aluminum reduction cell exhaust gases, *TMS Energy Technology Proceedings* 2011, 65-75.
4. Amal Aljasmi, Mark Jordan, Alexander Arkhipov, Abdalla Al Zarouni, Sergey Akhmetov, Didier Ostorero, Veroslav Sedlak and Haavard Arvesen, Heat recovery from aluminium

cells based on heat pipe technology, *11h Australasian Aluminium Smelting Technology Conference* 6th -11th December 2014, Dubai, UAE.

5. Yves Ladam, Asbjørn Solheim, Martin Segatz, and Odd-Arne Lorentsen, Heat recovery from aluminium reduction cells, *TMS Light Metals* 2011, 393-398.
6. S. Kothari, A. F. A. Hoadley and D. J. Brennan, An investigation of anode preheat on the thermal efficiency of a Hall-Heroult reduction cell, *7th Australasian Aluminium Smelting Technology Conference* 11th -16th November 2001, Melbourne, Australia.
7. Odd-Arne Lorentsen, Are Dyrøy and Morten Karlsen, Handling CO2eq from an aluminum electrolysis cell, *TMS Light Metals* 2009, 263-268.
8. Patent WO2010033037, M. Karlsen et al., A device for collection of hot gas from an electrolysis process and a method for gas collection with said device, 2008.
9. Martin Segatz, Jorund Hop, Pierre Reny and Håvard Gikling, Hydro’s cell technology path towards specific energy consumption below 12 kWh/kg, *TMS Light Metals* 2016, 301-305.
10. Kellinghaus Hans Dipl Schulte, Roland Rathgeber, Erwin Collet and Paul Wisniewski, Anode change with heat recovery during aluminium fusion electrolysis, German Patent DE 4344036 A1, 1993.
11. Mathias Ovrom Sem, Method of charging aluminium furnaces, US Patent 3,006,825, 1961.
12. Allan Jack Kiley and Harry T. Shiver, Electrolytic reduction cell with crust-breaking and ore feeding means, US Patent 3,371,026, 1968.
13. Barry Welch, Constraints and options for reducing energy consumption in aluminium smelting, *Proceedings of 31st International ICSOBA Conference*, Krasnoyarsk, Russia, September 4-6, 2013.
14. Dagoberto Schubert Severo and Vanderlei Gusberti, Heat exchanger for alumina preheating in aluminium reduction cells, *Proceedings of 35th International ICSOBA Conference*, Hamburg, Germany, October 2-5, 2017. Paper AL28, *Travaux* 46, 1059-1070.