Transforming the Way Electricity is Consumed During the Aluminium Smelting Process

Mark Dorreen, Linda Wright, Geoff Matthews, Pretesh Patel and David S. Wong

Abstract This paper examines the development of the new EnPot heat exchanger technology for aluminium smelters and the potential impact it could have on the sustainability and economics of primary aluminium production. The EnPot technology can be used to help the aluminium smelting industry be part of the solution to accommodate increased intermittency in our future renewable energy generation, post COP 21. The EnPot system provides for the first time, dynamic control of the heat balance of aluminium smelting pots across the potline, so that energy consumption and aluminium production can be increased or decreased by as much as plus or minus 30% almost instantaneously. This enables a new way of thinking to emerge when considering the relationship the aluminium smelter plays in connection to the power grid. The EnPot technology provides smelters with the means to free up power back to the grid, transforming the smelter from only an end user of power into a 'virtual battery' for the electricity network. This fundamentally changes the way electricity is consumed by the smelter and is a concept already being tested by several smelters.

Keywords Aluminium smelting · Energy flexibility · Virtual battery · Power grid · Enpot

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L. Zhang et al. (eds.), *Energy Technology 2017*,
The Minerals, Metals & Materials Series, DOI 10.1007/978-3-319-52192-3_2

Introduction

This paper examines the potential impact the newly developed 'EnPot' system [1] could have on the sustainability and economics of primary aluminium production. In particular, it tracks the development of the EnPot heat exchanger technology and explores how it could be used to help the aluminium smelting industry be part of the solution of accommodating increased intermittency in our future renewable energy generation, post COP 21 (2015 Paris Climate Conference).

The means by which our future growing energy needs will be met is one of the most globally discussed topics of our time. If the future of power generation is to come largely from renewable sources, replacing fossil fuel sources, then we must fundamentally change the way we consume energy.

Aluminium is one of the most important metals in our world today and is now the second most used metal globally after steel. Our per capita consumption of aluminium rises with our income as we purchase more consumer goods and seek to lightweight everything from phones and tablets, to cars. With the predicted rise in incomes in the developing world over the next 15 years, global demand for aluminium is expected to double over the same period and it is estimated that 40 to 50 new smelters will be needed to keep step with this increasing demand.

Aluminium smelting accounts for over 3% of the world's total electricity supply, which is equivalent to 16.5% of total global domestic consumption. In other words, the 200 smelters globally consume the equivalent amount of power as 1.2 billion people do domestically. The major challenge with aluminium smelting is that the process not only requires vast amounts of electricity, but it needs it continuously and at consistent levels to keep the electrolysis process running.

Current Model—The Energy-Production 'Straightjacket'

With the existing primary aluminium production process, the energy input to a smelter cannot be varied by more than roughly ±5% from its base operating point (Fig. 1). This means that a smelter essentially operates consistently at full capacity 24/7, 365 days a year, for its entire lifespan. The current maximum production 'straightjacket' that the aluminium industry is in has a significant and dramatic effect on both the cost of production for individual smelters, as well as the dynamics of the supply and demand curves of the industry as a whole. It also creates power supply issues for national grids, especially as nations seek to produce a higher percentage of their electricity from renewable sources (such as solar, wind, etc.), which inherently are more intermittent in their generation.

The electrochemical process used to make aluminium requires a powerful electric current (up to 600,000 A or 600 kA) to be driven through large carbon lined steel furnace pots filled with molten electrolytic bath (mostly cryolite, Na_3AlF_6) and aluminium oxide (Al_2O_3), kept at close to 950 °C. The electric

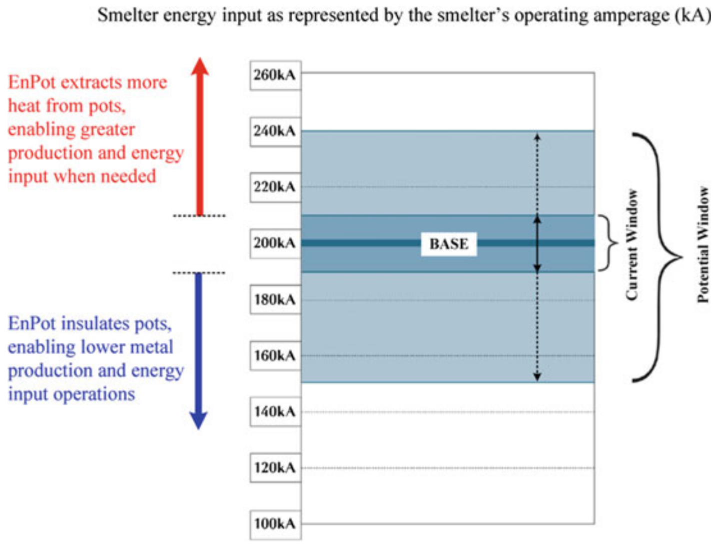

Fig. 1 Current window of flexibility in energy usage for smelters (±5%) compared to the potential operating window with EnPot technology (up to ±30%)

current breaks the molecular bonds of the oxide and the resulting denser metallic aluminium then collects at the bottom of the pot, ready for siphoning off and casting.

The inability of current smelters to be flexible in energy usage and production is due to the absolute importance of maintaining the aluminium reduction process within a very narrow "heat balance" temperature window, usually only within 30 °C, which must be maintained to keep the bath molten in pots and hence why smelters must consume electricity at a very consistent rate. The process produces a vast amount of heat as a by-product and how this heat is dispersed through the carbon lined steel pots is critical.

- If you want to *increase metal production*, you need to increase the amperage through the pot, increasing energy usage. This generates yet more heat, which then needs to be removed from the outside of the pot at a greater rate to prevent pot overheating and failure.
- Conversely if you want to *slow down production* or *reduce energy usage*, you need to reduce the amperage and then insulate the pot in order to keep it from cooling and solidifying (a worst case scenario resulting in loss of metal production entirely; reinstating full production is very costly, taking weeks if not months).

While smelters currently can carry out long-term increases and slow-downs in production and energy usage (through starting up/stopping individual pots from production, or small incremental increases in production after individual pots are

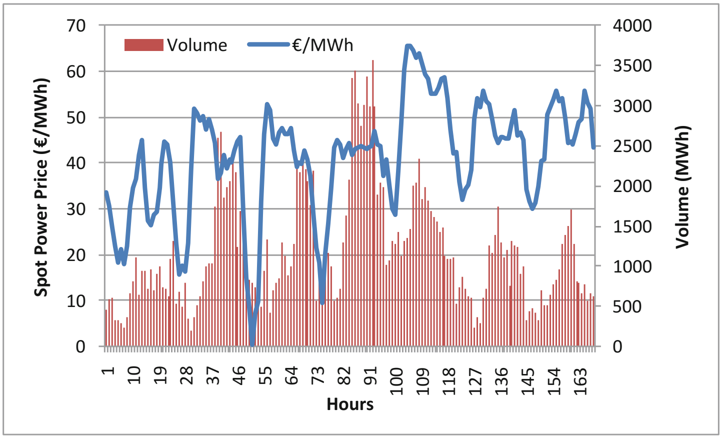

Fig. 2 European Energy Exchange (EEX) hourly power price and volume for the week of September 6, 2010. Reproduced from [2]

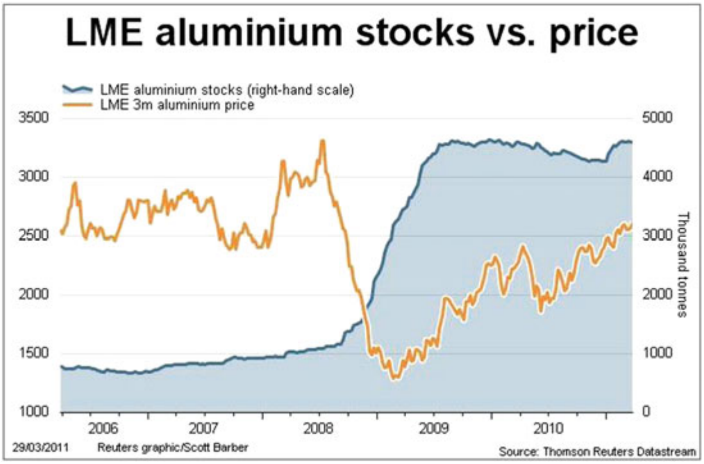

Fig. 3 Historic LME aluminium prices and how it can be affected by oversupplying and stockpiling in the aluminium market

upgraded to extract more heat), these require significant planning and capital expenditure. More importantly, the time scale for such changes (weeks/months) means that smelters are unable respond quickly to large daily/periodic shifts in either the energy market (spot power prices that smelters pay for electricity, for example Fig. 2), or in the metal commodity market (spot prices to sell metal produced, for example Fig. 3).

To operate flexibly and dynamically (on short notice) in both directions outside the current operating window therefore is practically impossible for most smelters.

With EnPot technology however, this fixed operating model has the potential to change fundamentally, providing an ability for smelters to increase/decrease production and energy usage almost instantaneously, whilst maintaining pots within a wider thermally balanced operating window.

EnPot Technology and Development

The EnPot heat exchanger technology was first developed and patented by a specialist team of researchers and engineers at the Light Metals Research Centre (LMRC) at The University of Auckland. Figure 4 highlights more than a decade of historical development, commencing with fundamental PhD research in 2003, lab to pilot scale development and commercialization over 2007–2008 [2, 3], and progressing onto smelter based industrial trials on individual and multiple reduction pots after 2009. Plans for a complete potline installation at a German smelter is now underway following a successful 12 pot trial in 2014–2016 [4].

As shown in the timeline, the EnPot technology was initially focused at providing smelters the ability to increase their metal production and amperage (particularly during the pre-2008 GFC era of high metal commodity prices), whilst maintaining the pot thermal balance within their operating window.

However, the ability to use the very same technology for *flexible amperage and production operations*, i.e. being able to scale production/amperage significantly both up and down, was soon realized. Teams at Energia Potior and the Light Metals Research Centre have since worked closely with Yunca Engineering to perfect the EnPot System to both cool or insulate aluminium reduction pots in order to act as an air-conditioner or a thermal blanket, depending on energy use and production requirements. The technology is now patented and has been developed significantly from the original research and prototypes into the now commercially available practical design and application package from Energia Potior Ltd.

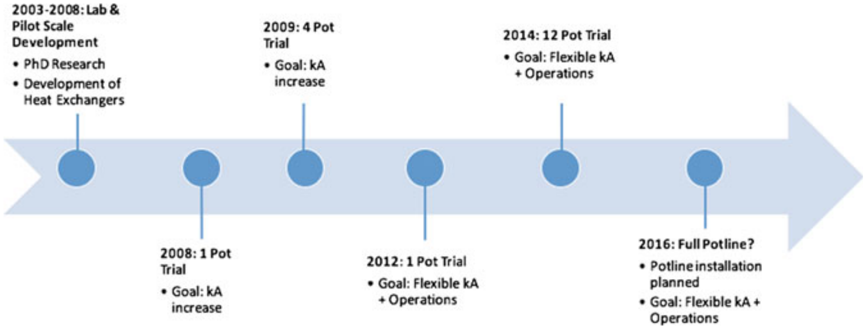

Fig. 4 Timeline showing historical development of EnPot technology at LMRC

The EnPot Heat Exchanger Concept

To maintain thermal balance on an aluminium reduction pot, roughly 50% of the energy input to a typical pot is lost as heat; 35% of this heat loss is through the sides of a pot (Fig. 5). Controlling this side-wall heat flow is critical, particularly during flexible amperage and production, as failure to do so results in either failure of pot integrity (when amperage and energy is increased) or solidification of the pot (when amperage and energy is ramped down). EnPot technology does this by regulating side-wall heat flow from pots, using a system of heat exchangers installed on the sides of each reduction pot. A schematic of individual exchangers is shown in Fig. 6, whereas an industrial installation is shown in Fig. 7; these units can be retrofitted non-invasively on existing pots in operation.

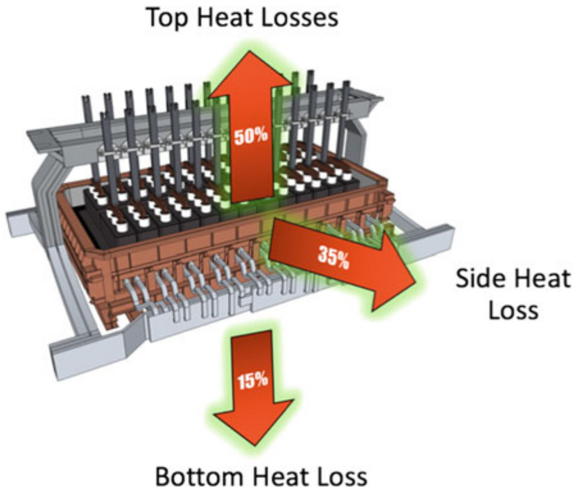

Fig. 5 Distribution of heat losses from a typical aluminium reduction cell

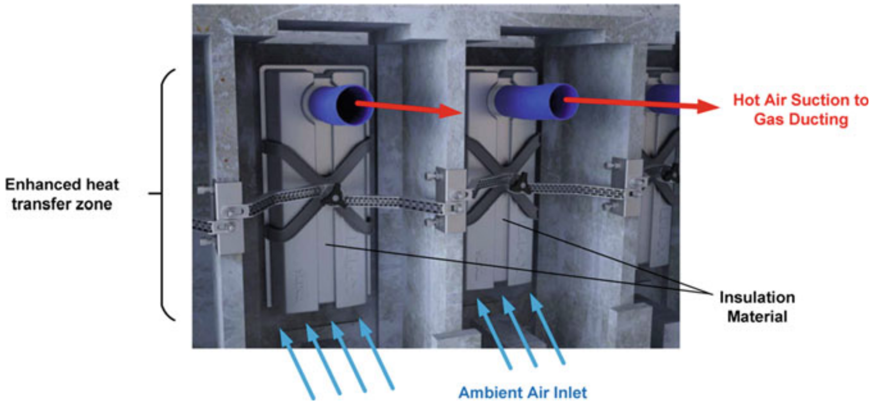

Fig. 6 Schematic showing the operation of two EnPot heat exchanger units installed on the sides of an aluminium reduction cell

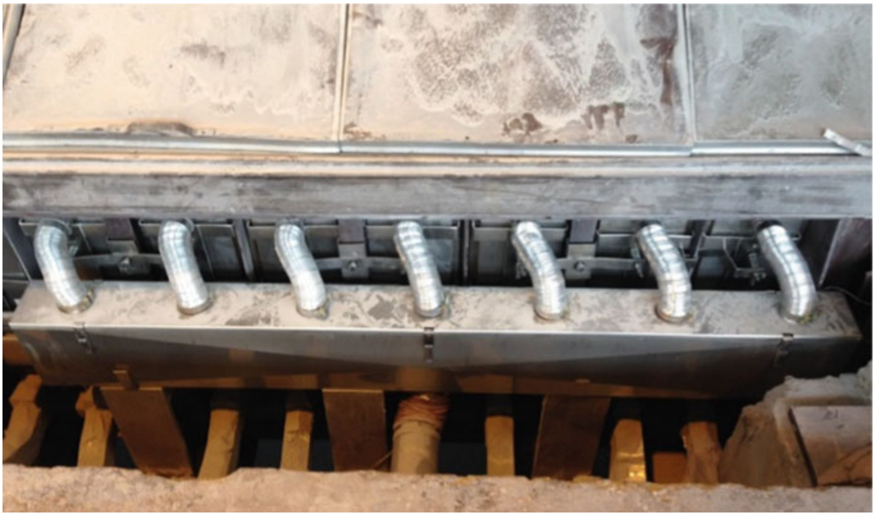

Fig. 7 EnPot heat exchanger units fitted on one sidewall of an aluminium smelting pot, connected to ducting for hot gas extraction, figure reproduced from [4]

When *higher metal production* (increase in amperage/energy) is required, the exchangers work by extracting cool ambient air past the pot sidewalls to a system of gas ducting and fans. The transfer of heat from the pot to the EnPot exchangers is enhanced by patented technology. The rate of gas extraction can be easily dialled up or down in order to provide variable heat extraction at the desired production/energy level (Fig. 8).

Conversely, when *lower metal production* is desired (or *energy usage* needs to be reduced), gas flows through the exchangers are reduced or completely halted. Exchangers then act as a thermal blanket around the cell, insulating the side-walls and reducing heat loss.

Industrial Trials

The EnPot technology was initially tested on individual pots in a number of smelters before being installed on a 12-pot partitioned section of a smelter in Germany in June 2014. Since then the EnPot System has performed above expectations, providing the smelter operators the ability to turn energy consumption up and down by as much as +20% to −13% for 48 h periods [4], with even greater fluctuations planned after potline installation (ultimately a potential to ramp up the operating window to ±30%). This has enabled the smelter to 'modulate' or be flexible in its power consumption from the electrical grid, and essentially become an energy-buffer or 'virtual-battery'.

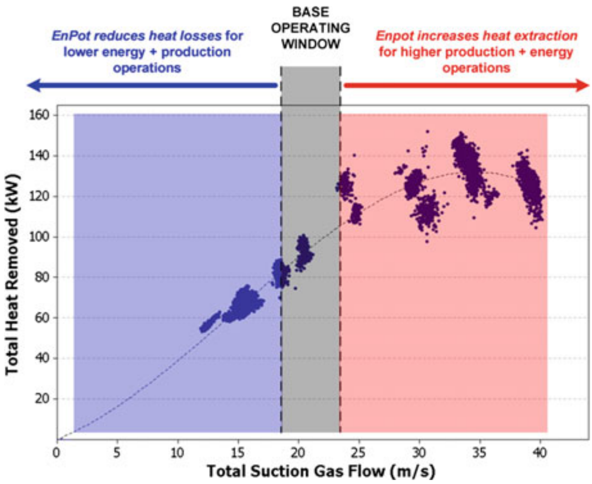

Fig. 8 Principle behind the EnPot system, with variable gas extraction flows providing dynamic control of the heat extracted from an aluminium smelting pot, figure adapted from [4]

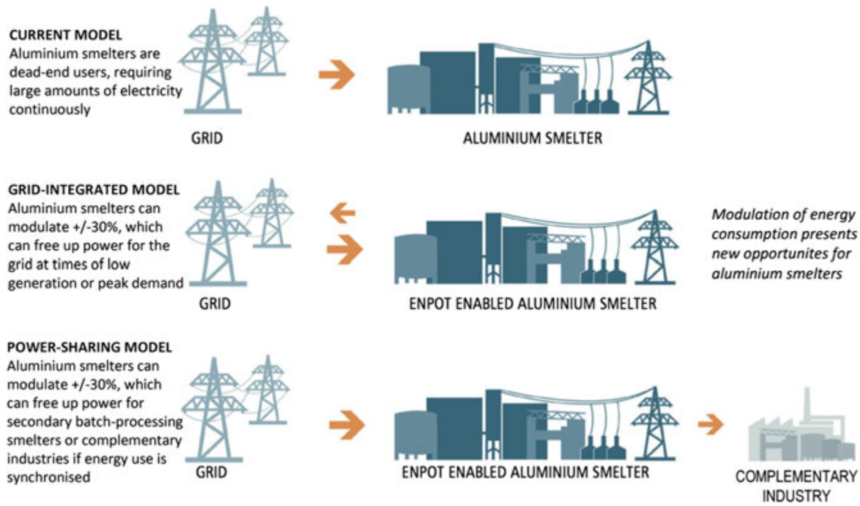

Fig. 9 Current end-user versus potential future models of smelter-power generator relationships with the use of EnPot technology, figure adapted from [5]

Smelters who apply this technology can sell or supply energy back to the grid during periods of peak power demand in the surrounding community; conversely, during off-peak periods, smelters can use the extra energy available to produce more metal. This provides a win-win situation for both the smelter and energy suppliers.

This model of operation (Fig. 9) fundamentally transforms the way electricity is consumed during the aluminium smelting process. This enables production output to be varied to match supply and demand and also to take advantage of off peak power prices and to accommodate the intermittency associated with renewable power supply.

Opportunities and a New Model for Smelters

Several new models of smelter-power generator relationships are now possible with the new EnPot technology (Fig. 9). In contrast to the current model, where smelters are only constant 'dead-end' users of electricity, EnPot provides smelters the potential to modulate their power usage by ±30%, enabling them to be either:

- 'Grid-integrated'—where smelters can free up power for the grid at times of low generation or peak demand, or
- 'Power-sharing'—where smelters free up power for other complementary industries or smelters with batch-energy requirements.

As such, the implications of this new technology are enormous, not only for the aluminium smelting industry, but also for the nations that host smelters and that struggle to generate enough clean power to meet domestic consumption at times of peak demand or low power generation, without the need to invest in new or back-up generation capacity. The EnPot technology could provide the first transformative change to the aluminium smelting industry since the 1950s; furthermore it is estimated that it could free up enough electricity regionally at peak consumption times to power 2.5 million homes in Europe, 1.1 million homes in North America and 25 million homes in China.

For many countries the installation of the EnPot technology in local aluminium smelters, could help alleviate problems with intermittency in their national grids, and could even enable the decommissioning of fossil fuel or nuclear power stations. It also frees up peak power for nations to use, accommodates intermittency in the gird, improves process efficiency, enables smelter operators to control production output, increases profits to smelter shareholders, reduces the need for subsidies, improves working conditions for employees and reduces insurance risk.

While not the focus of this paper, recovery of the 'waste' heat removed from smelters using EnPot technology (typically hot air extracted from pots in the range of 140–180 °C) presents another opportunity for the smelting industry. In addition, for the smelter to supplement its own energy needs, there is further potential to

Fig. 10 Potential future model of smelter-industry/community relationships recovering heat from EnPot technology to complement surrounding industries or heating needs in the community

complement the heating needs of surrounding industries or community facilities (e.g. swimming pools, domestic heating, etc.) as shown in Fig. 10. Breakthrough technologies to use or convert low-grade waste heat into power (e.g. modified organic rankine cycle [6], multiple effect distillation) will enable further opportunities for the industry.

Conclusions

The EnPot technology was originally designed to provide smelters the ability to increase their amperage and therefore metal production, whilst maintaining the pot thermal balance within their operating window. However, due to changes in the economic environment, development of the EnPot technology has since moved in a transformative new direction. The technology now has the potential to provide smelters with *±30% flexibility in metal production and energy usage*, in a production process that is well known for its inflexibility. Smelters utilizing this technology have the potential to fundamentally change their entire model of operations, from a constant dead-end user of electricity, to a 'grid-integrated' user who can free up power for the grid at times of low generation or peak demand, or a 'power-sharing' user, offloading power to nearby industries with complementary energy needs. Rather than just being a consumer of energy, the EnPot technology enables smelters to be a vital contributor to energy security of the community—a need that will arise with the intermittency of renewable energy sources.

Who We Are

Energia Potior is a partnership between Auckland UniServices Limited (the commercialisation arm of the University of Auckland) and Yunca Holdings Ltd. The EnPot technology was first developed and patented by the Light Metals Research Centre (part of Auckland UniServices Ltd.). During this development, Yunca provided the experience and expertise to retrofit the technology in operating aluminium smelters.

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http://www.springer.com/978-3-319-52191-6

Energy Technology 2017
Carbon Dioxide Management and Other Technologies
Zhang, L.; Drelich, J.; Neelameggham, N.R.; Guillen, D.P.; Haque, N.; Zhu, J.; Sun, Z.; Wang, T.; Howarter, J.A.; Tesfaye, F.; Ikhmayies, S.; Olivetti, E.; Kennedy, M.W. (Eds.)
2017, XXII, 499 p. 244 illus., Hardcover
ISBN: 978-3-319-52191-6