

## Findings from Operating a Pot with Heat Recovery System

Amal AlJasmi<sup>1</sup> and Abdalla Alzarooni<sup>2</sup>

1. Lead Engineer, Modeling,

2. Vice President, Technology Development and Transfer

Emirates Global Aluminium, Dubai, U.A.E.

Corresponding author: amaljasmi@ega.ae

### Abstract

A heat recovery system, HRS, was installed in one pot at Emirates Global Aluminium's Jebel Ali site, to evaluate the potential for energy recovery from the cell as well as the impact of this system on pot operation. The pot is extensively instrumented to allow analysis and monitoring of all related parameters. The impact is two directional: the pot impacts HRS and what happens in the pot impacts energy collected by HRS. The pot operation is impacted by HRS as it influences the cell heat losses and its thermal balance. This can be seen from the shell temperature, bath temperature and excess AlF<sub>3</sub> variation. The HRS was also used to reduce the heat losses from the pot during a planned power reduction. The HRS is also impacted by the events that take place in the pot such as the removal of an anode with spike and changes in bath temperature. The paper summarizes these key findings and shows the potential of optimizing the pot performance with HRS.

**Keywords:** Heat recovery; pot shell sidewall heat recovery; thermal balance.

### 1. Introduction

Aluminium smelting is an energy intensive process with half of the energy required in the cells lost as heat. This raises interest in the possibility of recovering this wasted heat. The studies in this subject have come a long way: from theoretical calculations and lab testing to full scale trials and industrial potline application. The areas with highest heat losses from the cell are the cell off-gases and the pot shell sidewalls and thus, these these two areas are the main target for heat recovery.

Most of the efforts to recover energy from aluminium pots focus on off-gas cooling. Many reasons made the off-gas energy collection attractive, including the positive impact on gas treatment plants when the off-gas is at lower temperature and thus reducing the volume of gas going for treatment. [1] Also, the recovery from the gas duct does not interfere with pot operation which means installing such a system does not disturb normal pot operations. Off-gas cooling has been tested on industrial scale in many smelters and is planned to go for a full potline installation in Potline 4 in Alba [2].

Recovering heat from the pot shell sidewall has not been as popular. Concerns include the impact on pot heat losses and thermal balance and as a result pot operation and production. However, sidewalls have potential for higher energy recovery rates compared to the off-gas ducts [3]. In addition to the recovered heat, having an external mechanism to turn up or down the heat losses from the sidewall makes power modulation possible on a wider range of amperage [4]. It also means potential for amperage increase with the same pot lining design for smelters that do not use power modulation.

In EGA, as a part of the company strategy to reduce energy consumption, a heat recovery system was installed in one of the pots in the Eagle section where DX+ Ultra cells were commissioned in 2014. The section has five pots and the middle pot was chosen for heat

recovery installation. These pots are monitored and followed closely which gives the benefit of availability of measurement and data for comparison when it comes to evaluating the impact of the heat recovery system (HRS). The initial findings from this HRS trial at EGA were published in 2015 [3]. The aim of this paper is to show some of the findings from operating a pot with heat recovery including how it impacted the pot and how in turn the pot impacted some of the parameters in the HRS.

## **2. Method**

The HRS is based on heat pipe technology and was designed by Goodtech Recovery Technologies, a Norwegian company specialized in heat pipe technology for heat recovery applications. The team working on heat recovery from aluminium cells worked on improving the system from the experience in EGA and started Cronus Technology AS. The HRS system consists of two parts: off-gases energy collector (GOC) and pot shell sidewall energy collector (GEC). GECs were installed on the side wall along the length of the pot only, keeping the tap and duct ends design unchanged from normal pots. The HRS is instrumented to be able to monitor all the relevant parameters through a dedicated HMI including temperature of each unit, oil inlet and outlet temperature and oil flow rate.

During the design stage of HRS, ANSYS thermoelectric model was developed with a simplified representation of HRS on the sidewall. This model allowed prediction of cell thermal balance with different energy collection rates from the sidewall. The model also helped with the prediction of the impact on shell temperature and expected freeze. These calculations were later validated with measured values and found to be in good agreement. While some parameters were calculated, other remained unpredictable until we started the pot operation such as required oil flow rate for a given energy collection rate. The focus in this paper will be on the pot shell sidewall energy collector and how it impacts the pot. The term ‘HRS’ will be used to indicate heat recovery from pot shell sidewall and ‘normal’ pot will refer to pot without HRS.

## **3. Findings**

One of the findings is the range of heat recovery that was observed from the installed system. Also, in terms of the influence of HRS on the pot, impact on shell temperature, bath temperature, excess  $\text{AlF}_3$  and freeze thickness are discussed. Additionally, the impact of bath temperature and formation of spikes on the energy recovered by HRS are also shown.

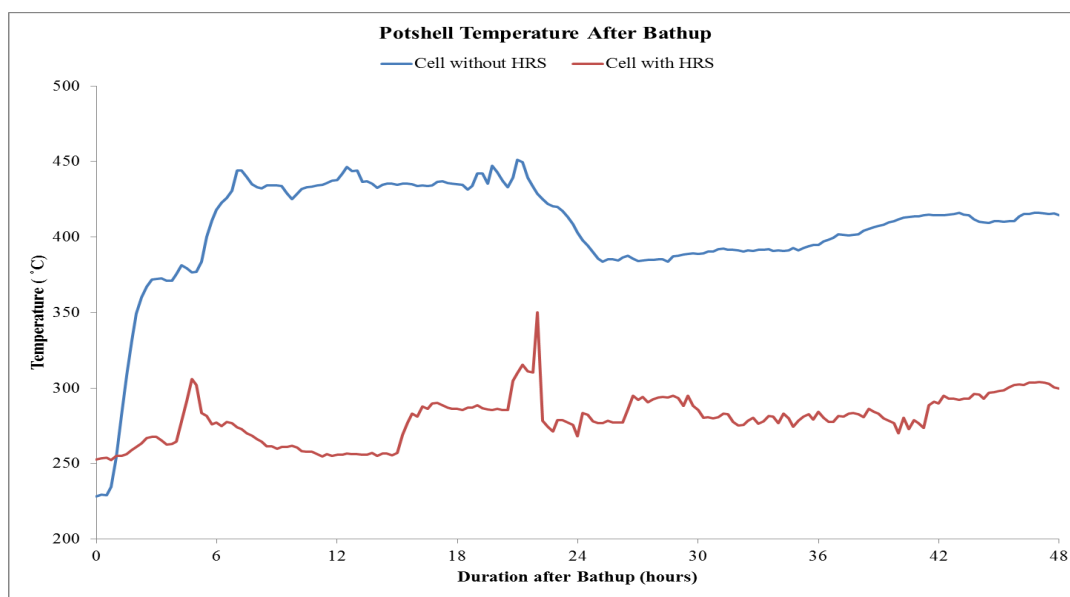
### **3.1. Energy Collected**

The energy collection rate from the pot shell sidewall was varied using the oil flow rate which was one of the input parameters in the HRS. The maximum oil flow rate was used during start-up (after bath-up) to reduce shell temperature and allow faster freeze formation. The energy collection rate from the sidewall at this stage was 200 kW. This rate was dropped to 100-120 kW during normal operation. There was no requirement to change the oil flow rate and adjust the energy collection from the HRS except during power outage.

### **3.2. Shell Temperature**

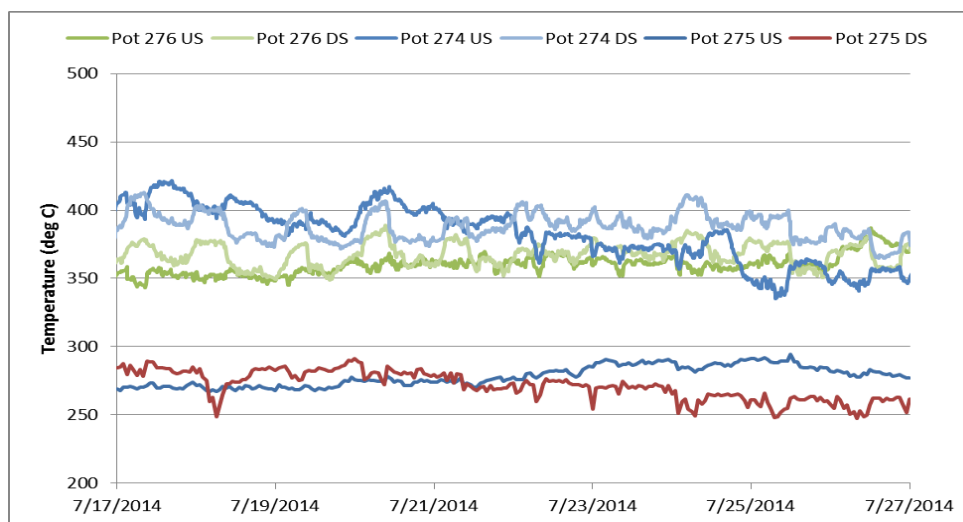
Shell temperature is directly impacted by the HRS. The energy collection panels are placed between cradles above the cathode level up to the bottom of deck plate. The heat pipe technology used in these energy collectors has high thermal conductivity in the vertical direction resulting in almost uniform temperature along the block [5]. Thermocouples placed on the shell at the metal bath interface level were used to monitor and compare shell temperature in the pot with HRS and pots without HRS. Figure 1 shows the shell temperature after pouring

bath. The cell without HRS had cooling pipe installed and directed toward the shell after bath-up to allow faster formation of freeze and reduce the high shell temperature. The comparison shows a difference of 100 – 200 °C between the two shell temperatures.



**Figure 1. Pot shell temperature at metal-bath interface after pouring bath [3].**

Figure 2 shows the shell temperature at the metal bath interface for two locations in pot with HRS compared to other pots during normal operation. The temperature for other pots is in the range from 340 – 420 °C approximately while the pot with HRS has temperature in a narrower range between 250 and 290 °C.



**Figure 2. Upstream and downstream potshell temperatures at the metal bath interface in HRS pot (Pot 275) and other 2 pots during normal operation.**

While the difference in shell temperature seems to be quite big, the impact of this temperature difference is not directly proportional to the impact on freeze because of the distribution of shell temperature along the region of heat extraction.

### 3.3. Freeze Thickness

An important indication of the pot thermal state is the freeze profile and thickness. Figure 3 show the freeze in pot 275 with HRS as well as three of the conventional pots. Each line represents the average of six measurements along upstream and downstream of the pot. The freeze in the pot with HRS is showing a typical profile with higher thickness on top of cathode, thinnest close to metal bath interface, and thicker in the bath region.

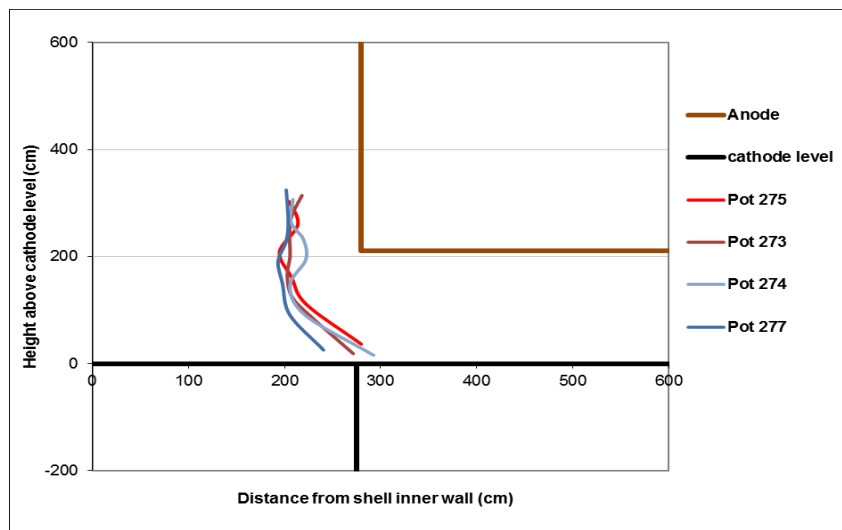


Figure 3. Freeze profile in pot 275 with HRS as well as three conventional pots.

In a campaign to validate the impact of HRS on freeze formation, the freeze thickness was measured during anode change, so in one or two cathode blocks depending on the location of anode changed. The measurement in each pot was made at the same anode position. The average freeze thickness in each measurement is shown in Figure 4. Again, this measurement does not show any significant difference between the freeze in the pot with HRS compared to the control pots.

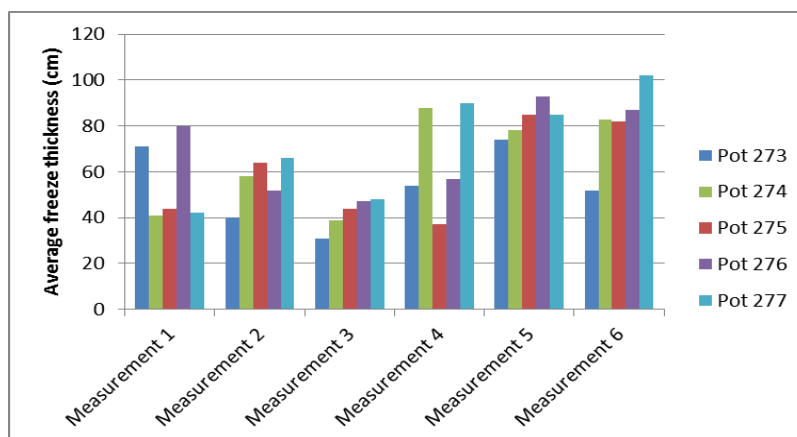
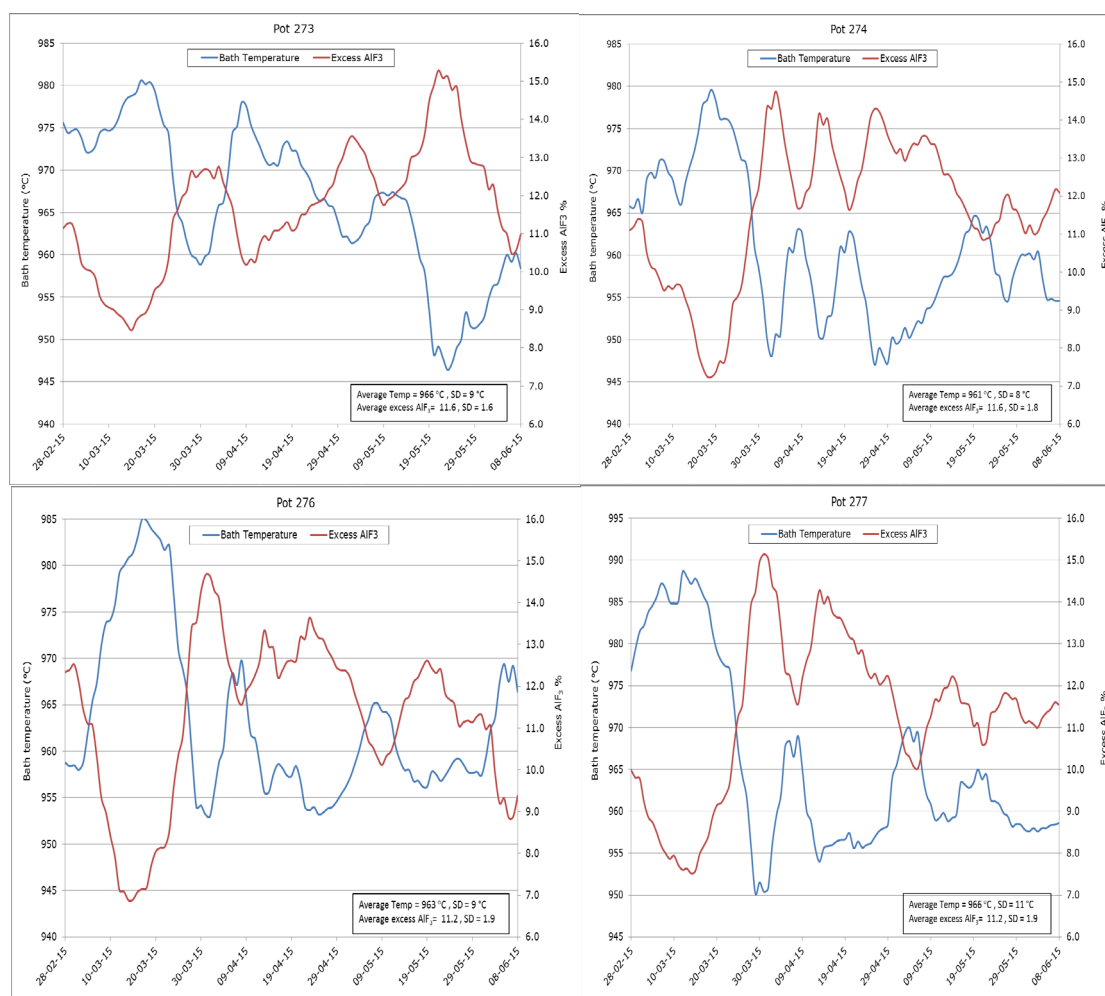


Figure 4. Average freeze thickness in any position at anode change.

The DX+ Ultra pots were stopped in March 2017 for validation through autopsy and industrial busbar modification. The autopsy report showed that the pot with HRS had similar freeze coverage as the other pots.

### 3.4. Bath Temperature and Excess $\text{AlF}_3$

The bath temperature and excess  $\text{AlF}_3$  control also reflect the pot thermal balance. Figures 5a and 5b show plots of seven-day moving average of bath temperature and excess  $\text{AlF}_3$  for three months at 455 kA. The selected period follows a test period during which higher amperage of up to 470 kA was tested. The thermal balance was shifted to a region of high temperature and low  $\text{AlF}_3$  in all pots except HRS Pot 275. The HRS pot showed bath temperature and  $\text{AlF}_3$  that was more controlled within the upper and lower limits of these parameters. The standard deviation in bath temperature in the HRS pot was 5 °C while it was 8 – 11 °C in the rest and the standard deviation for excess  $\text{AlF}_3$  was 1.1 in HRS pot compared to 1.6 – 1.9 in the other pots. Less fluctuation in bath temperature and chemistry usually means also less fluctuation in freeze thickness. It seems that the HRS helps the pot react slower to changes in the pot energy and thus causes less drastic fluctuations in temperature and excess  $\text{AlF}_3$ .



**Figure 5a. Seven-day moving average of bath temperature and excess  $\text{AlF}_3$  in non-HRS pots.**

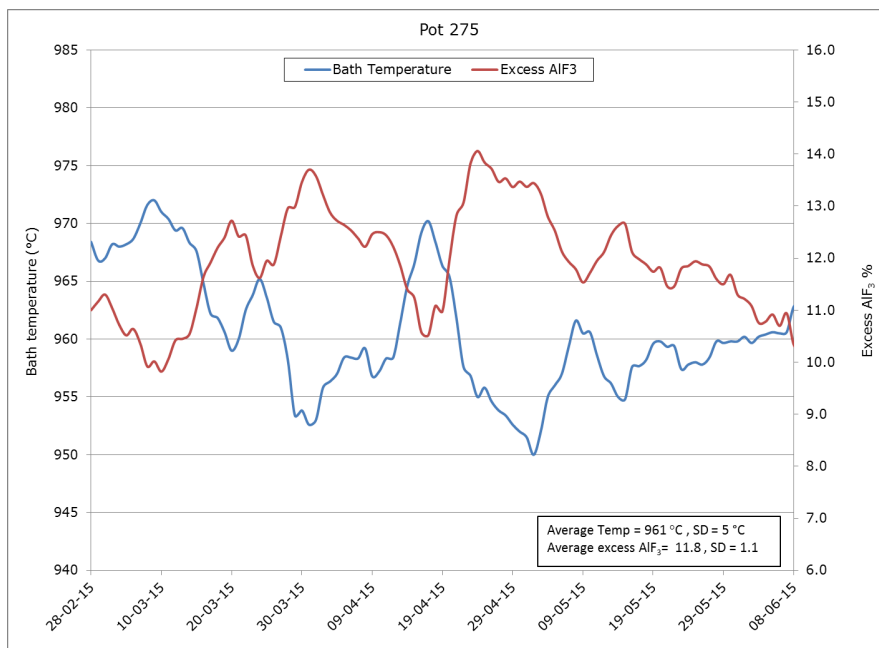


Figure 6b. Seven-day moving average of bath temperature and excess AlF<sub>3</sub> in HRS pot.

### 3.5. Power Outage

As part of plant operation schedule, a planned power outage took place in the DX+ Ultra pot for one hour and 45 minutes. The power outage gave us the opportunity to test the impact of such reduction in amperage on the HRS. The normal procedure for giving voltage adds before outage was applied. In the pot with HRS, a further step was tried to further keep the heat in the pot during outage. The flow in the HRS system was reduced in steps to increase the retained heat. However, this did not mean reducing flow to minimum or completely stopping the system. The constraint in this case was one of the HRS requirements is to keep the temperature in the units below 320°C to avoid change in oil thermal properties. The oil flow was reduced in steps to reduce heat losses from the pot as shown in Figure 6. Figure 7 shows the reduction in energy collected from sidewall during this process. The reduction in energy collection was about 45 kW.

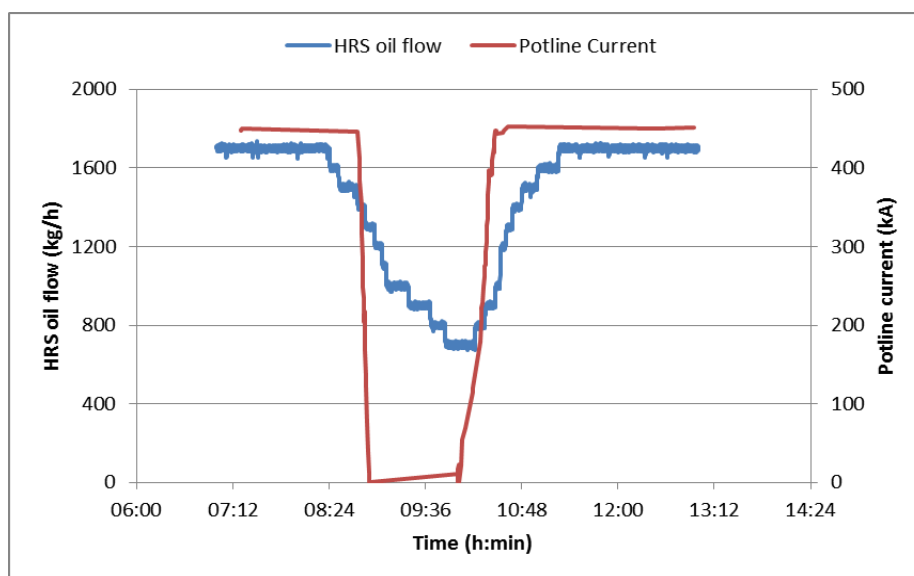


Figure 7. Reduction of oil flow during amperage shut-down.

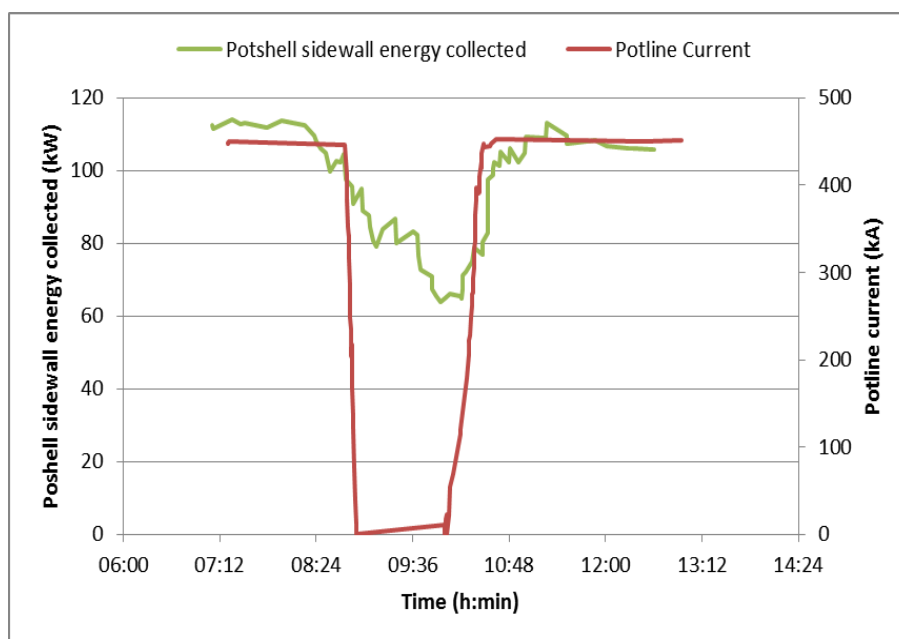


Figure 8. Reduction of heat recovery during amperage shut-down.

### 3.6. Bath Temperature

The bath temperature affects the total energy removed from the cell. Figure 8 shows how the energy collected increased following the increase in bath temperature. The oil flow rate in the HRS was not modified during this period. This also agrees with the previous findings on bath temperature and AlF<sub>3</sub> concentration. The energy removed increases with the increased bath temperature which in turn helps remove some of the extra heat and cool down the bath temperature faster than other cells.

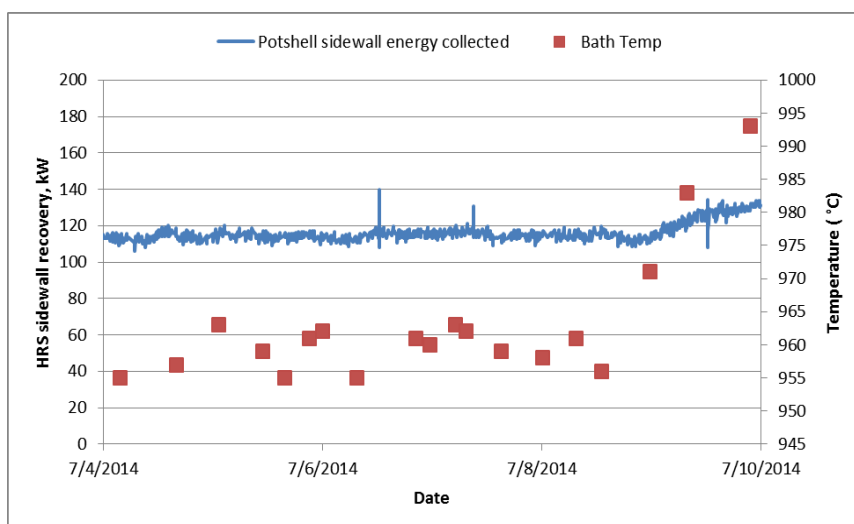


Figure 9. Increase of energy collected with increase in bath temperature.

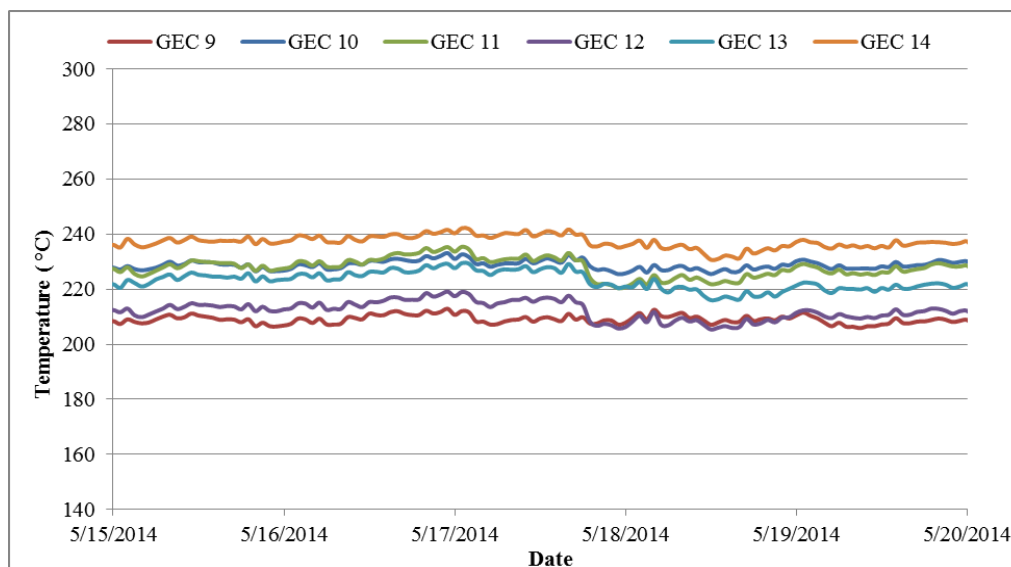
### 3.7. Removal of Anode with Spike and Burnoff Anode

Spikes are parts of anode that are not consumed. Cone spikes grow as prolonged vertical pieces and short circuit to the metal causing current efficiency loss and bath temperature increase at

least locally. The impact of these spikes on temperature was indirectly analyzed through the temperature on HRS units next to the removed spikes. An example of these spikes is shown in Figure 9. Figure 10 shows the temperature on HRS units near the removed anode with spike. The bath temperature drops after the spike removal. The anode removed (anode 11) is above GEC 12 and the highest temperature drop can be seen in GECs 11 and 12 which show a drop of about 10 °C.



**Figure 10. Anode spike from HRS pot.**



**Figure 11. Temperature on HRS units.**

A more drastic change in temperature was seen in a case of an anode burn-off. Figure 11 shows the temperature drop in the HRS units opposite to an anode removed with burn-off. In this case, the burn-off anode is above GEC 48 and causes an increase in temperature on a larger part of the cell with the highest temperature drop observed after removing this anode being about 55 °C.

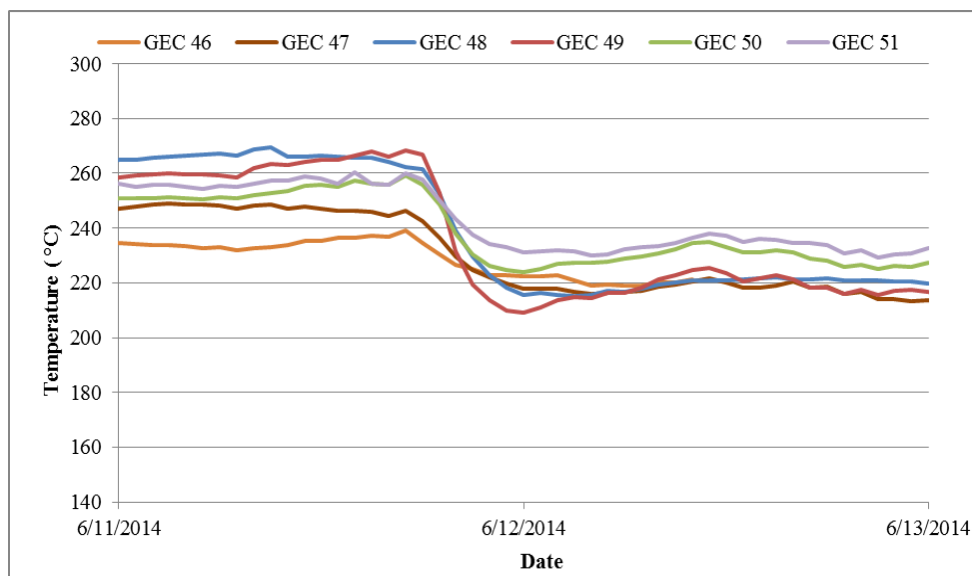


Figure 12. Temperature drop on HRS units after removal of a burn-off anode.

#### 4. Pot Performance

DX+ Ultra technology key performance indicators are given in Table 1 for the period from 1 June 2015 to 17 March 2017 when all five pots were stopped for building DX+ Ultra industrial design pots. Most performance parameters of HRS Pot 275 and the average of the other for pots are nearly equal, except for current efficiency which was 1% lower, and consequently specific energy consumption which was 0.2 kWh/kg Al higher in HRS pots than the average of four other pots. This difference is believed to be due to other design differences causing higher pot noise in Pot 275. The average pot noise for Pot 275 was 20 mV while the average of the other pots is 11 mV. Also, the carbon consumption is slightly better in the other pots compared to HRS pot.

Table1. Key Performance Indicators of DX+ Ultra Technology Eagle cells for the period from 1 June 2015 to 17 March 2017.

KPI	Units	HRS Pot 275	Other 4 pots
Amperage	kA	456.2	456.2
Current efficiency	%	94.0	95.0
Metal production	kg/pot day	3452	3492
Cell voltage	V	4.08	4.08
DC specific energy consumption	kWh/kg Al	13.0	12.8
Gross carbon consumption	kg C/t Al	529	523
Net carbon consumption	kg C/t Al	408	403
Bath temperature	°C	964	964
Excess AlF <sub>3</sub>	%	10.3	10.2
Fe	%	0.031	0.031
Si	%	0.028	0.027
AE frequency	AE/pot- day	0.014	0.014
AE duration	s	4.7	5.6
PFC Emissions CO <sub>2</sub> Equivalent*	kg/t Al	1	1
Average pot noise	mV	20	11

\*CO<sub>2</sub> equivalent is calculated as in Reference [7], using the Tier 2 method and SAR (Second Assessment Report).

## 5. Practical Aspects

The main aspect is on maintenance. The HRS energy collection units were not replaced since installation. However, many thermocouples on these units needed replacement. These thermocouples might be unnecessary for industrial applications. Also, a cooling system needs to be in place for shutdown of HRS as these units are expected to heat up to about 400°C while the oil in the HRS should be kept below 320°C to avoid any changes in properties. A permanent cooling system was installed to allow easy on and off usage of cooling in case of emergency shutdown of HRS.

## 6. Conclusions

Heat recovery is believed to impact the thermal balance of the pot. The appropriate settings of this particular HRS allowed similar behavior in this pot compared to pots without HRS. One of the benefits of HRS is the possibility of faster formation of freeze during start-up. The additional energy used to cool down during this period indicates the possibility of amperage increase as more heat can be removed from the pot with HRS. Also, it seems that HRS allows better control of bath temperature and excess  $\text{AlF}_3$ . The pot response during a power outage shows possibility of insulating the pot with HRS. It is believed that HRS did not affect the other main key performance indicators in the pot while being able to collect about 100 - 120 kW of power from the shell sidewalls.

In summary, the pot performance with HRS was not very different than the performance of normal pots, but with a few additional features it had faster response to thermal imbalance in the pot. It appears that the HRS would be able to operate at higher amperage and it would better tolerate power modulation. The energy collected, if it could be used, could be subtracted from the specific energy consumption of the pot.

## 7. References

1. Anders Sørhuus and Geir Wedde; Pot gas heat recovery and emission control, *Light Metals* 2009, 281-286.
2. Stephan Broek, James Farrell, Muna Alamoodi, Nadia Ahli, Milton Khan; An approach to a sustainable aluminium smelter design, *Proceedings of 33<sup>rd</sup> International ICSOBA Conference, Travaux No. 44*, Dubai, UAE, 29 November – 1 December 2015, Paper AL12, 599-611.
3. Amal Aljasmii et al., Heat Recovery from aluminium pots based on heat pipe technology, *Proceedings of 11<sup>th</sup> Australasian Aluminium Smelter Technology Conference*, Dubai, UAE, 6 – 11 December 2014, Paper 14M10.
4. Pascal Lavoie, Sankar Namboothiri, Mark Dorreen, Mark Taylor; Increasing the Power Modulation Window of Aluminium Smelter Pots with Shell Heat Exchanger Technology, *Light Metals* 2011, 367-374
5. Yaser Mollaei, Mohsen Asadi and Haavard Arvesen, A Novel Heat Recovery Technology from Aluminum Reduction Cell's Sidewalls: Experimental and Theoretical Investigations, *Light Metals*, 2014, 733-738
6. Ali Alzarouni et al., DX+ Ultra – EGA high productivity, low energy cell technology, *Light Metals* 2017, 769-774.
7. Ali Al Zarouni et al., DX+, an optimized version of DX technology, *Light Metals* 2012 697–702.