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EXTERNAL POTSHELL INSULATION: A MULTI-USAGE TOOL IN LOW POWER OPERATION

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Abstract

In the context of global climate change and Hydro's focus on reducing its greenhouse gas footprint, Hydro's Primary Metal Technology (PMT) department has been focusing on low energy pot development for the last decade. Disclosing some of the development is meant as one of Hydro's contributions to the industry's effort in reducing greenhouse gas production. This paper presents Hydro's PMT experiences with the use of external potshell insulation. It presents its early uses as a tool to improve pots having cold spots, to a solution for maintaining a cathode free from bottom deposits on pots where heat input is sharply decreased, opening the door to cheap retrofitting of smelters for low energy consumption. The authors also mention recent development where external insulation is becoming part of pot design, which, along with other efforts in reducing voltage drops, allows stable pot operation below 12kWh/kg.

Introduction

Hydro's efforts in reducing costs and improving productivity date back to more than 20 years [1]. The "classic" technological strategies to reduce costs typically involve increasing amperage on the potlines while somewhat compensating for the effects:

1- Increase amperage while increasing heat input to the pots, resulting, amongst others, in a more difficult operation and increased specific energy consumption
2- Increase amperage while keeping power input constant, resulting in decreased specific energy consumption. The best choice if ACD (Anode-Cathode Distance) can be lowered
3- Increase amperage after pot modifications to increase pot heat loss, which ultimately also increases specific energy consumption

All of these strategies have been used in the Hydro system. They are facing sooner or later a typical problem: as amperage is increased overvoltages and power input also increase very fast, quickly resulting in reduced efficiency and fragile heat balance. Such choices (except strategy #2 above) also result in increased specific energy consumption, to sometimes intolerable levels for old smelters having gone through multiple such volume increase programs. Such high specific energy consumption levels may be acceptable in smelters with low power costs, but they are not for the majority of those with already high or surging power costs.

For Hydro, it is clear that the future of aluminum smelting is going to depend on technology that will allow to sharply decrease specific energy consumption to produce the metal. This is why efforts to reduce specific energy consumption while maintaining high performance in all aspects of pot operation (current efficiency, current density, lining costs, operating costs, etc.) have been at PMT's focus for the last decade.

Now that other organizations have published about it [2,3], it is time that Hydro discloses some exciting development in achieving low power pot operation, and share some experience about it, in hopes that it helps the aluminum industry at large to reduce its energy use and greenhouse gas production.

Back in 2006 in Kurri Kurri, Australia, another "classic" cost improvement program was started to improve the cost situation of the plant, and strategy 2 above was first choice. As amperage was increased however, it became evident that one of the three potlines in particular was suffering from noise while the two others were remaining stable and even were improving. Investigation showed that this potline, featuring narrower pots than the other two, was suffering from massive bottom ledge development on the corners and long sides, causing deformed anodes, poor anode setting accuracy and noise. This potline had suffered from this condition well before the amperage increase, but it became just overwhelming when amperage was increased. A rather radical solution was tested to get rid of the excess ledge in these areas: pads of insulation were attached on the potshell on the areas that had the most ledge. The impact was evident in a week, but took a few months to fully develop as the pots melted excess ledge (see Figure 1). Ledge creeping on the cathode surface was reduced, and the deformed butts, and noise, also reduced, opening the door to more amperage increase and ACD reduction.

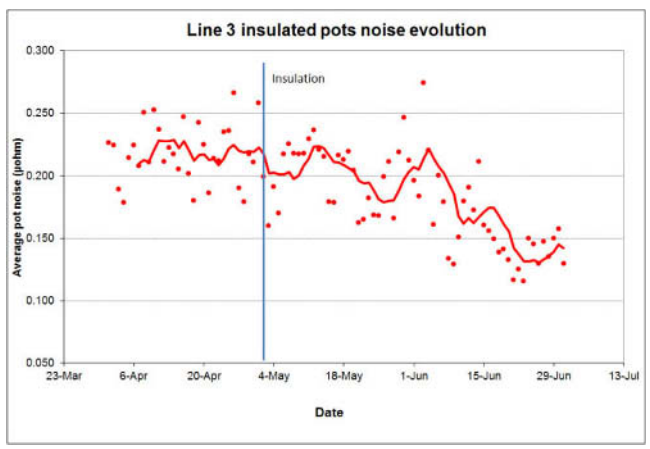

Figure 1. Noise evolution of Kurri Kurri line 3 pots after potshell insulation

Obviously, adding insulation on potshells seems a desperate fix for desperate situation. However, insulated pots in Kurri Kurri have operated without problems from 2006 to 2012 until the plant was stopped for economic reasons. Over that period, no pot experienced a tap out on the insulated areas, and the "fix" was even used in the other potlines, to help pots with excessive ledge due to heat loss in a damaged lining area. All that helped build confidence on this idea, and more efforts were deployed to better understand how external potshell insulation affects the linings and the uses that can be made of it.

Starting in 2009 external insulation was applied to an existing instrumented test pot at Årdal Reference Centre in Norway to better understand how it should be used, and what benefits can be expected from it. Results were outstanding. External insulation, not even optimised as was learned to do in later experiments, allowed keeping the pot in stable operation while reducing its average voltage by more than 100mV, and even improving current efficiency all the while. These results prompted the promotion of external potshell insulation from an interesting curiosity to a design feature that is needed to design pot technology that will successfully operate at very low specific energy consumption. The first pot with external potshell insulation being an integral part of the thermal design was started in 2012, and was called HALsee (for Hydro ALuminium Super Energy Efficient) demonstrating consistent operation with specific energy consumption below 12kWh/kg.

The problem with low power operation

The electrochemistry laws show that the specific energy consumption (EC) in Hall-Héroult cells depends on only two parameters:

$$EC\ [kWh/kg] = \frac{2.98 * \text{Pot Voltage}}{\text{Current Efficiency}} \qquad (eq.1)$$

Where pot voltage is in Volts and Current efficiency is in fractional value. According to equation 1, it is therefore required to reduce pot voltage and/or increase current efficiency to reduce specific energy consumption. In fact, current efficiency is really a result of pot operation, depending on many parameters that are still today not totally well understood, making any attempt at increasing current efficiency vulnerable to uncertainties. In contrast, pot voltage is an easy parameter: the operator has full control on the voltage a pot will be allowed to operate. As a result, smelters always strive to operate pots at the lowest possible voltage, but quickly face devastating loss in current efficiency when they attempt to go too low, leading them to go back and stabilize at some "optimised" operating voltage. The classic reasoning to justify the voltage limit is that the ACD has got too low, explaining the loss in current efficiency. This is in stark contradiction with detailed experimental work such as that of Solli [4], who found that current efficiency keeps constant as ACD is decreased, down to very low values approaching 10mm. Smelters never get anywhere close to 10mm ACD, so something else is causing the current efficiency loss as voltage is reduced.

Evidence from our results show that the cause for the current efficiency loss observed as pot voltage is reduced is not a too low ACD, but the development of insulating deposits (commonly named bottom ledge) on the periphery of the cathode surface, leading to magnetic disturbances that result in metal waves (seen as noise), deformed anodes and all commonly seen problems associated with the loss of current efficiency typically blamed on too low ACD. This is easily verified with a squeeze test, where ACD can temporarily be sharply reduced without making a pot noisy. Figure 2 presents average ledge profiles of the same test pot operated at high and low voltage, which correspond with low and high noise operation, respectively.

Too low voltage (or more appropriately too low thermal power input) usually shows up first as bottom ledge covering the cathode around pot corners, creeping to the short and long sides as power is reduced further. Bottom ledge on the corners and short sides in particular has a strong potential for magnetic disturbance that leads to metal wave development in the pots [5], and deformed anodes (see Figure 3).

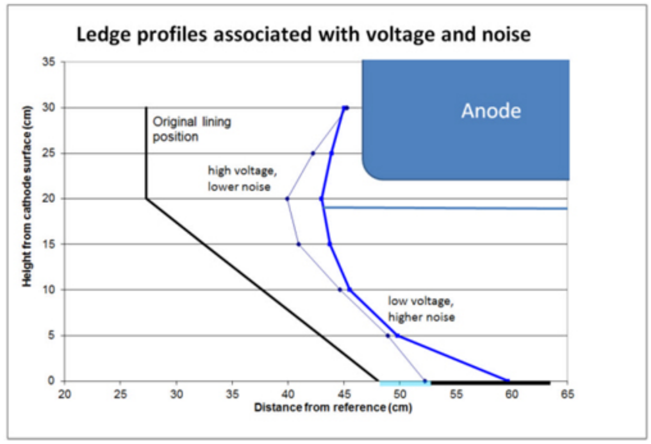

Figure 2. Ledge profiles associated with high and low voltage and noise

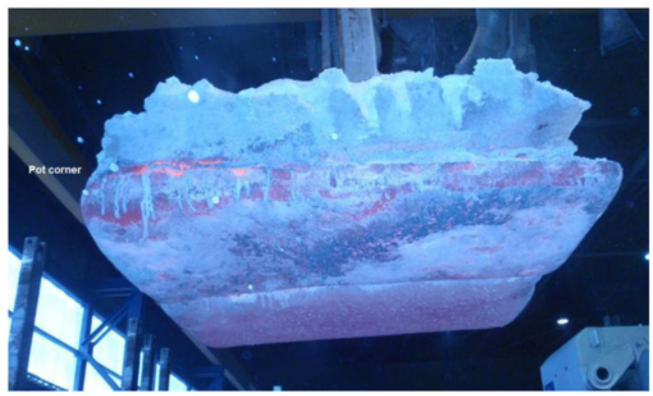

Figure 3. Deformed butt from a corner position where bottom ledge is present

Figure 4. An example of potshell insulation on a pot corner

In this context, the effect of external insulation is straightforward: insulating the potshell at the right locations, like the corner shown in Figure 4, will shift the internal isotherms outward, which will therefore shift the areas where bottom ledge is stable. Figure 5 presents such a shift on a modelled cathode, the amplitude depending of course on the parameters of the insulation, like conductivity, thickness and position.

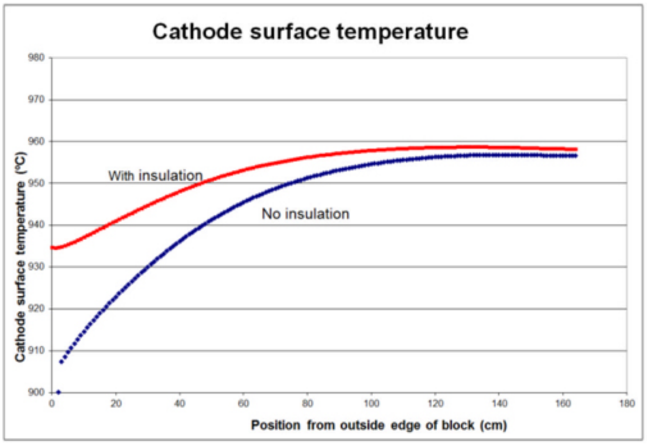

Figure 5. Cathode block surface temperature with and without external potshell insulation

The use of external insulation

The concept of external potshell insulation is still in development in Hydro. There are a number of hurdles that must be overcome in order to properly use this idea to its full potential. For example:

1- One must admit that an organization has to pass the fear element associated with adding insulation to a potshell. Many smelters have increased the amperage of their potlines over the years, ultimately by increasing the power input to their pots to the maximum allowed by the lining construction or even new, high heat loss linings. This makes the pots very fragile to thermal "excursions" that cause side lining damages, ultimately leading to increased tap out rates. Adding external insulation to such pots is extremely sensitive.
2- Some lining designs are indeed less friendly to external insulation, especially those that are designed to lose a lot of heat, because they tend to have a higher potshell temperature to start with. Adding insulation to already warm potshells areas may increase the risk of damage to the metal by corrosion or bowing.
3- Insulation has to be used to correct problems that it can correct. For example, pots with large amounts of muck (hard, recrystallized alumina deposits) that is wrongly diagnosed as bottom ledge will never get better even if insulation is added. A thorough analysis of the pots' situation is in order before applying insulation.

From Hydro's experience, external potshell insulation is **not** a fix-it-all solution that can be implemented uniformly anywhere and will give consistent results. Rather, positive results are achieved only if it is used to solve issues linked to excess side or bottom ledge that is causing magnetic disturbances to pots. Therefore, an excellent knowledge of the ledge situation in pots is an unavoidable prerequisite to properly and safely implementing external potshell insulation. This involves a detailed mapping of the ledge around pots. Indeed, pots commonly have uneven side- and bottom ledge profiles along their periphery, so while applying insulation in excessively ledged areas will greatly help a pot, applying it to areas that already have too little ledge can lead to side lining damage on the same pot. Uneven ledge profile may stem from internal conditions in the pot (heat transfer by liquid flow, lining damage, construction…) or external factors like different ventilation patterns around the pots or potshell cooling obstruction by fallen crust or anode cover material for example.

The use of external potshell insulation is very flexible, which makes it an excellent and accurate tool for adjusting pots heat balance over time, as well as addressing local issues with uneven heat loss. It can be added or removed, or more can be added as pot's input power is reduced.

External insulation is presently used for three main reasons in Hydro:

1- Stabilize existing noisy pots that have "cold cathode" condition and enable them to operate at lower specific energy consumption
2- Reduce the heat loss of existing pots to enable them to operate in a stable manner at lower specific energy consumption
3- Design linings having sharply lower heat loss while keeping the cathodes free from bottom ledge, all in existing potshells

<u>Helping pots with "cold cathodes" operate at lower specific energy consumption</u>

Pots with lining damage, or simply old linings that have lost their original insulating properties, lose more heat than other pots in better condition. This often leads to the "cold cathode" syndrome characterized by a higher noise that is usually reduced by operating the pots at higher voltage, e.g. supplying more heat, most often with only limited success and an increased risk of early failure. External insulation can be used to return the potshell heat loss to lower levels, thereby reducing the need for extra voltage.

Tests have shown that existing pots, with a long history of noisy or high voltage operation, can be tamed and brought to stable operation when added external insulation, and their operating voltage reduced 100mV or more below original level. This corresponds to a potential specific energy consumption reduction of about 0.3kWh/kg and more. Figure 6 presents the voltage and noise evolution of an instrumented pot that was insulated to test the retrofit potential of the idea. After encouraging development, the pot noise slowly increased again, until it was found that parts of the insulation panels had fallen off. After the panels were reset to their position, the pot became stable again and voltage could be lowered further without increasing the noise.

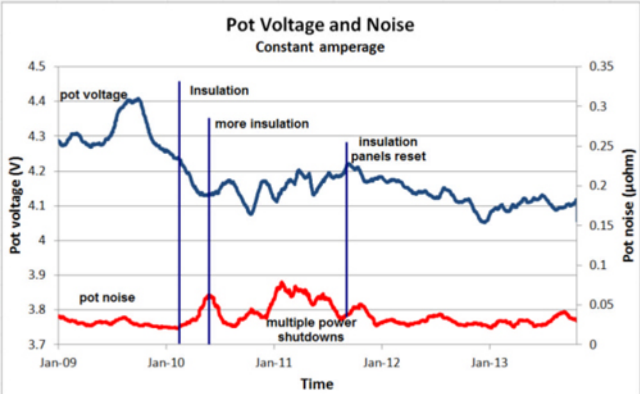

Figure 6. Voltage and noise evolution of a pot where external potshell insulation was added to test the potential of the idea

Cheap and easy retrofit for decreased specific energy consumption

As pots' voltage is decreased, some areas (corners and short ends, typically) tend to become "cold" first and grow bottom ledge "toes" that increase noise. Adding external insulation to these areas avoids this local cooling, enabling potlines to operate at power levels that were not possible before. External potshell insulation has enabled the demonstration that ACD is usually not a limiting factor in achieving low power operation for a good magnetic compensated cell.

As mentioned above, applying external potshell insulation to aging pots enables the continuous operation of these pots at the same voltage throughout their whole life, contributing to further reduction in a potline's energy consumption.

The ease and low cost of installing external potshell insulation makes it an outstanding candidate for cost efficient, specific energy consumption reduction "retrofit" for existing smelters.

Design element for pots designed for low energy consumption

It is clear that external potshell insulation cannot solve all issues encountered when designing low power pot technology. High voltage drops and uneven or moving metal pads do impose limits on how low voltage pots can be run. External potshell insulation is however one of the tools Hydro is using in designing its next generation of low specific energy consumption pot technology. Together with innovations in other design areas that enabled decreased resistance, external potshell insulation is used to ensure that heat balance at low power input, and in particular a "warm" cathode, is maintained within the physical constraints of existing potshells and potline dimensions.

Recent results for the HALsee test pot mentioned above are presented in Figure 7. Current efficiency is maintained around 94%, pot voltage around 3.75V and anode effect frequency is below 0.02AE/day. This pot operates at an anodic current density of 0.86A/cm^2.

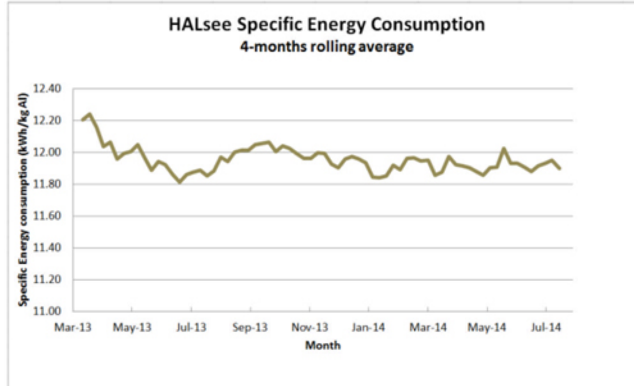

Figure 7. Specific energy consumption of experimental pot designed for low specific energy consumption

Clearly, strong modelling capability and calibrated models are essential tools that PMT uses to save time and money when designing linings and the associated external insulation. Proper modelling allows the design of safe and secure solutions by precisely defining where and how the insulation should be added. Over the years, PMT has developed, and continues to refine such tools that enable fast development of pot technology at energy levels that are at the lower end of the present technology spectrum. These include heat and voltage balance models, as well as magneto hydrodynamic models that allow prediction of metal stability at low ACD.

Observations on insulated pots

We share below a number of observations on critical elements in pot technology that are affected by external potshell insulation.

Effects on potshell temperature

Installing external insulation on potshells has quick effects on pots. As can be seen on Figure 8, potshell temperature under the insulated area increases instantly when insulation is added. The temperature increase will of course depend on the insulation position and thickness. The maximum potshell temperature increase observed in Hydro is moderate.

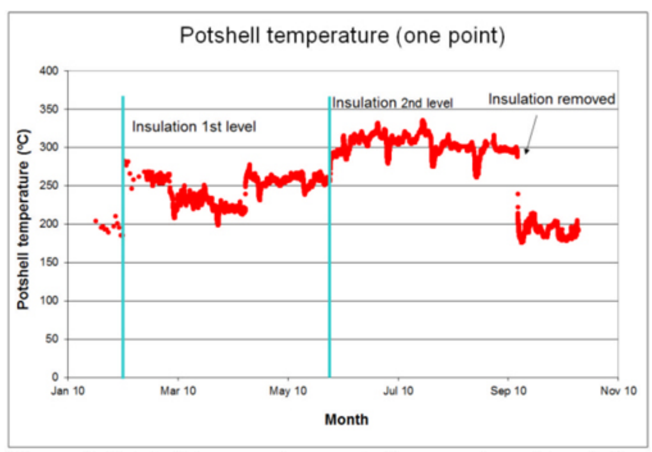

Figure 8. Potshell temperature evolution as external insulation is added, and then removed.

The potshell temperature never gets back to the original level however such that a stable, net increase is obtained after some time (4-8 weeks), which gives a good idea of the involved ledge dynamics.

Effects on ledge shape

External insulation is quite effective as a tool to shape ledge profiles in pots. Figure 9 presents an example where external insulation was applied to the potshell of a pot where ledge covering the cathode was found in some areas.

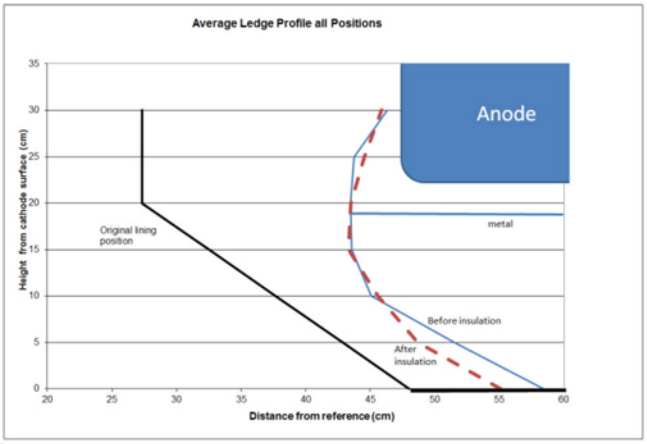

Figure 9. Ledge shape change before and after external potshell installation (average for all measured positions).

The insulation was applied only on some parts of the potshell. The two measurements are two months apart. The ledge shape change clearly shows that external insulation has the potential to affect only some parts of the ledge profile while letting the rest intact. Pot voltage was not changed during the test.

Effects on lining temperature

Similarly to potshell temperatures, lining temperatures are also affected by external potshell insulation. The effect is quite local however. For example, when adding insulation to the side of the potshell, lining temperatures under the cathode blocks are totally unaffected, whether they are just under the block or at the bottom of the potshell. Mostly the temperatures of the side lining facing the insulated area will change, with similar amplitude as that of the potshell. Figure 10 shows an example of the side lining temperature evolution before and after external insulation is added to the potshell's side in front of the thermocouple's location. Note the slow temperature decrease before the insulation, as ledge was building up.

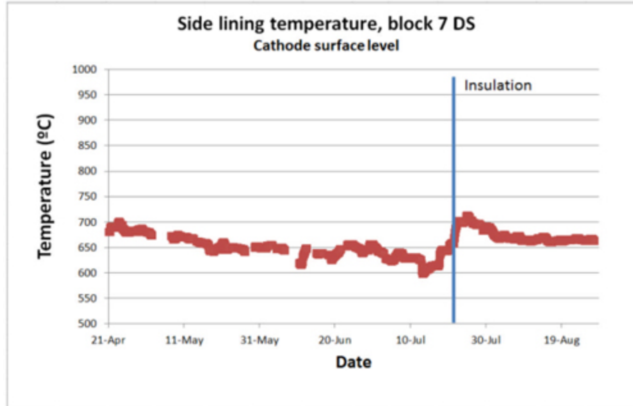

Figure 10. Side lining temperature evolution when external insulation is applied to the potshell's side (at cathode surface level)

The risks of external potshell insulation

It definitely takes strong nerves when first trying to use external potshell insulation. Managers, engineers and operators used to deal with overpowered pots will understandably see many risks with such an idea. While many advantages are demonstrated, there are also a number of concerns that will naturally arise. Some are real, while some have not been observed in Hydro (see below). As mentioned earlier, pot technologies used around the world differ in many aspects, as well as the conditions they are used in. Therefore, every pot situation needs to be thoroughly evaluated before deciding on applying external potshell insulation.

Losing sidewall ledge protection The obvious main risk with external potshell insulation is the loss of protective ledge on the side lining and subsequent attack that can lead to a side tap out. This can indeed happen, but a proper follow-up of the ledge easily allows avoiding any damage. As mentioned above, in 8 years of small and large scale external insulation, Hydro did not experience any failure directly caused by external potshell insulation. The risk factor increases if the follow-up is inadequate: side lining directly exposed to liquid bath will survive a few months before failing, which gives time to discover an issue.

Damage to the lining The shift in internal isotherms caused by external potshell insulation has the potential to extend or speed up the transformation of lining material, thereby reducing their insulation properties and cancelling all or part of the insulation's benefits. This does not seem to happen. Indeed, as shown on the right of Figure 8, experiments to test any permanent damage to the lining by removing the insulation after several months show that the potshell temperature returns to the exact original value, suggesting that no permanent change to the insulation's properties was caused. Autopsies of pots that lived multiple years with thick layers of external insulation on their sides showed no significant advance in the reaction zone compared to pots without insulation. Likewise, on pots with extensive insulation, a low target resistance can be maintained for years without need for an increase. The reverse trend is true in fact: as more confidence builds, target resistance tends to be further lowered as engineers and operators try to see how low the pots can go.

Achieving too high potshell temperatures Another risk with potshell insulation concerns the potshell temperature. It is known that if the walls of the potshell become too hot, the combination of the loss of strength and thermal expansion of the steel will cause the walls to bulge outward, resulting in permanent deformation and loss of thermal contact with the lining (which can well lead to tap outs). This is particularly true for pot designs modified for high heat loss.

Conclusions

Work done in Hydro over the last 9 years shows that external potshell insulation has the potential to allow smelters to reduce their energy consumption in producing aluminum. The insulation can be used in a number of ways:

1- Stabilize existing pots that have damaged lining or "cold cathode" condition and enable them to operate at lower specific energy consumption
2- Reduce the heat loss of existing pots to enable them to operate in a stable manner at lower specific energy consumption
3- Design linings having sharply lower heat loss in existing potshells, enabling the development of pot technology able to operate below 12kWh/kg in existing smelters

While some risks do exist to cause damage to pots if insulation is done carelessly, it seems that basic precautions and follow-up easily allow avoiding damages and benefiting from the use of external insulation.

Since it can be used on existing potshells, smelters can use external insulation, alone or together with appropriate lining changes to obtain high cell energy efficiency at a very low cost.

Acknowledgements

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