PREHEATING AND START-UP OF PREBAKED ALUMINIUM REDUCTION CELLS

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ABSTRACT

Coke bed preheating with shunt rheostats is considered one of the most popular methods used in the aluminium reduction cells preheating. Typical cathode heat-up rate during preheat and start-up as well as typical start-up anode effect were achieved. This paper studied the important considerations affecting the preheating and start-up of 210 kA prebaked cells at Egyptalum, as well as the evaluation of performance of the coke bed preheating method with shunt rheostats. The average preheating time was found to be 53 hours with energy consumption of up to 115,000 kWh. The effect of using different shunts-rheostats materials on cell current was illustrated. Also cell voltage before, during and after finishing the anode effect was studied. It was found that the cell voltage and time of anode effect during this stage varied in the range from 12 to 23 V and 60 to 120 min. respectively. The cell performance parameters, like current efficiency, energy and carbon consumption, were improved.

Keywords: Coke bed preheating method- Shunt rheostats- Aluminium reduction cells - Start-up anode effect and cell voltage - Quality of preheating and start-up process

1. Introduction

Preheating and start-up of aluminium reduction cells contributes to 25 % of the factors affecting the cell life such as materials (10 %), construction (20 %), design (20 %) and normal operation (25 %)[1]. The good methods for aluminium cell preheating are considered resistor coke bed preheating, aluminium metal preheating and the thermal preheating. The last method is preferred due to many reasons [1-4]. The main aims of cell preheating were illustrated elsewhere [1-5].

The quality of preheated cathode is evaluated by many factors like the final average cathode surface temperature, the final cathode surface temperature distribution, the vertical temperature gradients down through the cathode materials, the heat-up rate during the preheating and the anodic current distribution [2-5].

The resistor coke bed preheating with shunts-rheostats properly executed is probably the preferred preheat method for prebaked cells [2-8], and this method was applied at Egyptalum since 1991[6]. This method offers a low voltage start up and requires careful preparation followed by care attention during execution [2]. While using shunts will have the advantage that a current lower than the cell current can be applied. Thus reducing the thermal gradients in the cathode during preheating and reduce the risk of damage to the lining materials [9]. The careful application of coke bed preheating method can avoid thermal stressing and hence offer longer potlife [4].

Several modifications of cell preheating process were carried out at Egyptalum including the reduction of coke bed thickness from 50 to 20 mm with using strips of coke instead of a full bed, using anode flexible connectors, achieving the good contact between the coke bed with anode and cathode blocks, lowering the preheating rate, lowering the preheating time (if the initial cell current is high), fixing the sources of carbon materials and follow up the preheated zones of the cathode surfaces during the preheating process [6-7]. The pot lives were improved from 22 months to more than 69 months in association with reducing energy and coke consumption [7].

The general start-up features are illustrated as follows: molten bath is added to the preheated cell, current is connected to the cell and the anodes are raised to get an anode effect, the anode effect is terminated after about one hour, removal of the remaining coke, and liquid metal is added after about one day [2].

The preheating process is finished when the cathode surface temperature reached close to the normal operating temperature (850 to 950 °C) [2, 3], then molten bath is added to the preheated cell as soon as possible after removing the preheating equipments. When molten bath covers the whole cathode surface, the anode beam is raised to obtain the target voltage. The added molten bath to the preheated cells must be free from aluminium and bath temperature is not less than 1000 °C) [2, 3, and 10]. During this period voltage, temperature and bath composition must be controlled. Bath will penetrate into the cracks in the cathode blocks until it reaches a temperature where it solidifies. The final step in this process is metal addition, and the normal industrial time range is between 4-36 hr [2, 3]. The metal should be delayed until sodium has adequately penetrated carbon cathode blocks. If the metal is added too early it may penetrate the seams or peripheral gaps caused by baking shrinkage and greatly shorten cell life.

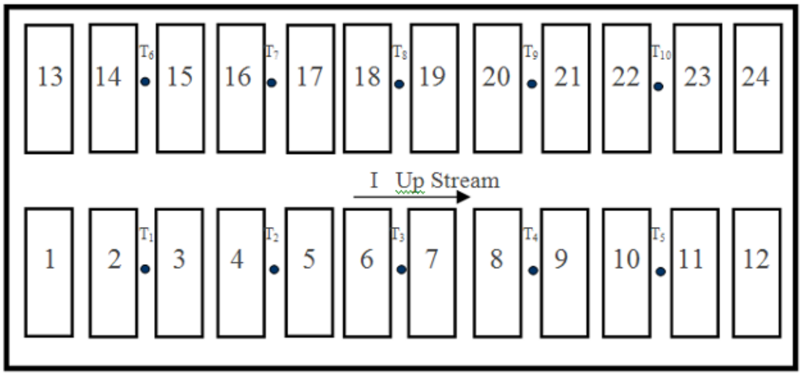
This paper examines the method of preheating and start-up of the cells with the affecting parameters. The study extends to the evaluation of the performance.

2. Preheating and Start-up of The Prebaked Aluminum Reduction Cells

The cell preheating and start up process includes the following items: cell preparation, charging the solid materials, use of the preheating and start-up process.

2.1. Cell preparation

Petroleum coke - 2 Cm thickness and particle size of (- 5+2 mm) – is spread between the anodes bottom and cathode block surface using strip pattern from stainless steel. The coke bed provides an additional electrical resistance, sufficient to act as a major heat source throughout the preheating phase, also to distribute as evenly as possible the current to the underlying cathodes. 24 anodes are positioned on the top of coke bed and are connected to the anode beam. Ten thermocouples as shown in Figure 1 are fixed on the cell cathode surface, in order to measure the temperature distribution during the preheating process [11]. According to these measurements, the preheating and the switching off the shunts-rheostats times are determined.



Arrow denotes to current direction in the cell and numbers denote to blocks numbers.

Fig. 1. Locations of temperature measurements on the cathode surface

2.2. Charging the solid materials

The cell sides are packed with some of sodium carbonate and artificial cryolite to form an artificial ledge. The materials needed for this process per one cell operate at 210 kA[11] are shown in Table 1. These quantities are compared with the cells work at 350 kA [12]. This table shows as the cell current increases, the quantity of materials needed for start-up process increases. The pot cavity is covered by insulating materials to protect the anode and cathode surfaces from oxidation.

Table 1.
Materials required for this process per one cell

Material / Cell Ampere, kA	Cryolite, t	Sodium carbonate, t	Petroleum coke, t	Anode blocks	Electrical energy, kwhr	Aluminium, t
210	16	3	0.5	24	115000	8
Q-350 [12]	42	6	.75	48	-	20

2.3. Using the preheating method

The coke bed preheating method with shunts-rheostats and anode flexible connectors is used. When all things in the cell are ready, the shunts-rheostats are connected from anode beam to cathode bus bar. The shunts-rheostats part is made from different materials like nickel chromium and stainless steel of predetermined length allowing part of the current to be diverted from passing through the anode and cathode [6, 9]. The switching off the shunts-rheostats is done after 6 hours for the risers carrying the lower current. At another time the rest of shunts-rheostats switch off and full current going through the cell.

These times are depended on many factors like types of cathode carbon blocks and ramming paste used, type of shunts-rheostats used and the temperature distribution on the cathode surface. In this work the sources of cathode carbon materials was fixed. The preheating process is continuous at the full current until the average cathode surface temperature reached to 800-900 ^{o}C. Before 12 hours from the end of preheating process, the insulating materials are removed, and the start-up materials are added along the periphery of the cell cavity. The relationship between cell current and preheating time for some cells using different shunts-rheostats materials is shown in Figure 2. The initial cell current for nickel chromium shunts is started from 43 to 48 % of the line current, and then reached to 60 % after shut down the first shunts group, then worked at last the 3:6 hrs on the full current. While for stainless steel shunts the initial current was started from 71 % for nearly two days and up to full current in the rest time [13]. These results show that using of nickel chromium shunts was succeeded than stainless steel shunts and this is related with lower current applied. This action reduces the thermal gradients in the cathode during preheating and reduces the risk of damage in the lining materials.

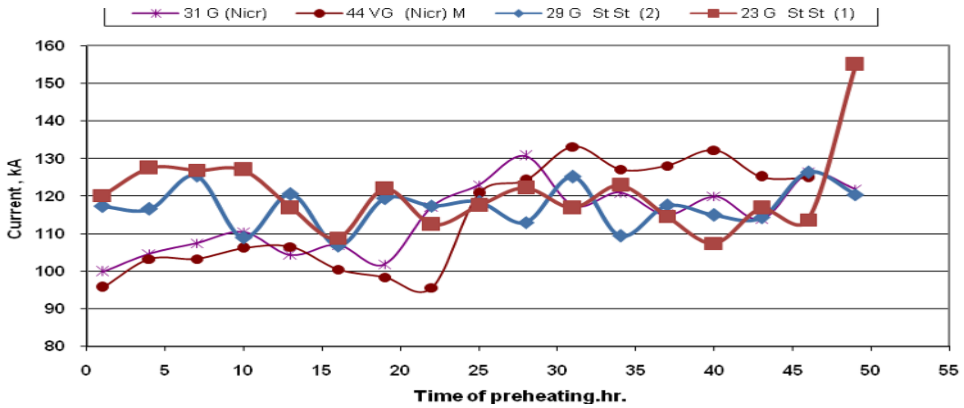


Fig. 2. Progress in cell current during the preheating process for different shunts

2.4. Cell start-up process

The start-up process can be divided into 3 stages. The first is that adding 8-ton of molten electrolyte on the cathode surface blocks after finishing the preheating process. The second is that raising-up the anode carbon blocks until the anode effect will happen and killing during one hour. The last stage is that adding molten aluminium after one day from electrolyte addition.

The main aim of anode effect is to supply enough energy to the cell in order to avoid any formation of solid bath on the cathode surface. Start up of anode effect is extinguished using palm branches under the anodes, then soda and artificial cryolite are added to the cell. The cell voltage before, during and after finishing the anode effect for some cells in this group [13] is illustrated in Figure 3. The time and cell voltage during the period of anode effect is varied in the range from 60 to 120 min. and from 12 to 23 V respectively, and reached in some cells to 40 volt. These results were compared with the published data [2, 5, 12, 14 and 15] as shown in Table 2. These results illustrated that as the value of cell voltage increases the time of anode effect decreases, and this is related with heat necessary to melt completely the solid additives to the cell. While the relationship between the cell voltage and time of anode effect with the average cathode surface temperature at the end of preheating process is illustrated in Table 3. These data shown that there is no clear relation between these items, and this difference may be due to two reasons, to ensure that all additives must be completely melted and also some cells need to addition time to remedy the difficult anode effect.

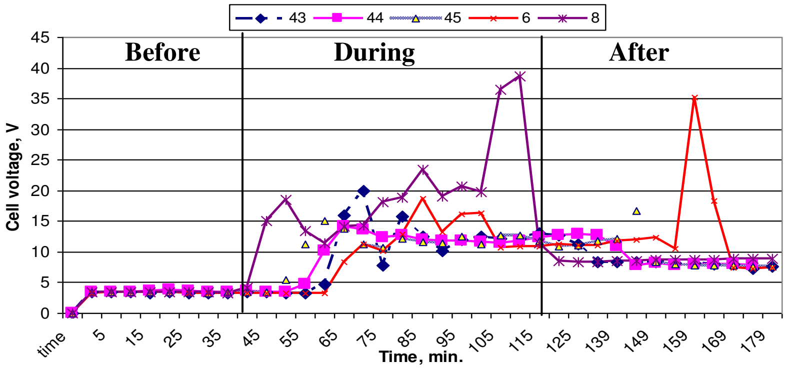


Fig. 3. Cell voltage before, during and after finishing the anode effect for some cells

Table 2.
Comparison between cell voltage with time of anode effect in some companies

Item / Company/ Cell capacity kA	Cell voltage, V	Time of anode effect, min.	Liquid aluminum addition after, hrs.
Egyptalum/210	12-23	60-120	24
Aluminium Pechiney /180	20	45	24-32
Elkem/-	50	30	20
Dubal/217	11-12	-	-
VAW/-	35	40	-
Q-350, China/350	15	40	24
SY350/SY400, China/350 &400	10	-	24

Table 3.
Cell voltage, time of anode effect with the average cathode surface temperature at the end of preheating process for some cells

Item / Cell No.	Cell voltage during anode effect period, V	Time of anode effect, min.	Average cathode surface temperature at the end of preheating process, °C
46	13.94	95	836
45	12.25	90	827
44	12.18	80	819
43	12.94	65	834
11	18.26	60	822
10	16.73	65	812

Item / Cell No.	Cell voltage during anode effect period, V	Time of anode effect, min.	Average cathode surface temperature at the end of preheating process, °C
09	14.12	70	821
08	19.35	75	831
07	15.89	60	828

8-ton of liquid aluminum is poured after 24 hours from bath pouring in. The main purpose for this late in time is to wait enough time to fill any cracks in the cathode blocks with molten bath, and to give a enough time for the ramming paste to expand in order to prevent any metal penetration in the cathode materials and be baked [2.3].

The average preheating time for this group is 53 hours. The preheating time was increased as compared with the published in elsewhere[7], and this is related with using modified shunts-rheostats which work on lower the initial current entering to the cells and hence reducing the heat up rate.

3. Evaluation the Quality of Preheating and Start-Up Process

Preheating and start-up process take short period (2 to 3 days), and happen at easy working conditions (lower temperatures) as compared with the normal operation period (5-7 years) and at higher temperatures, so more careful and care is required to success of this process. The quality of preheated cathode is evaluated by many factors like the final average cathode surface temperature, the final cathode surface temperature distribution, the vertical temperature gradients down through the cathode materials, the heat-up rate during the preheating and anodic current distribution [2-5,19].

The average cathode surface temperature measurements for these cells at the end of preheating varied in the range from 808 to 876 °C with a relative standard deviation of 6 %, while the maximum temperature was between 842 to 938 °C. Also no hot spots were observed on the cathode surface blocks [11, 13]. Some examples for some preheated cells are shown in Table 4. As the difference between minimum and maximum temperature values for most cases decreases the cell evaluation moves to the best grades. These values and observations reflect the good contact between coke bed with anode and cathode blocks, and this mean that long potlife will be expected for these cells. Also, the heat-up rates for these cells varied in the range from 10 to 19 °C/hr, and these values are nearly considered the best values as compared with the published data [2, 3]. This means that greater baking density of the ramming paste then will be obtained[4].

Table 4.

Temperature distribution on the cathode surface at the end of preheating process for different cells

Cell No. with its grade	Temperature measurements on the cathode surface at different locations as shown in Figure 1, °C										Average temp.
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	
05 "Pb"	802	812	825	850	828	770	880	775	831	810	818

Cell No. with its grade	**Temperature measurements on the cathode surface at different locations as shown in Figure 1, ^{o}C**										**Average temp.**
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	
10 "A"	861	802	842	800	732	862	824	801	792	799	811
28 "G"	830	800	840	855	860	877	830	881	834	810	848
46 "VG"	824	823	832	842	848	835	840	837	833	842	835

Very Good (VG), Good (G), Acceptable (A), with problem (penetration) (pb)

The average cathode surface temperature as a function of time during the preheating process for different cells and for various evaluations is shown in Figure 4. The heating rate at the last times in preheating process shows the increasing in temperature is smaller as compared with the initial preheating times.

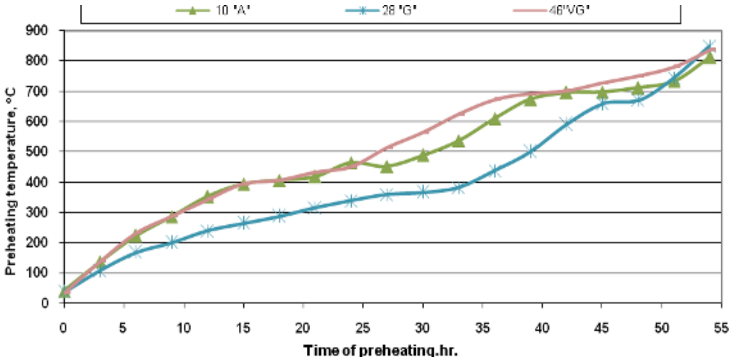


Fig. 4. Average cathode surface temperature as a function of time during the preheating process for different cells

In the same time, the anodic current distribution for cells using individual anode flexible connectors is illustrated in Figure 5. The average relative standard deviation (RSD) for anodes current for these cells was lowered to 12 % and this value is considered as a good to obtain uniform anodes current distribution [16, 17]. This result was compared with the cells preheated without using the flexible connectors, where the RSD reached to 40 % and lowered to 20 % with using the flexible connectors [7]. The improvement in this work is due to increase in worker experience and follow up connection and disconnection of the anode blocks. These results were reflected on the cells temperatures distribution and improved cells behaviour.

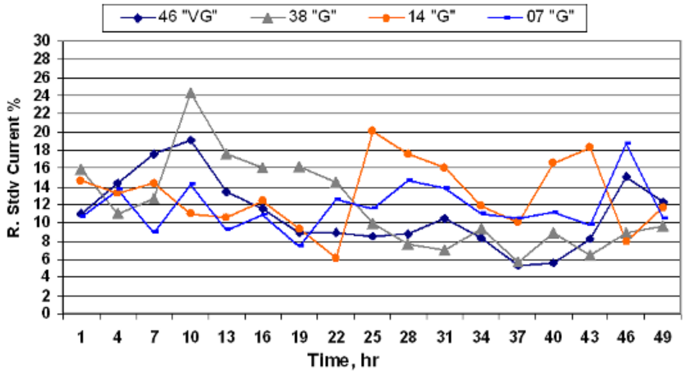


Fig. 5. Relationship between the RSD for cell current and preheating time

Also, the performance of preheating and start-up process can be evaluated by many factors like measuring the temperature distribution on the bottom of the cathode steel shell and measuring of metal height after four days from metal addition [18]. 17 locations as shown in Figure 6 are determined for measuring the temperature distribution for one week according to schedule program. The obtained results show the preheating quality and illustrate that is there any metal penetrate into the lining and insulation materials or not.

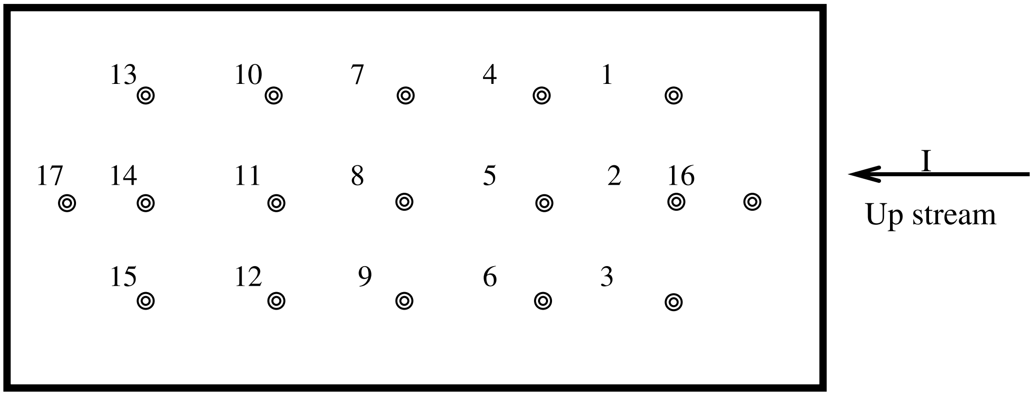
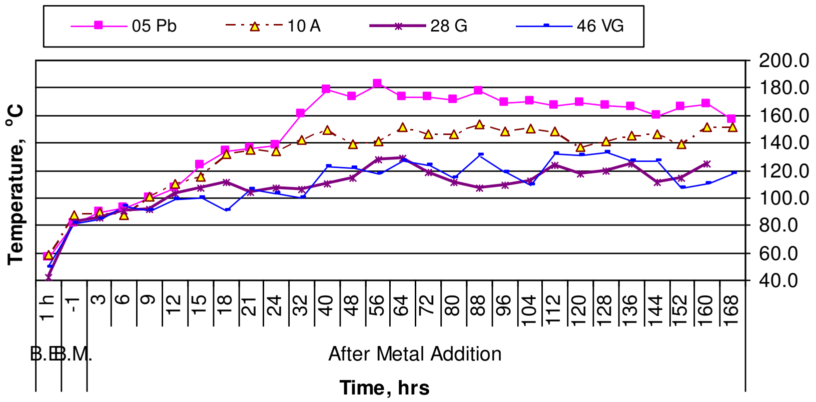


Fig. 6. Locations of temperature measurements on the bottom of cathode steel shell

Comparison between time of measurement with the average and the maximum cathode bottom shell temperature during one week for different cells with various evaluations [13] are shown in Figures 7 and 8 respectively. These results show that as the temperature values decrease, the preheating cells behaviour move to best evaluation. In the same time if metal height is increased to the actual daily production of the cell, the preheating cells behaviour move to best evaluation and this means that no metal penetrate in the materials lining.



Before Electrolyte addition (B.E.), Before Metal addition (B.M.)

Fig. 7. Average cathode bottom shell temperature measurements during one week

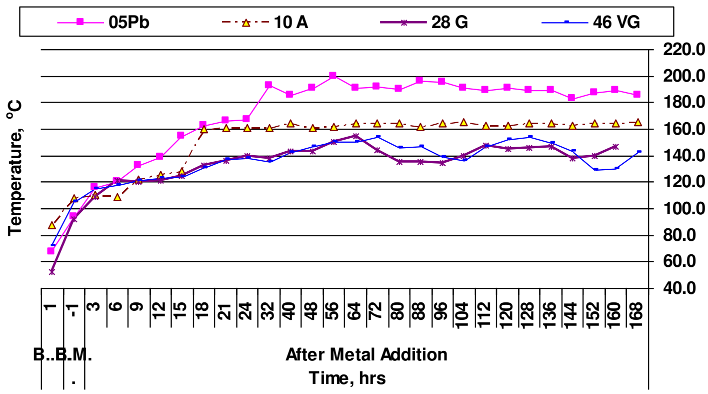


Fig. 8. Maximum cathode bottom shell temperature measurements during one week

The performance of these cells is summarized as follows: Current efficiency stood at almost 95.2 %, energy consumption was 13850 kWh/t, carbon consumption was 410 kg/t. and hence pot service life will be improved [11].

4. Conclusions

The coke bed preheating method with some modified procedures was succeeded for preheating prebaked aluminium cells. The use of nickel chromium shunts was found to be more successful than stainless steel shunts which is related to lower current applied. Using anode flexible connectors, with improving in workers experience, improved the anodic current distribution. Good cathode temperature distribution during preheating and start up process and hence improved cell behavior were reflected on cell potlife. Times of cell preheating and shunts rheostats switch off, time of anode effect and cell voltage during preheating and start up process were determined. Good results for the process of preheating and start up cathode and consequence cell performance were obtained.

5. References

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تحميص وبدء تشغيل خلايا استخلاص الالومنيوم سابقة التحميص

الملخص العربى

تعتبر طريقة الوسادة الكربونية مع استخدام مجزئات التيار واحدة من الطرق شائعة الاستخدام فى عملية تحميص خلايا استخلاص الالومنيوم، ويعود ذلك الانتشار إلى التدرج فى تسخين الخلية خلال عملية التحميص بشكل مثالى والى عمل تأثير أنودى نموذجى خلال مرحلة بدء التشغيل للخلية. يدرس البحث أهم الأعتبارات المؤثرة على عملية التحميص وبدء التشغيل للخلية210كيلو امبير بشركة مصر للألومنيوم، كما يقوم بتقييم الاداء لهذه الطريقة المستخدمة. بينت الدراسة ان زمن تحميص الخلايا وصل الى 53 ساعة وبمعدلات استهلاك للطاقة بلغت 115000 كيلو وات ساعة. كما وضحت الدراسة تأثير استخدام انواع مختلفة لمجزئات التيار على تيار الخلية. كما عرضت الدراسة لفولت الخلايا قبل واثناء وبعد الانتهاء من التأثير الأنودى حيث وجد ان فولت الخلية تراوح بين 12 الى 23 فولت حين تراوح زمن التأثير الأنودى من 60 الى 120 دقيقة. لقد اظهرت النتائج حدوث تحسن فى مؤشرات اداء الخلايا (كفاءه التيار واستهلاك الطاقة الكهربائية والمواد الكربونية) مع استخدام هذه الطريقة.