Economic feasibility analysis of construction of high amperage aluminium smelters

S. Akhmedov[1], V. Kozlov[2], V. Rozanov[3], M. Gorlanov[4]
1. General Director
2. Technical Manager
3. Deputy General Director on Foreign Relations
4. Manager
ALCORUS Co Ltd, Saint Petersburg, Russian Federation
Corresponding author: office@alcorus.ru

Introduction

Since the 1970's we have seen continuous amperage increase from 180 kA to 600 kA. It is considered that amperage increase allows reducing specific power consumption, unit capital costs on the construction and labor costs on the maintenance as well as decreasing the harmful emissions to the atmosphere.

The paper gives the results of the investigations related to the specific power consumption and current efficiency based on data published in Light Metals for the period of 1984-2015. The investment calculations related to the construction of an aluminium smelter are done while varying parameters on specific power consumption, capital costs on construction, labor costs on operation, discount rate and service life of the pots. The conclusions are made on the substantiation of using high-amperage pots.

Keywords: High amperage smelters; economic analysis, capital cost.

1. Analysis of process parameters of the pre-bake anode pots based on publications in Light Metals for the period of 1984-2015.

The history of electrolytic aluminium production that begins in 1886 with introduction of the technology developed by Hall-Heroult, and with start-up of the first smelter based on this technology in 1888 in Neuhausen, Switzerland, could be presented as road map of updating the designs of aluminium pots. There are three types of the pots: pre-bake pots, vertical stud Soderberg pots and horizontal stud Soderberg pots.

During the evolution of the pot design, the pre-bake pots turned out to be the most viable on the basis of process, economic and environmental parameters. The common trend in the design of prebake pots testifies that since 1970s and till 2015 continuous amperage increase has been taking place in the pots from 180 kA to 600kA. Actually some developers propose to continue the amperage increase to 700 кA and higher. Such trend of increasing the amperage in the prebake pots is substantiated by the following main requirements:

1. Reduction in specific power consumption,
2. Reduction in unit capital costs on the potrooms construction,
3. Reduction in relative rates of harmful gas emissions to the atmosphere.

The construction of any primary aluminium smelter passes through the same stages: scientific investigations, engineering, construction, commissioning and operation. Every stage forms its own database that includes process parameters (specific power consumption, current efficiency, emissions to the atmosphere), information about the costs on equipment, on construction of the buildings and facilities as well as information about unit costs related to the aluminium smelter construction.

All these parameters that reflect the real data on the smelter construction are usually confidential and as a rule they are not published in public media. Data that are published in commercial overviews of some publishers and information providers like Aluminium-Verlag Marketing & Kommunikation, Brook Hunt, CRU, Metal Bulletin, and others do not usually have any references to the sources of the information and do not give any details that would be sufficient to carry out any methodologically feasible comparative analysis of the achievements in technological parameters and capital costs related to the construction of an aluminium smelter. This does not allow analyzing documentary the technological and economic advantages of introduction of high-amperage pots.

At the same time over the last 40 years the TMS conference has been publishing information about pilot-industrial tests and industrial operation of aluminium pots. This information is exposed as scientific articles with a certain evidence-based information format. The analysis of the information, published in Light Metals, can have some features of interest as it allows identifying the results achieved in the operation of aluminium pots. It is believed that the reduction in specific power consumption is the most important factor in the trend of amperage increase; due to this the Figure 1 gives the data on the specific power consumption by the pots of different types. These data were published in Light Metals 1984-2015 [1-52].

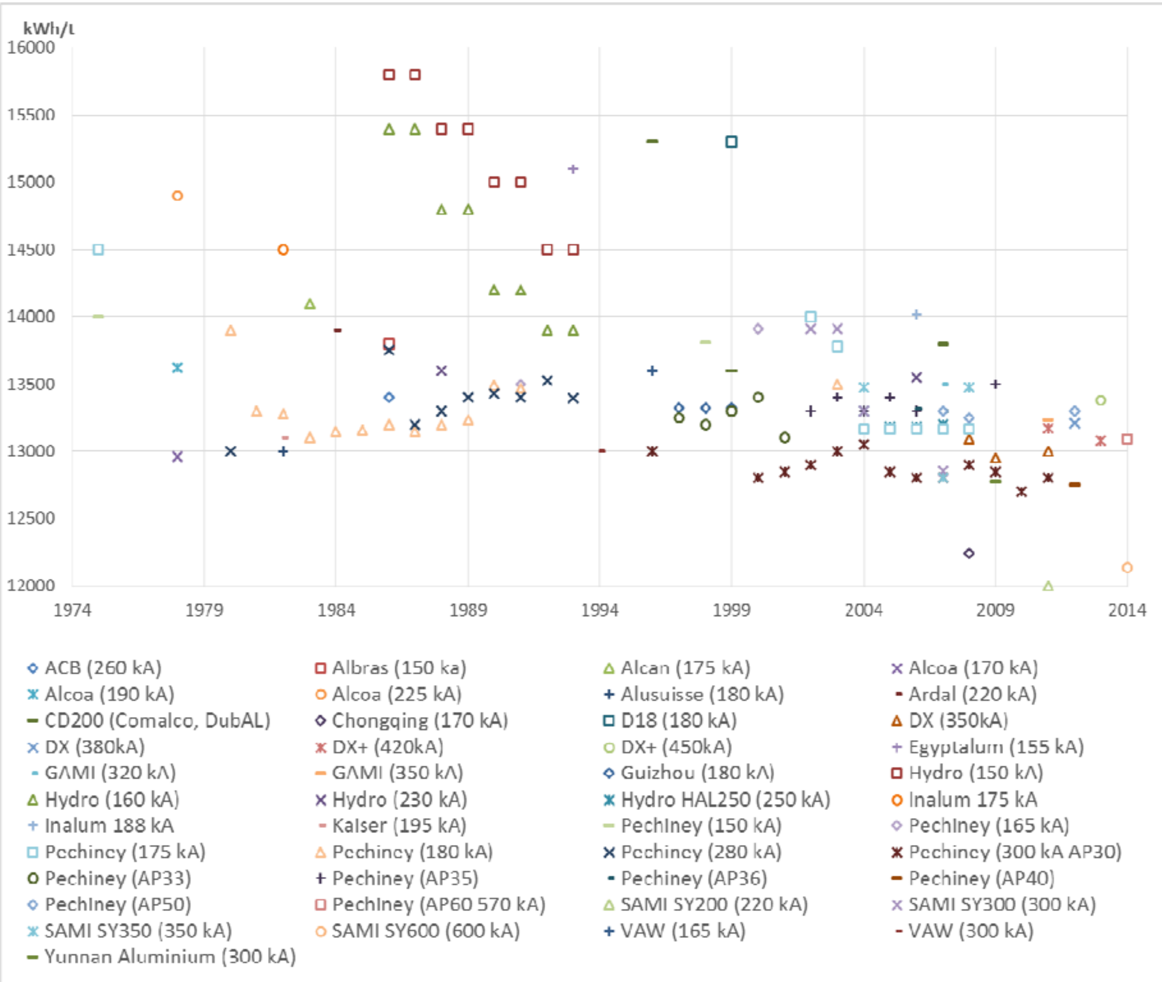

Figure 1. Specific power consumption by the pots of different types.

Based on this information it is possible to try to reveal certain relationships. For example, Figure 2 summarizes data on specific power consumption by the pots with different amperage:

up to 200 kA, from 200 to 300 kA and over 300 kA. Lines on Figure 2 represent the linear approximation convenient for the visualization of common conformity and for its perception. It could be seen that during the period of 1985-2014 the pots with any amperage tended reduce specific power consumption from 14500 kWh/t to 13000 kWh/t.

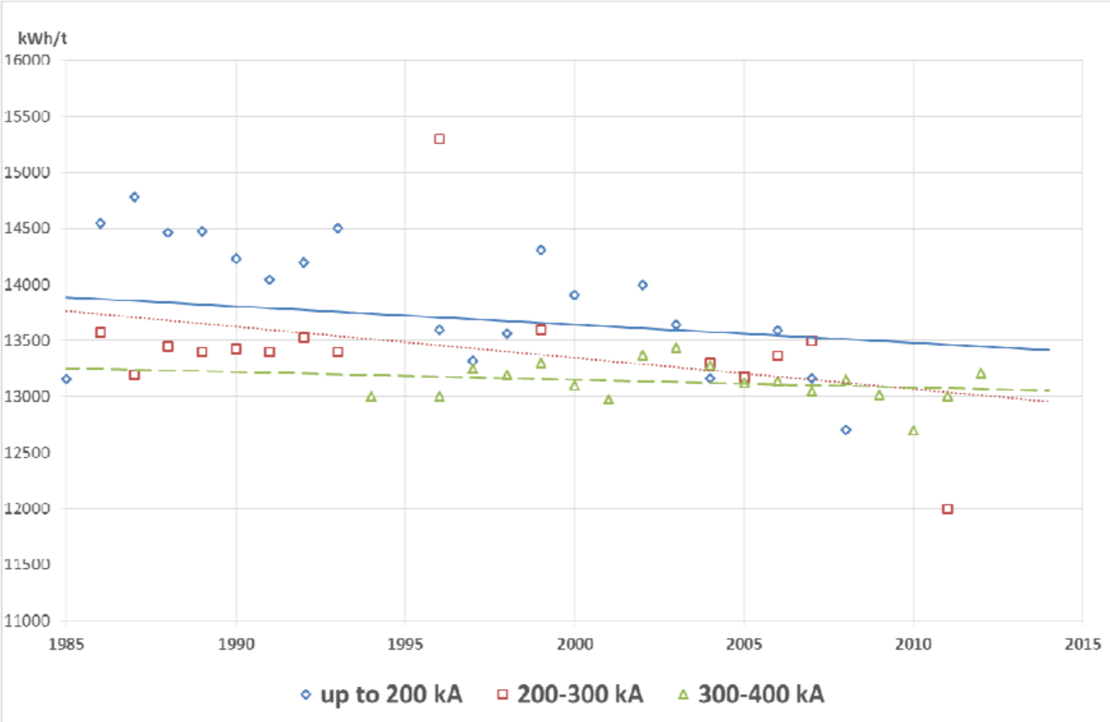

Figure 2. Specific power consumption by the pots with different amperage.

Figure 3 shows the excerpts related to the specific power consumption for the pots that were developed by Pechiney, Hydro, GAMI, SAMI and are in operation in different smelters in the world. These companies were dealing to the fullest extent with the development of high-amperage pots, their testing and industrial implementation. This demonstrates that the major leader in the development of technologies for the pre-bake anode pots – Pechiney - has factual data on specific power consumption that varies within the range from 12 700 kWh/n to 13 000 kWh/t.

It is interesting to notice how companies GAMI and SAMI entered the world competition for the reduction in specific power consumption, and if some very equivocal data for the expert assessment are excluded, then nevertheless the result that best reflects the achievements is 13 000 kWh/t.

Figure 4 shows the average power consumption by pots of different types (i.e. pots with different amperage and from different companies) by stages of their introduction from 1985 to 2014.

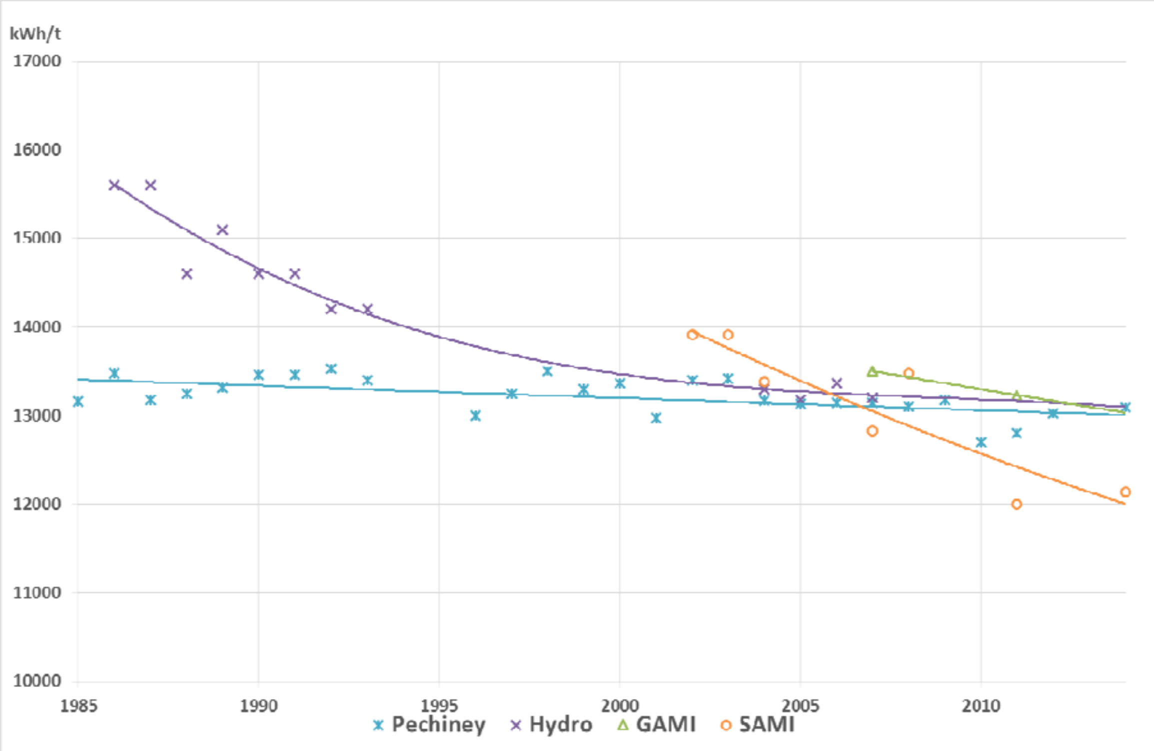

Figure 3. Power consumption by different pots.

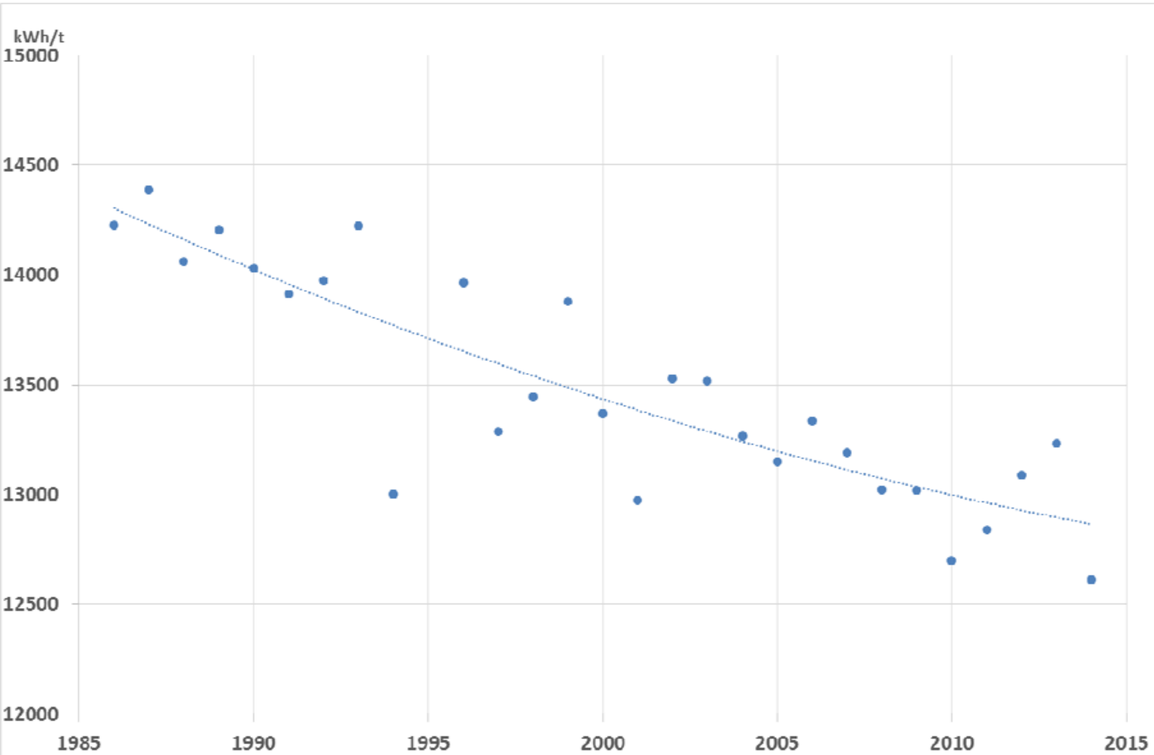

Figure 4. Average values of power consumption by pots of different types.

The polynomial approximation shows that during the period of 1985 - 2014 the reduction of specific power consumption from 14 200 to 12 613 kWh/t was achieved. Figure 5 gives data, published in Light Metals for the period of 1984-2015. There is concrete source of information in the Light Metals papers to which the every point on the figure corresponds.

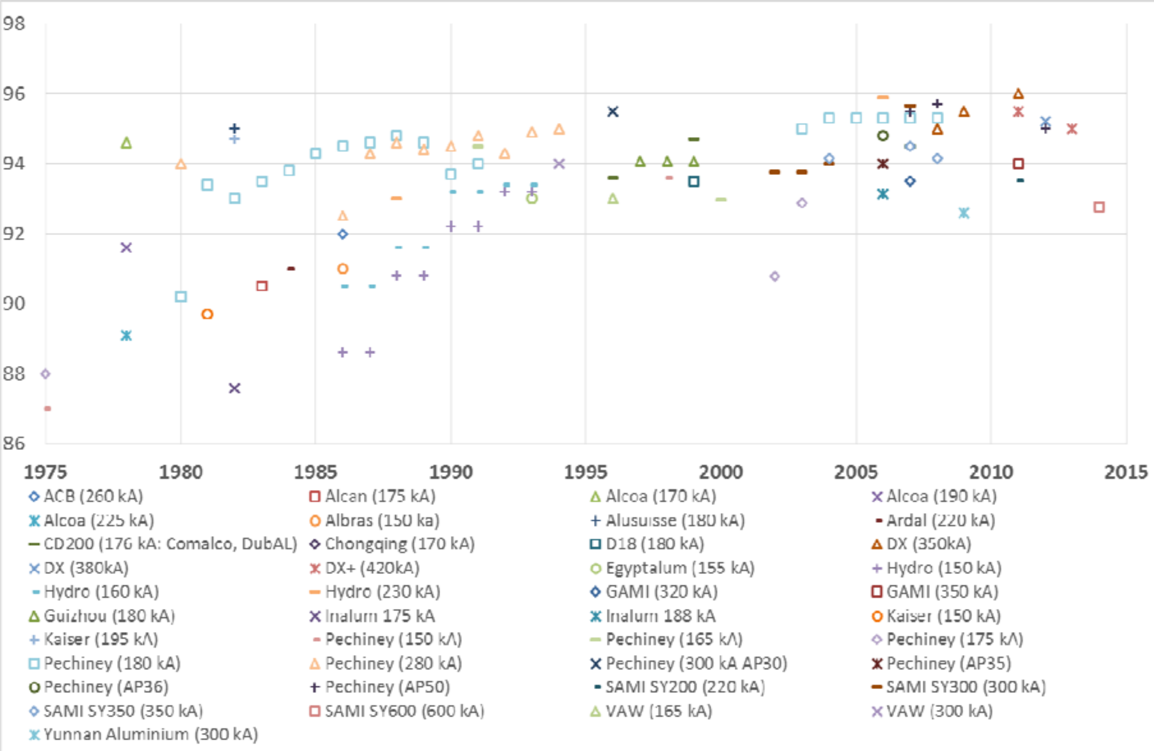

Figure 5. Current efficiency in pots of different types.

Figure 6 shows the excerpts related to the current efficiency for the pots that were developed by Pechiney, Hydro, GAMI, and are in operation at different smelters in the world.

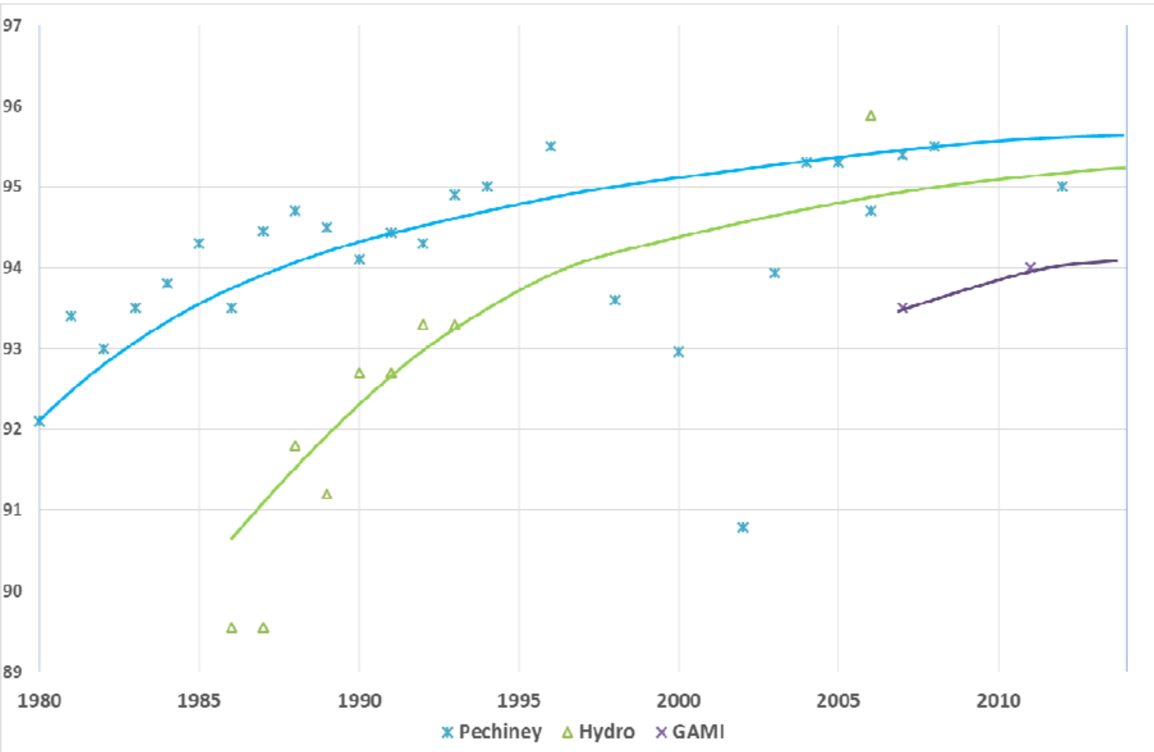

Figure 6. Current efficiency in pots of different types.

Figure 7 shows average values of current efficiency for the pots being in operation in different smelters in the world.

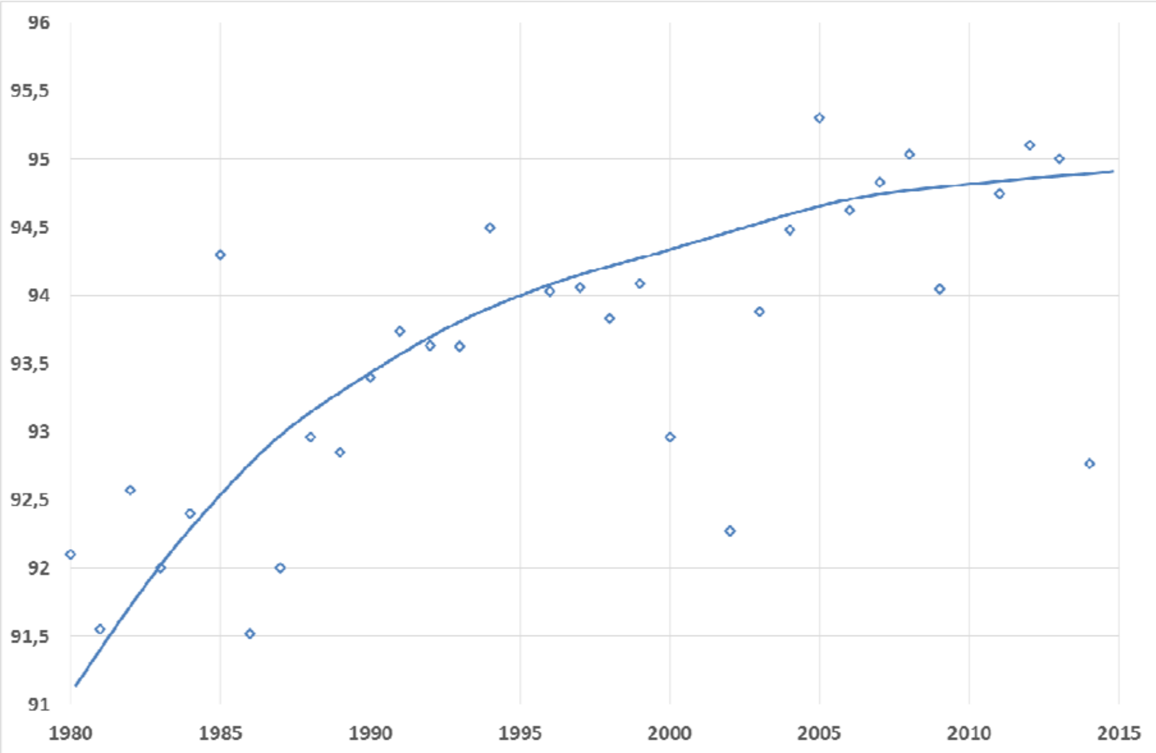

Figure 7. Average values of current efficiency for the pots of different types.

Current efficiency could be considered as convenient indicator of the advantages in operating the aluminium pots. Data from Figure 7 more likely characterize the fact that the current efficiency increases with time in pots of any amperage as during 40-year period obvious positive results were achieved due to the implementation of acid electrolytes, automatic alumina feeding systems, automated control systems, new lining and cathode materials and many other design innovations. For sure, current efficiency determines, in a great measure, the costs on aluminium production. Under the conditions of permanence of other process parameters the increase of current efficiency provides the increase in productivity of the pot and the respective reduction of consumption rates. However, the direct comparison of current efficiencies in pots of different types would not necessarily reflect the relationship of operation costs. For example, the pot that due to its design operates with high anode – cathode distance, could have a higher current efficiency, but this advantage can be neutralized by high electric power consumption. Therefore, current efficiency is not always suitable parameter to be used in investment calculations.

2. Investment calculations related to the construction of high amperage aluminium smelters

Light Metals data, shown on Figures 1 - 7 could be used when analyzing financial-and-economic indices of investment projects of the construction of high amperage aluminium smelters.

To fulfill these calculations it is necessary to define benchmarks to be put into the calculations. To the authors mind, following values could be used as benchmarks:

1. Unit capital costs on the construction of greenfield smelter – 5000 USD/t;
2. Sale price of primary aluminium – 2200 USD/t;
3. Total cost of primary aluminium – 1520 USD/t;
4. Specific power consumption – 13000 kWh/t;
5. Unit labor costs – 140 USD/t;
6. Service life of the pots – 6 years;
7. Discount rate – 8 %.

Based on benchmarks and data obtained with respect to specific power consumption it is possible to carry out the investment research and define, e.g., the cumulative cashflow for the construction of aluminium smelter with capacity of 500 000 t/a primary aluminium (Figure 8).

From Figure 8 it is possible to define how the payback period (PP), internal rate of return (IRR), net present value (NPV) vary in the cases when the specific power consumption changes from 12 000 kWh/t to 14 000 kWh/t primary aluminium; the payback period being changed from 9.5 years (at 12 000 kWh/t) to 10.2 years (at 14 000 kWh/t).

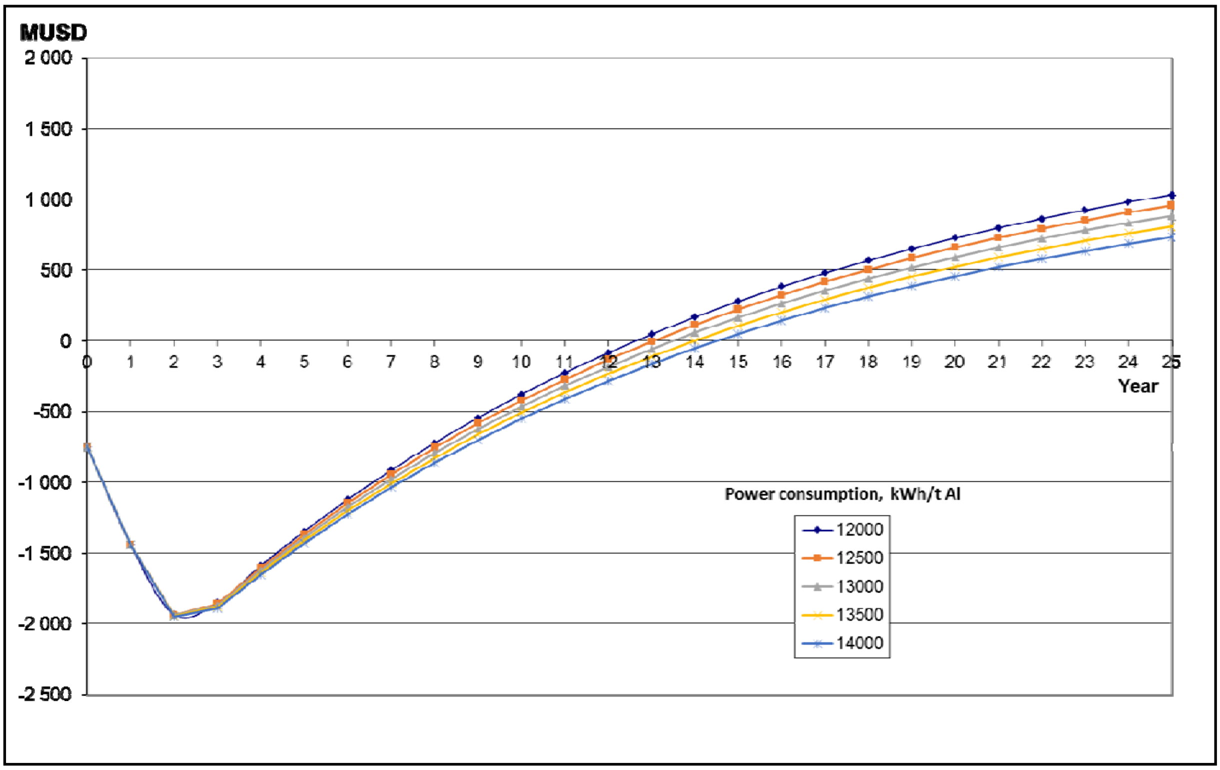

Figure 8. Cumulative discounted cashflow for the construction of aluminium smelter with capacity of 500 000 t/a primary aluminium.

Similar investment calculations could be done for the cases when unit capital costs on the aluminium smelter construction, unit labor costs on the primary aluminium production, discount rates and service life of the pots vary. The results of calculations are given in Table 1.

Table 1. Results of investment calculations.

№	Parameter	Value	NPV (MUSD)	IRR, %	PP (years)	DPP (years)
1	Power consumption (kWh/t)	12000	1032	12.9	9.5	13.7
1.1.		12500	958	12.5	9.7	14.1

№	Parameter	Value	NPV (MUSD)	IRR, %	PP (years)	DPP (years)
1.2.		13000	883	12.2	9.9	14.5
1.3.		13500	808	11.9	10.0	15.0
1.4.		14000	734	11.5	10.2	15.5
2	Capital costs (USD/t)	4500	1112	13.8	9.1	12.7
2.1.		4750	997	12.9	9.5	13.6
2.2.		5000	883	12.2	9.9	14.5
2.3.		5250	769	11.5	10.2	15.5
2.4.		5500	654	10.9	10.6	16.7
3	Labor costs (USD//t)	120	976	12.6	9.6	14.0
3.1.		130	930	12.4	9.7	14.2
3.2.		140	883	12.2	9.9	14.5
3.3.		150	836	12.0	10.0	14.8
3.4.		160	790	11.8	10.1	15.1
4	Discount rate (%)	6%	1539	12.2	9.9	12.7
4.1.		7%	1186	12.2	9.9	13.5
4.2.		8%	883	12.2	9.9	14.5
4.3.		9%	622	12.2	9.9	15.8
4.4.		10%	397	12.2	9.9	17.4
5	Service life of the pots (years)	4	697	11.4	10.3	15.8
5.1.		5	808	11.9	10.0	15.0
5.2.		6	883	12.2	9.9	14.5
5.3.		7	936	12.4	9.7	14.2
5.4.		8	976	12.6	9.6	14.0

The publications in Light Metals do not give any value on which the capital costs on aluminium pots construction are reduced when changing the amperage. Some publications declare the reduction of capital costs but do not give any concrete data. It would be interesting to know how the unit capital costs would reduce when changing over from 300kA pots to 400kA pots or at any other change of the amperage. The specialists know well that when changing the amperage the length of potroom decreases, the quantity of lining materials and steel structures for the pots and their costs reduce as well as the costs of automation systems, fume treatment plants etc. In any case the total reduction in unit and capital costs while changing the amperage could vary on 10 – 20 % from benchmark value.

When changing over to the higher value of the amperage the labor costs would naturally decrease as the operation efficiency of pot tending machines, automated alumina feeding and centralized distribution systems increases and the specific consumption of raw material (alumina, fluorides and anodes) tends to reduce. These variations could occur within the range of 25% or 12.5 % from the benchmark of unit labor costs. Table 1 shows that this fact leads to the change in DPP from 14 years (at the rate of 120 USD/t) to 15.1 years (at the rate of 160 USD/t).
Table 1 illustrates also the impact of pot service life and discount rate on investment performance data.

Figure 9 gives the results of the cumulative cashflow calculation while modifying parameters of groups 1-3 in Table 1 that reflect the changes in specific power consumption, unit capital and labor costs. These data reflect the range of variations in DPP from 12 to 15 years when modifying the power consumption by 500 kWh/t, capital costs by 250 USD/t and labor costs by 10 USD/t.

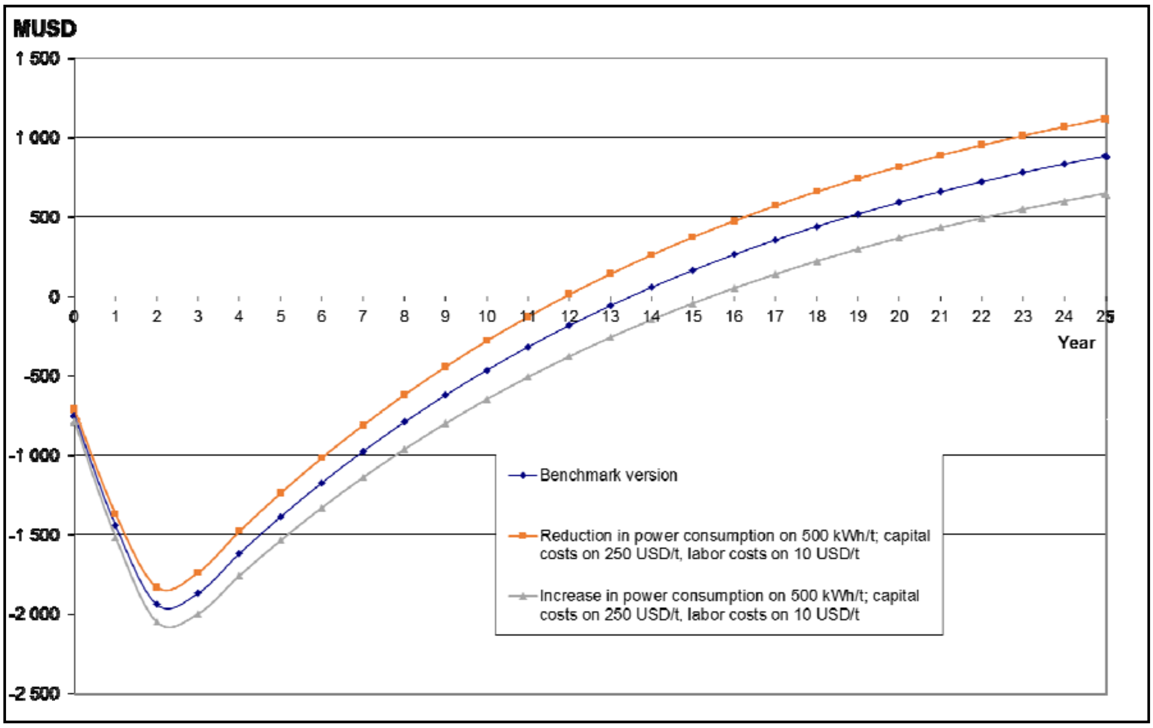

Figure 9. Cumulative discounted cashflow for the construction of aluminium smelter with capacity of 500,000 t/a of primary aluminium.

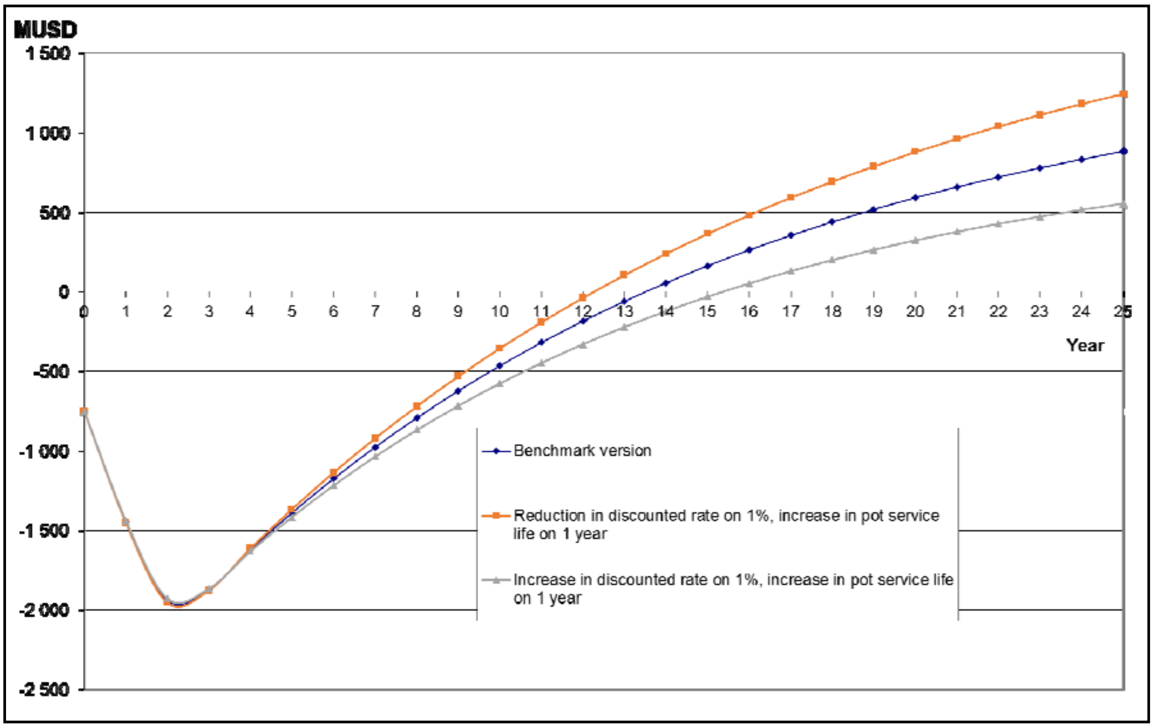

Figure 10. Cumulative discounted cashflow for the construction of aluminium smelter with capacity of 500,000 t/a of primary aluminium

Figure 10 gives the results of the cumulative cashflow calculation while modifying parameters of groups 4-5 in Table 1 that reflect the changes in discount rate and pot service life. These data reflect the range of the variations in DPP from 12 to 15 years when modifying the discount rate by 1 % and the pot service life by 1 year.

The comparison of DPP variation ranges on Figures 9 and 10 allows concluding that within the indicated ranges of variations the combined impact of such indices like power consumption, capital costs and labor costs is practically equivalent to the combined impact of such indices like discount rate and pot service life.

This conclusion could be interpreted in other words: the increase of the pot amperage should lead to the investment profit due to the reduction in specific power consumption, capital costs and labor costs. The increase in discount rate will deteriorate the investment attractiveness of the project. In addition the increase in amperage will inevitably result in the reduction of average service life of the pots. So, the amelioration of the investment attractiveness by technical-and-economic improvements could be compromised by equal deterioration due to the increase of discount rate and decrease of service life of the pots.

3. Concluding remarks

The investment calculations are usually based on modelling pre-requisites. If public media would publish the information on cost estimates related to the capital construction of aluminium smelters, calculations of production costs (estimates), information about production parameters of the potrooms (current efficiency, specific power consumption, raw material consumption parameters) and more especially, data on average service life of the pots that are an integrating indicator of the technology level, it would be easy to carry out investment calculations and to show the efficiency of aluminium smelters construction while changing over from the lower amperage to the higher one. Unfortunately, all this information belongs to the category of confidential information. Any protection of information is always suspicious, first of all, for investors. It appears that over the period of 40 years the community of aluminium industry specialists was declaring the technical profitability of high-amperage smelters construction, forcing the investors to believe in declarable profit resulted from the reduction in the specific power consumption and in capital costs. At the same time the community was doing the best to hide the fact that in case of average pot service life decrease all parameters would decline (aluminium grade, specific power consumption), the consumption of fluorides and alumina would increase, the costs on capital repair of the pots would grow and, which is the most important, the losses would grow because of the downtime of the pots being under capital repair.

Specialists know very well the facts reported about potlines equipped with 180 kA pots that were in operation during 30 years even though their average service life was foreseen for 9 - 12 years. At the same time there are already enough examples of that the average service life of 300-400 kA pots hardly achieves 5 years. These data are not officially published but the parameter of average service life together with the fact that the value of dollar has been reduced by the factor of seven during the period from 1970 to 2014 because of inflation; neutralize the investment attractiveness of high-amperage aluminium smelters.

4. Conclusion

The development of the technology for the production of aluminium using the high-amperage pots does not demonstrate any obvious investment advantages for building aluminium smelters.

5. References

1. E. Basshard et al, EPT 18: The new 180kA pot of Alusuisse, Light Metals 1983, pp 596-605
2. E.B. Sarcinelli et all, The construction and operation of an aluminium plant in the amazon region, Light Metals 1987 pp 215-229;
3. H. Medina et al, The Venalum 230kA Potline, Light Metals 1989, pp 345-351;
4. B. Langon and Jm. Peyneau, Current efficiency in modern point feeding industrial potlines, Light Metals 1990, pp 267-274;
5. V. Katic and I. Kralj, From 89 to 95 modernization of potline im Sibenik, Light Metals 1992, pp 333-336;
6. M. Deshaies et al, An overview of ABI's experience with Pechiney 180 kA Cells, Light Metals 1992, pp 337-341;
7. O. Mertin, G-line in St.Jean De Mauriene, Six operation Years, Light Metals 1992, pp 343-346;
8. M.F. El-Demerdash et al, Modeling of metal topography and flow regions in working prebaked aluminium pot, Light Metals 1993, pp 369-374;
9. T.A. Utigard et al, Visualization of the Hall-Heroult process, Light Metals 1994, pp 233-240;
10. D. Vogelsand et al, Development of 300 kA reduction cell: application of simulation tools for the conceptual design, Light Metals 1994, pp 245-251.
11. T. Moen et al, Review of the retrofit program for brebake potlines of Hydro Aluminium, Light Metals 1994, pp 413-415;
12. M. Reverdy et al, AP 30 pot technology and experience gained from the recently started potlines, Light Metals 1995, pp 405-411;
13. D. Vogelsang et al, Retrofit Soderberg smelter at ALUSAF Bayside plant. Part - 1 Conceptual design and engineering Light Metals 1996, pp 327-333;
14. J.-P.Aussel et al, Commissioning of Alusaf Hillside smelter reduction pots, Light Metals 1997, pp 227-232;
15. G.P. Bearne et al, The CD200 Project - The development of a 200 kA Cell design from concept to implementation, Light Metals 1997, pp 243-246;
16. S. Feng et al, Development of High Amperage Prebake Cells in China, Light Metals 2000, pp 171-178;
17. A.J.M. Kalban et al, Reduction cell technology development at Dubal through 20 years, Light Metals 2000 pp 215-220;
18. L. Fiot et al, Tomago aluminium AP22 project, Light Metals 2004, pp 173-178;
19. G.E. da Mota and J.E.M. Blasques, Process improvements to raise the line current at Albras, Light Metals 2004, pp 185-190;
20. S. Haibo et al, Henan HongKong Longquan Aluminum Co.Ltd., China -- Growing Up, Light Metals 2004 pp 233-236;
21. O. Martin et al, The Next Step to the AP3X-HALE Technology: Higher Amperage, Lower Energy and Economical Performances, Light Metals 2006, pp 249-254
22. Dante Sinaga et al, Technical Improvement in Inalum, Light Metals 2007, pp 237-242;
23. Haibo She et al, Henan Hongkong Longquan Aluminum Co. Ltd., China-Second Phase, Light Metals 2007, pp 249-252;
24. Oliver Martin et al, The Latest Developments of Alcan's AP36 and ALPSYS Technologies, Light Metals 2007, pp 253-258;
25. Abdelhamid Meghlaoui et al, Anode effect and Specific Energy Reduction through Cell Control and Operating Parameters Optimization, Light Metals 2007, pp 399-404;
26. Ben Benkahla et al, Last Development in AP50 Cell, Light Metals 2008, pp 451-456;
27. Marvin Bugge et al, Expansion of the Potline in Slovalco, Light Metals 2008 pp 261-266;

28. Oliver Martin et al, The FECRI Approach and the Latest Development of AP3X Technology, Light Metals 2008, p255-260;
29. Cus Zlatko, and Avgust Sibila, 20 Years of continues improvements in TALUM Smelter, Light Metals 2008, pp 467472;
30. Z. Ming et al, The Advancement of New Generation SY350 Pot, Light Metals 2009 pp 377-379;
31. M. Al-Jallaf et al, Evolution of CD20 Reduction Cell Technology towards Higher Amperage Plan at Dubal, Light Metals 2009, pp 451-454;
32. B. Kakkar et al, 2008: A Milestone in the Development of the DX Technology, Light Metals 2009, pp 359-364;
33. B. Benkahla et al, AP50 Performances and New Development, Light Metals 2009, pp 365-370;
34. L. Fiot et al, Development of the AP39: The New Flagship of AP Technology, Light Metals 2010, pp 333-338;
35. A. Zarouni et al, DX Pot Technology Powers Green Field Expansion, Light Metals 2010, pp 339-344
36. Z. Jia et al, The Pot Technology Development in China, Light Metals 2010, pp 349-354;
37. L. Jie et al, Industrial Test of Low-voltage Energy-saving Aluminum Reduction Technology, Light Metals 2010, pp 399-404;
38. W. Ziqian et al, Study of Surface Oscillation of Liquid Aluminum in 168kA Aluminum Reduction Cells with a New Type of Cathode Design, Light Metals 2010, pp 485-488
39. Y. Xiaobing, and T. Qinghong, Development and application of a multivariate process parameters intelligence control technology for aluminum reduction cells, Light Metals 2010,p523-527;
40. O. Martin et al, Low Energy Cell Development on AP Technology, Light Metals 2012, pp 569-574;
41. P. Coursol et al, The Transition Strategy at Alouette towards Higher Productivity with a Lower Energy Consumption, Light Metals 2012, pp 591-594;
42. J. Zhou et al, Depth Analysis and Potentiality Exploitation on Energy-Saving and Consumption-Reduction of Aluminum Reduction Pot Light Metals 2012, pp 601-606;
43. D. Zhou et al, Development and Application of SAMI's Low Voltage Energy-Saving Technology, Light Metals 2012, pp 607-612;
44. A. Al Zarouni et al, DX+, An Optimized Version of DX Technology, Light Metals 2012, pp 697-702;
45. A. Al Zarouni et al, The Successful Implementation of DUBAL DX Technology at EMAL, Light Metals 2012, pp 715-720;
46. P. Thibeault et al, Rio Tinto Alcan AP4X Low Energy Cell Development, Light Metals 2013, pp 543-548;
47. M. Bastaki et al, DUBAL Cell Voltage Drop Initiatives Towards Low Energy High Amperage Cells, Light Metals 2014, pp 451-456;
48. D. Zhou et al, CHINALCO 600kA High Capacity Low Energy Consumption Reduction Cell Development, Light Metals 2015, pp 483-488;
49. A. Zarouni et al, Development History and Performance of Dubal DX+ Demonstration Cells, Light Metals 2015, pp 489-494;
50. M. Forté et al, Arvida aluminum smelter - AP60 technological center, start-up performance and development of the technology, Light Metals 2015, pp 495-498.