Energy saving from a reduction pot

This paper puts forward the benefits of energy-saving in an aluminium reduction pot by minimising heat loss through the use of a new thermal insulation lining, an insulated and sealed hood, composition and thickness of the anode covering layer and installing an 'irregular' cathode with bevelled edges.

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The key technologies applicable to primary aluminium production are low-temperature reduction, increasing the current, on-line measurement of superheat, Three-variable control technology, anode slotting, bevelled cathode blocks, thermal insulation of pot hoods, drainable cathodes and the application of new lining designs and materials. These are being studied and developed in China with the aim of raising aluminium reduction technology to an advanced level.

The consumption of energy and raw materials for aluminium reduction has been high recently especially in regards to power consumption. Aluminium reduction costs must be lowered.

The most efficient method to achieve this is to lower the consumption of the DC current used for electrolysis by increasing the current efficiency (CE) and reducing pot voltage.

The pot energy balance has been summarized by Warren Haupin[1] as:

Heat input

1. Current (variable)
2. Voltage
2.1 Anode (constant)
2.2 Cathode (constant)
2.3 ACD (Anode Cathode Distance)
2.3.1 Bubble voltage drop (variable)
2.3.2 Bath voltage drop – ACD, bath ratio (variable)
2.3.3 Back-EMF (constant)

Heat output

1. Heat dissipation at pot top
– internal cause: cell operating temperature (Topr)
– External cause: material and thickness of anode covering materials, flue gas velocity and degree of sealing of pot hood.
2. Heat dissipation at pot side
– internal cause: Tsuper heat
– External cause: bath level, metal level, pot lining design.
3. Heat dissipation at pot bottom
– internal cause: cell operating temperature (Topr)
– External cause: material and thickness of cathode lining

The objective is to minimise the voltage drop across the cell by a combination of adjusting the heat input, mainly by adjusting the voltage drop across the cell between the anode and cathode (ACD).

The heat generated during electrolysis arises from the Joule heat produced by the current passing through the bath between the anode and the cathode.

Stable production is maintained by ensuring a dynamic balance of heat lost by the pot and heat input by the Joule effect during operation.

If the Joule heat generated is insufficient to balance the heat output, the pot gradually cools, and the process can stop and the pot freeze.

The energy balance of a pot can be maintained by reducing the heat dissipated from the pot and balancing the heat input by reducing the voltage across the pot.

Lowering voltage

About half of the total power input of a pot is used for electrolysis and half is lost through heat dissipation. Thus the focus on achieving a lowering of pot voltage is to reduce the heat lost from the pot. The optimum thickness of the side profile ledge formed in the bath is a core factor in lowering the voltage.

Too thick or too thin a ledge will have a negative effect on the pot stability during production, affecting the voltage required and the current efficiency (CE) and possibly resulting in leakage from the pot. Therefore, the distribution of heat dissipation and the formation of an optimum thickness of the side ledge are key to pot design and has led to a new thermal insulating lining being developed.

Heat dissipation: Pot top

As the heat lost from the top of the pot accounts for about half of the total heat loss the focus on lowering heat loss is in this area. For a conventional pot, the heat lost from the pot top equates to 1.0V to 1.2V (the figure is expressed in volts since Topr = heat loss in kW / Cell current in kA) and the pot voltage is required to be above 4.16V. However, based on the statistics of the pots operating with

Area	Heat Dissipation Area		Heat Dissipation (kW)	Heat Dissipation (V)	(%)
Anode area	Pot hood	Pot side cover plate	112.8	0.348	18.4
		Pot rim plate	15.5	0.047	2.5
		Pot end cover plate	15.0	0.046	2.4
		Sub-total	**143.2**	**0.439**	**23.4**
	Pot superstructure	Pot top	43.4	0.133	7.1
		Anode guide bar	7.4	0.023	1.2
		Fume	181.5	0.557	29.7
		Sub total	**232.3**	**0.713**	**38.0**
		Total	**375.5**	**1.152**	**61.4**

Table 1 Distribution of heat loss from the anode area for a Type A conventional pot

Area	Heat Dissipation Area		Heat Dissipation (kW)	Heat Dissipation (V)	(%)
Anode area	Pot hood	Pot side cover plate	97.1	0.299	18.1
		Pot rim plate	21.0	0.064	3.5
		Pot end cover plate	18.3	0.050	2.7
		Sub-total	**134.4**	**0.412**	**22.2**
	Pot superstructure	Pot top	67.1	0.206	11.1
		Anode guide bar	6.9	0.021	1.1
		Fume	111.5	0.342	18.5
		Sub total	**185.5**	**0.569**	**30.7**
		Total	**319.8**	**0.981**	**52.8**

Table 2 Distribution of heat loss from the anode area for a Type B pot

	Conventional	Irregular Cathode
Lining thickness (cm)	22	12
ACD (cm)	5.4	4.5
Superheat (°C)	8	7
Pot voltage (V)	4.17	3.85

Table 3 Comparison of physical parameters of different 350kA pots

various currents, heat dissipation at the top is below 0.98V for pots with a voltage lower than 3.9V. A lowering of the heat dissipated from the top of the pot thus has the greatest effect on lowering overall heat loss and contributes the greater part to a lowering of pot voltage.

There is an important relationship between heat dissipated from the top of the cell and the pot voltage. Using data from a 320kA pot in a Chinese smelter, this paper illustrates this relationship for two types of pot.

The first type (Type A), is of conventional design with a thinner cover material on the anode and bath, a voltage of 4.16 to 4.18V and heat dissipation of 1.153V in the anode area. The total heat loss from the hood and superstructure of the pot in the anode area are summarised in **Table 1**.

The second type of pot (Type B), is a redesigned version with a thicker layer of covering material, a pot voltage of 3.8 to 3.85V and heat dissipation of 0.98V in the anode area, as summarised in **Table 2**.

Pot covering

The composition and thickness of the pot covering layer regulates the thermal balance which can be controlled by adjusting the proportion of alumina in the mixture of alumina and crushed bath electrolyte which makes up the covering material as well as its thickness.

For large pots, it is necessary to take measures to improve the insulating properties at the middle and at the ends of the pot by increasing the thickness of the covering layer to ensure uniformity of the total thermal balance of the pot so as to achieve a uniform and regular side ledge within the pot.

The thickness of the cover materials has the greatest impact on heat dissipation at the top of the pot. Taking a 350kA pot as an example, the covering layer was made up of equal parts of crushed bath and alumina.

Application of new pot hood

A new energy-saving sealed pot hood has been designed. This is lined with a high temperature fire resistant layer and with thermally insulating composites on both the inner and outer surfaces of the hood. This insulating layer prevents the heat from the top of the pot escaping through the sides of the hood and so reduces heat loss from the pot. It was observed that the external surface temperature of the pot hood was lowered by more than 10°C and the voltage reduced by 5 to 15mV using the new pot hood compared to a conventional hood.

Heat loss at pot sides and bottom

The heat dissipated from the sides and bottom of the pot accounts for half of the total heat output. The degree of superheat of the electrolyte is directly related to heat dissipation, the principle of which is to maintain stable production at minimum voltage by adjusting the superheat to ensure an energy balance. The design of the lining of the pot is indirectly related to dissipation of heat. The purpose is to form a uniform but not excessive thickness of the ledge under a low superheat while guaranteeing stable and effective production.

Conventional lining structure	(mV)
Anode voltage drop	346
Clamp voltage drop	15
Guide rod voltage drop	26
Explosive welding voltage drop	8
Anode stub welding drop	42
Voltage drop of iron/carbon joint	105
Carbon block voltage drop	150
Bath layer voltage drop	1502
Bubble layer voltage drop	170
Cathode voltage drop	284
Cathode steel bar voltage drop	109
Cathode joint voltage drop	106
Cathode carbon block voltage drop	69
Counteraction electric potential	1672
Voltage drop for busbar around pot	200
Pot working voltage	**4.174 (V)**

New thermal lining structure	(mV)
Anode voltage drop	347
Clamp voltage drop	15
Guide rod voltage drop	26
Explosive welding voltage drop	8
Anode stub welding drop	42
Voltage drop of iron/carbon joint	104
Carbon block voltage drop	151
Bath layer voltage drop	1228
Bubble layer voltage drop	170
Cathode voltage drop	229
Cathode steel bar voltage drop	106
Cathode joint voltage drop	64
Cathode carbon block voltage drop	59
Counteraction electric potential	1672
Voltage drop for busbar around pot	200
Pot working voltage	**3.846 (V)**

Table 4 Comparison of voltage distribution

A pot operating at a lower voltage must maintain the thermal balance at a lower superheat. Thus the thickness of the pot lining must be matched to ensure sufficient heat dissipation and a uniform yet not excessive ledge thickness.

Simulation software to show the energy balance of an aluminium reduction pot was developed by GAMI and combines the thermal field simulation software developed by Prof Marc Dupuis.

The software aims at modelling various size pots as well as advanced reduction technologies and process parameters and employs models for heat loss at the cathode, pot sides and pot ends as well as an anode model.

These are combined through a three-in-one unifying method[3]. The models are based on data collected over a number of years to verify optimum heat dissipation and correct ledge thickness.

Comparison of designs

The results calculated for two different pot designs both operating at 350kA, one with a conventional lining and a flat bottom cathode installed using conventional paste to seal the steel conduction bar into the cathode block. The second heat dissipation calculation was for a pot with a so called 'irregular' cathode (a term adopted in China which first produced such cathodes in which the long edges of each carbon block forming the base of the pot are bevelled – see **Fig 2**) and connected to the steel bus bars by sealing with molten cast iron poured between the block and recesses bus bar.

The physical parameters of the conventional pot with flat cathode are compared with those of the pot fitted with the irregular cathode in **Table 3**.

A comparison of heat dissipated at the various parts of each pot is presented in **Table 4**.

A comparison of the temperature distribution shows the highest temperature to be at the side steel plate of a conventional lined pot reaching 301°C while that for the pot fitted with the irregular cathode was 230°C (**Fig 2**).

Comparing the profile ledge formed in the two types of pots, the thickness of the profile ledge at the sides of the conventional pot was 10.9cm and that for the redesigned pot 12.4cm and the ledge thickness at the end of the pots was 16.7cm and 17.6cm respectively.

The ledge toe along the sides of the pots showed a much greater difference at 18cm for the conventional and 30cm for redesign and the ledge toe at the pot ends was 13.8cm and 27cm respectively.

From a comparison of the distribution of heat dissipation, the greatest heat loss for the conventional pot is in the cathode area, while that for the redesigned pot is in the anode area. The distribution of heat

Pot region	Conventional		New design	
	Heat loss V	% Total heat loss	Heat loss V	% Total Heat loss
Anode total	**0.971**	47.02	**0.928**	54.16
Cathode total	**1.094**	52.98	**0.785**	45.84
of which side	0.663	32.11	0.388	22.65
Rim plate	0.103	4.99	0.068	3.97
Bottom	0.163	7.90	0.143	8.33
Steel bar head	0.165	7.98	0.187	10.89
Total	**2.065**		**1.713**	
Energy utilisation ratio	45.21%		50.25%	

Table 5 Comparison of heat dissipation distribution

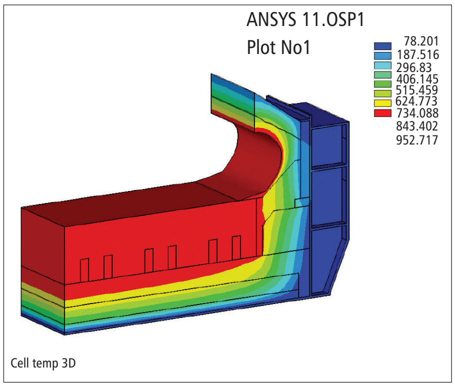

Fig 1 Calculated temperature distribution for a conventional pot with flat cathode (pot end)

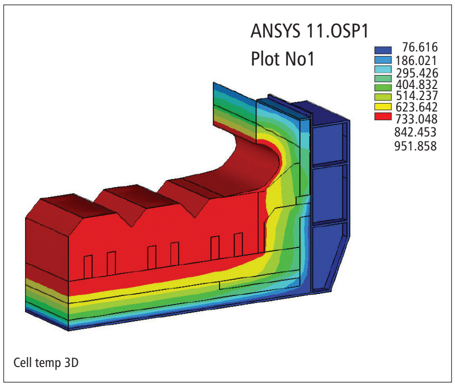

Fig 2 Calculated temperature distribution in a redesigned pot with irregular cathode (pot end)

loss in the anode and cathode areas in a conventional lined pot are 47.02%, and 52.98% respectively and for the new design 54.16% and 45.84% respectively. Thus the proportions of heat loss in the two types of pot are reversed (**Table 5**).

In the cathode area, the heat dissipation from the pot sides accounted for the greatest heat loss amounting to 32.11% of the total pot heat loss in the case of the conventional pot and falling to 22.65% of the total for the redesigned pot, but still remaining the major contributor to heat loss in the cathode area.

Economic benefit

With the prerequisite that the efficiency of the redesigned lining is 1-2% lower than that of the conventional lining, the redesign can still save 900kWh/t of electric energy consumption (**Table 6**).

Comparison of heat loss

Table 7 shows that the distribution of heat loss between the cathode and the anode for the new thermal insulation pot fitted with the irregular cathode is the reverse of that seen in a conventional lined pot with +54% of total heat lost from the anode in the new design compared with 43% in a conventional pot.

The largest difference is for the heat lost from the sides of the pots which decreases from 35% for a conventional pot to 25% for the new design.

In the past two years the application of the new insulation lining material has become a focus for the aluminium industry. Ceramic fibres and compounds of silica, magnesium-aluminium type thermal insulation materials are widely used to insulate the inside and outside of the steel pot structure.

Conclusions

The methods to reduce energy consumption through pot voltage reduction with respect to heat dissipation are:

– The thickness and composition of the anode covering material;
– The use of a new-design of thermal insulation including new types of material.
– Compared to a conventional pot, the reduction in cell voltage is around 200-450mV.
– The energy consumption per tonne aluminium is reduced by around 640-1440kWh/t at 93% current efficiency.
– The annual reduction in energy consumption of the pot line is typically between 32x107 to 72x107kWh/y for a pot line of capacity 500kt/y.
– Savings in operation cost of a 500kt/y smelter are in the range of RMB160M ($25.3M) to 360M ($57.17M) per annum based on a power price of RMB0.5 ($0.07)/kWh. ■

References

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Parameter	Conventional	New design
Current efficiency	94%	93%
Daily aluminium production	2650kg	2622kg
Direct current consumption	13231kWh/t	12323kWh/t

Table 6 (above) Comparison of economic benefit

	Conventional lining (%)	New thermal insulation lining %
Anode area	43	>54
Cathode area	57	<46
Lateral part of pot	35	<25
Pot rim plate	7	6
Bottom of pot	7	7
Collector bar head	8	8

Table 7 (right) Distribution of heat loss in a conventional lined pot and the new thermal insulation lined pot with irregular cathode