Reduction of Net Carbon Consumption - Different Avenues Tested

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Abstract

Decarbonization is a major issue for preserving our planet and the quality of life of its inhabitants. The development of industrial capacities and production methods in line with this challenge is essential. Aluminium Dunkerque is one of the world leaders in the production of low-carbon aluminum. The company has reduced its emissions by 17 % (scope 1 and 2) since 2013 and emits four times less greenhouse gases than the global sector average. Thanks to these assets, Aluminium Dunkerque intends to play a major role in the European production of low-carbon aluminum for the benefit of its customers and its communities. Therefore, in accordance with the objectives of COP21, we are accelerating our energy and environmental transition by giving ourselves an ambitious roadmap to 2050: the LowCAL project.

Although our strategy is geared towards the implementation of a CO_2 capture process, efforts remain sustained to reduce our emissions at their origins as much as possible. In this context, Aluminium Dunkerque was able to test two avenues for reducing net carbon consumption by: increasing the frequency of pot tending to maintain an airtight cover, and by coating the anodes in order to reduce their air burn (oxidation) and CO_2 burn (Boudouard reaction). The results are analyzed in a technical-economic context to be validated for generalization or a larger test.

Keywords: Aluminium electrolysis potroom, Net carbon consumption.

1. Introduction

Aluminium Dunkerque is a French plant located in northern France. The plant has 650 employees and uses AP40 technology on its 264 pots. Production totals over 280 kt/a at an operating current of 395 kA. Aluminium Dunkerque is part of the benchmark smelters in terms of low-carbon aluminium production, with a footprint of 4.4 t CO_2eq/t Al for scopes 1, 2 and 3. Scope 1 and 2 emissions have been reduced by 17 % since 2013 (Figure 1) thanks to continuous process improvements, introduction of low-energy pot linings and a less carbon-intensive energy supply. Nevertheless, the plant's overall scope 1 footprint is mainly due to the consumption of carbon anodes in the electrolysis process, which alone accounts for 85 % of smelter CO_2 emissions (Figure 2).

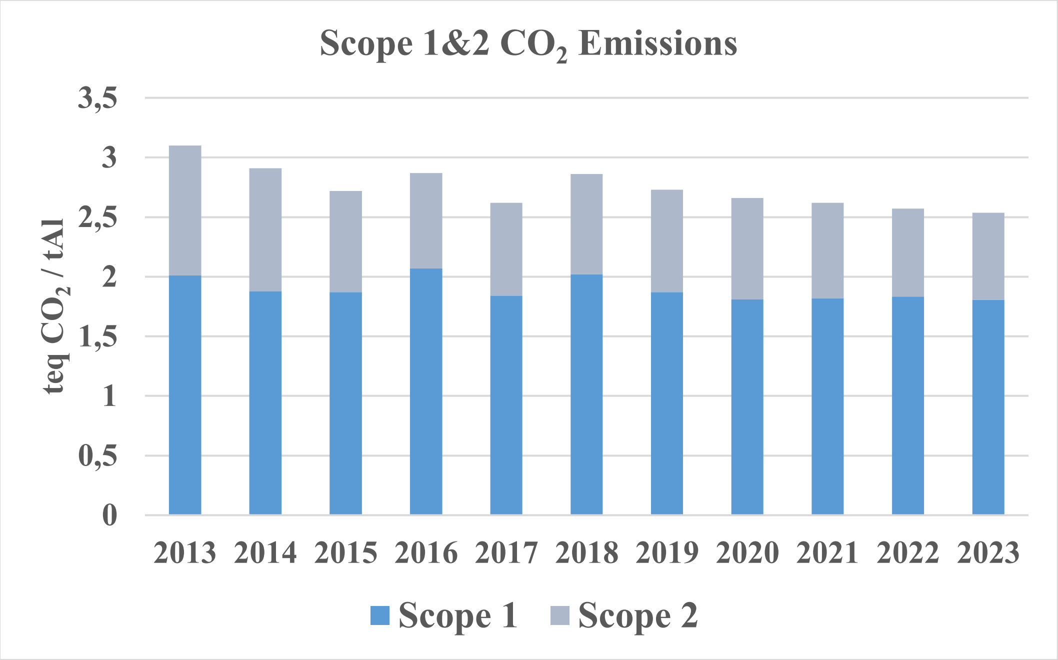

Figure 1. Scope 1 and 2 CO_2eq emissions in Aluminium Dunkerque.

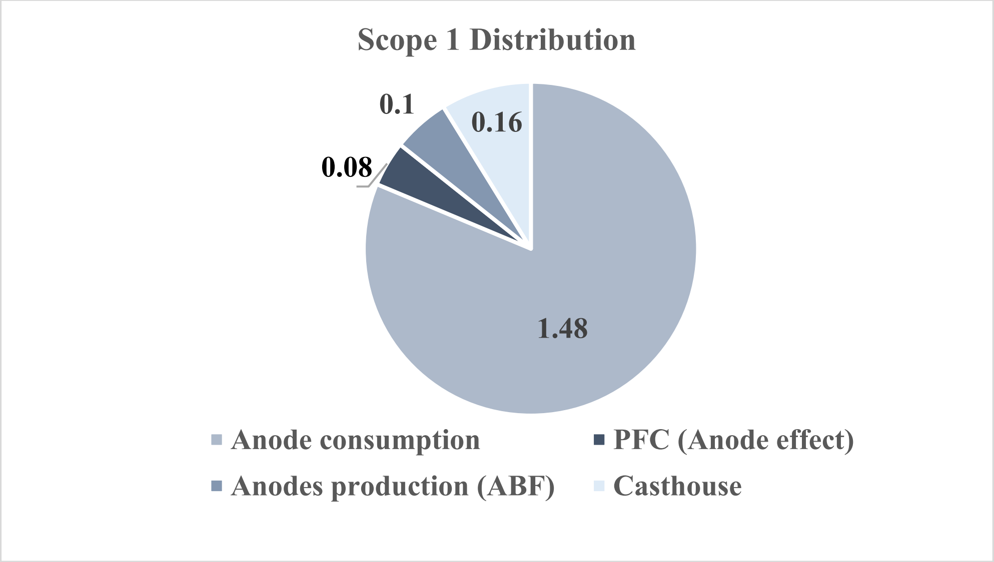

Figure 2. Scope 1 CO_2e emissions in the smelter.

Aluminium Dunkerque has implemented an ambitious strategy to decarbonise its facilities by 2050. This strategy, known as LowCAL@, is broken down into several milestones by 2030 aimed at increasing aluminium recycling capacity and implementing Carbon Capture and Storage (CCS) technology on the potline; benefiting from the future CO_2 hub to be developed in the region by bringing together manufacturers with significant carbon emissions.

In a second phase, the aim is to create a new electrolysis potline based on inert anode technology and then convert existing potline to this same technology by 2050.

Pending the introduction of these breakthrough technologies, Aluminium Dunkerque is continuing its efforts to reduce its carbon emissions by electrifying processes, reducing energy consumption, and cutting its net carbon consumption.

In this context, Aluminium Dunkerque has been able to test two solutions for reducing its net carbon consumption which is at 415 kg C/t Al annual average.

A. Testing a solution to increase the frequency of pot tending to improve anodic protection from air oxidation.
B. Testing a solution of anode coating to reduce oxidation by oxygen and CO_2 (Boudouard reaction).

We describe below, for each solution, the initial situation, test protocols used, results of the measurements carried out and estimated business case for each solution.

2. Solution A – Increasing Frequency on Pot Tending Operation

2.1 Initial Situation

The potline is composed of 264 pots; 5 operating teams taking turns working 8-hour shifts on a 6 × 4 work cycle (6 days on and 4 days off). The operations cycle lasts 32 hours, with a tapping weight average of 4 t/pot; the anode plane is lowered by 3.7 cm after each tapping.

The pot tending operation is planned for the pots which the team has the ownership in the potline. The pot tending operation consists of removing each hood of the pot and adjusting the thickness of the anode cover, plugging the cracks and holes caused during anode movements.

Given the work cycle of the teams (6 × 4) as well as the cycle of operations, the basic frequency of the pot tending operation is established in a range between 7 and 11 days with an average of 7.5 days.

Pots are equipped with anodes 1650 mm long and 650 mm high. The central channel is 190 mm wide. Anode covering material used is very fine (autogenous mill) and contains 45 % alumina; it is fluidised when applied with the pot tending assembly (PTA).

2.2 Test Protocol

Three reference pots and three test pots were selected from the same workgroup to have the same characteristics of the anode cover. The test was spread over a period of 3 anode cycles (approximately 3 months); during this trial period all the new anodes were weighed before being introduced into reference and test pots. A mobile floor scale was used to weigh anodes before placing in pots; the same scale was used to weigh anode butts once the anode cover had been removed. Reference pots A061-A062-A063 kept pot tending frequency at 7.5 days, while test pots A064-A065-A066 were switched to a frequency of 5 days.

The mass of carbon consumed was calculated using the differential mass found on the two weighings for the same anode assembly. Net carbon was calculated from metal tapped over each anode test cycle on reference and test pots. Nearly 280 measurements were carried out this way; when anode butts showed an anomaly such as a clean corner break, the corresponding data was not retained in the results. Anode life is 76 shifts of 8 hours.

Figure 3. Test of mobile weighing scale.

2.3 Measurement Results

2.3.1 Normality Test

The data measured shows a normality in its distribution and can be used for statistical comparison (Figure 4).

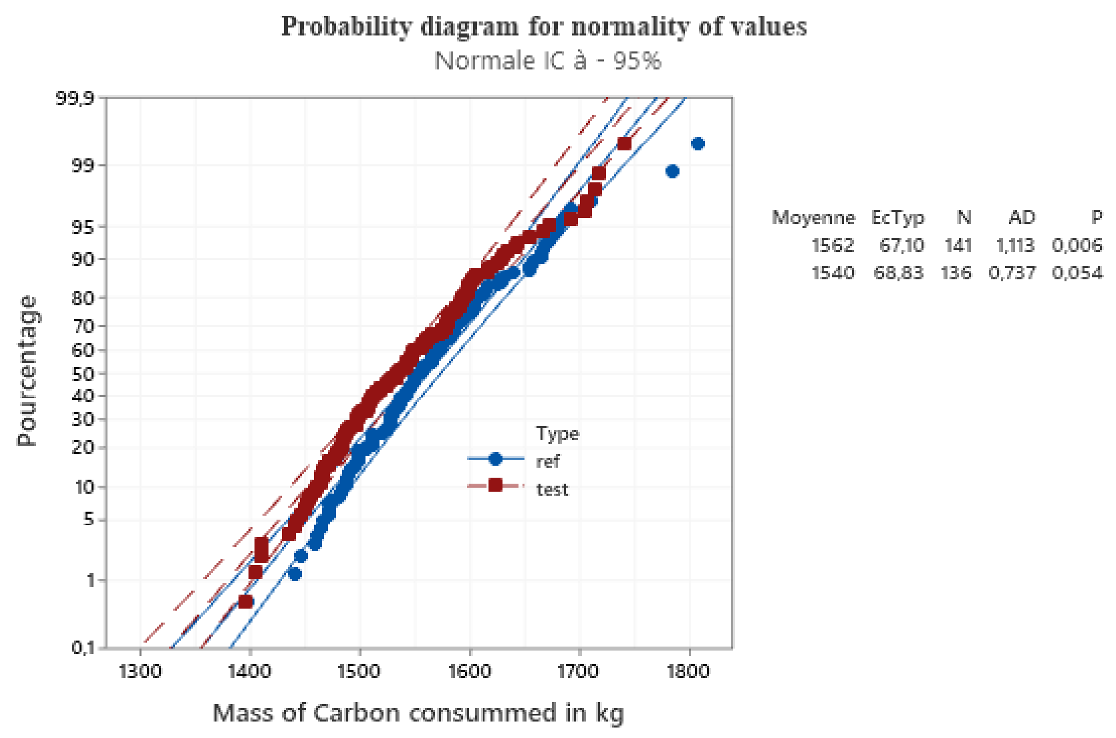

Figure 4. Data test for normality of carbon mass consumed.

2.3.2 Comparison of Anode Consumption

Measurements of anode mass consumption (calculated as new anode mass – butt mass) between reference (ref) and test pots shows a significant difference between them. The anode mass consumed was 22.5 kg/anode lower in test pots than in reference pots (Figure 5).

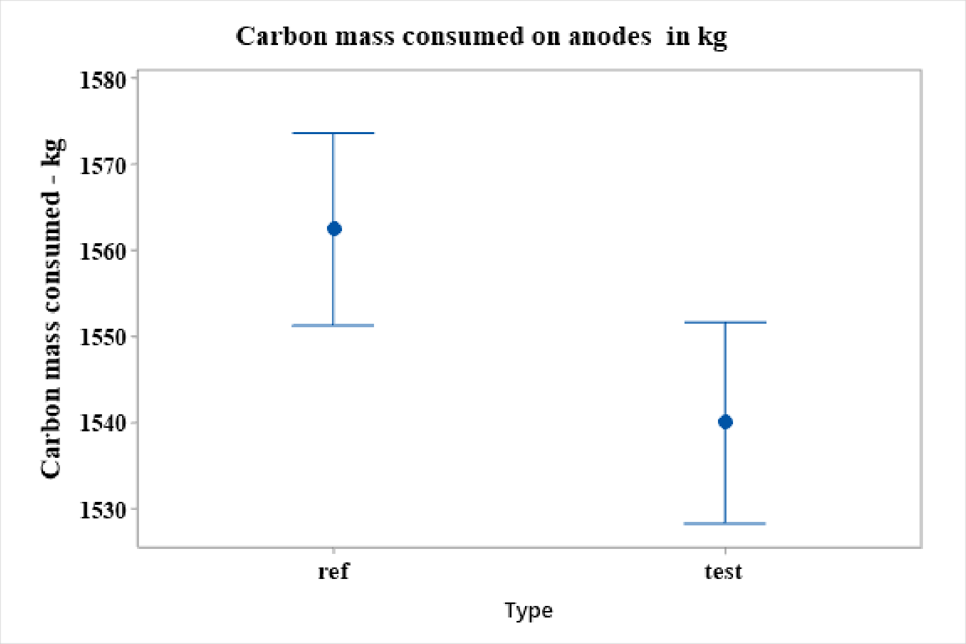

Figure 5. Baked anode mass consumed with standard deviation. The scatter bars are standard deviations in this and all subsequent graphs.

2.3.3 Net Carbon Consumption

Net carbon consumption was calculated by measuring anode butt weight, which was subtracted from the new anode mass. Then it is divided by the metal tapped from pots over the given period. Net carbon consumption is shown in Figure 6.

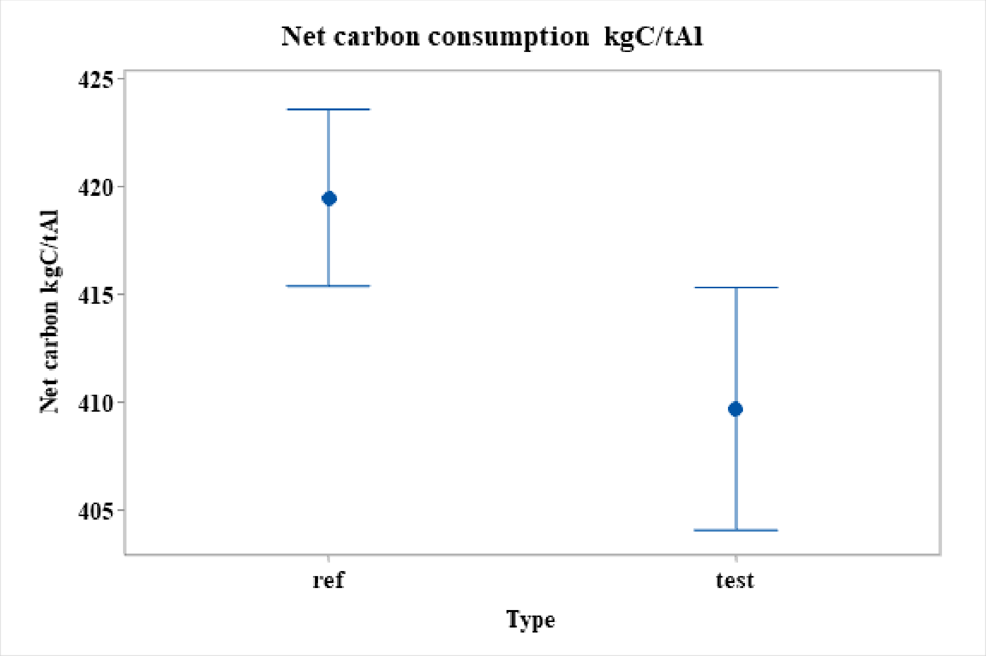

Figure 6. Net carbon consumption for reference and test anodes.

The difference in net carbon consumption between the two groups confirms the difference in carbon consumption. Net carbon consumption is 9.8 kg C/t Al lower in the test group.

2.3.4 Study of Variations Observed During the Test

During the trial period, variations in results were noted among the test pots. One of the three test pots obtained even worse results than reference pots (Figure 7).

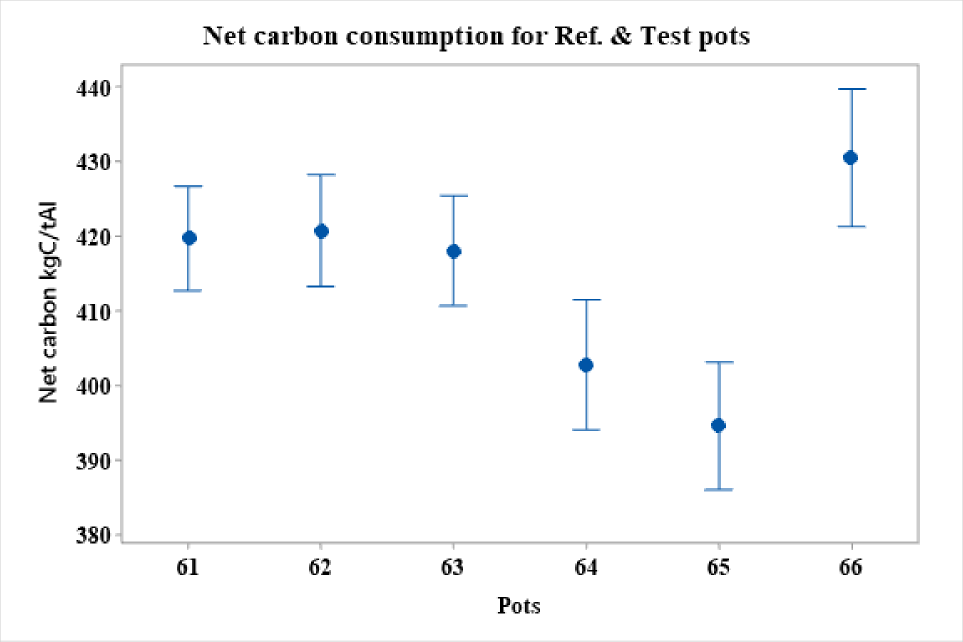

Figure 7. Net carbon consumption in different trial pots.

The reference pots were 61, 62, 63; the test pots 64, 65, 66. Pot 66 showed worse results than the other two test pots. The results obtained were also worse than in the 3 reference pots. The results obtained overall for test pots are therefore impacted by the results obtained for pot 66; we can assume that the reduction of net carbon would be significantly greater and come close to 20 kg C/t Al if pot 66 had behaved in the same way as the other two.

It is therefore important to understand the differences between pot 66 and pots 64 and 65.

Several operating parameters were considered in this analysis: number of alumina shots, anode effect frequency and anode effect overvoltage, bath temperature and superheat over the same operating period.

The only correlations that could be identified were with bath temperature and superheat. Figure 8 shows that pot 66 is very different from the other pots in bath temperature, with an average above 970 °C. There also appears to be a correlation with superheat, with pot 66 having superheat almost double that of the reference pots (Figure 9).

It can also be noted that bath temperature and superheat of test pots 64 and 65 are lower than in reference pots. Net carbon consumption of the test pots 64 and 65 may have been positively impacted by favourable thermal operating parameters.

After further analysis of individual data, correlations could be confirmed for parameters of superheat and bath temperature (Figures 10 and 11). However, the influencing factors appear to be different, with bath temperature having a greater influence than superheat.

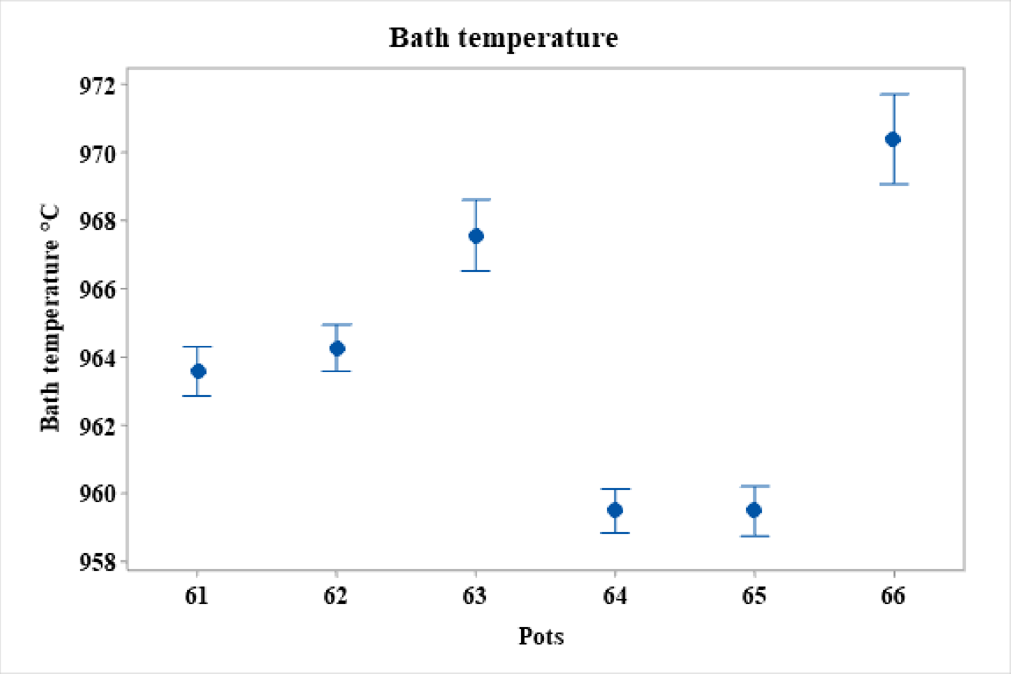

Figure 8. Bath temperature with standard deviation on reference and test pots.

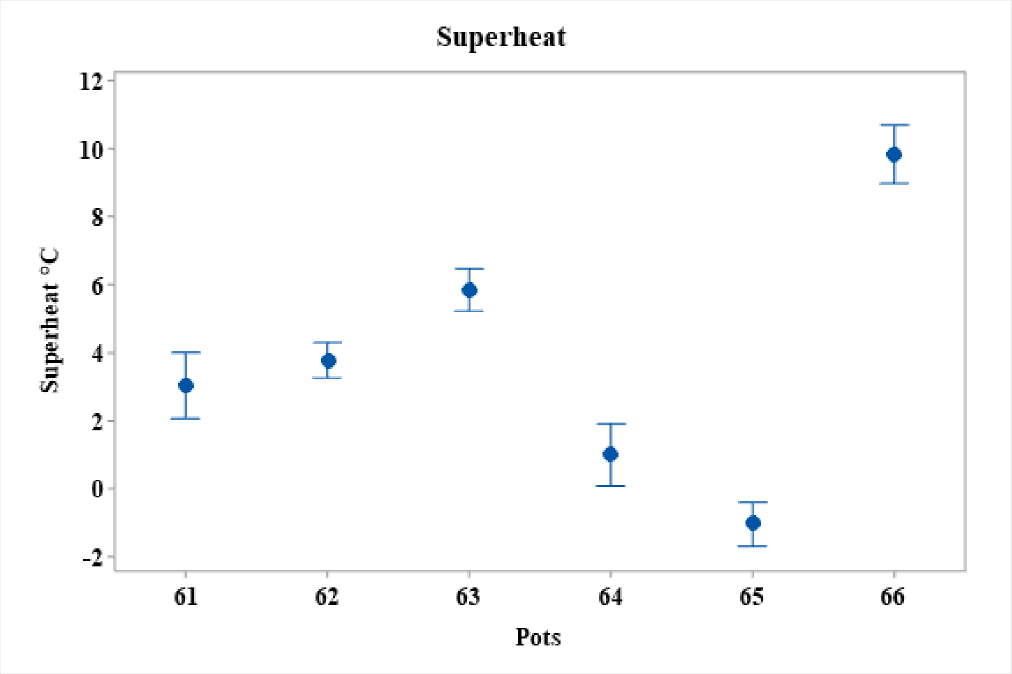

Figure 9. Superheat with standard deviation in reference and test pots.

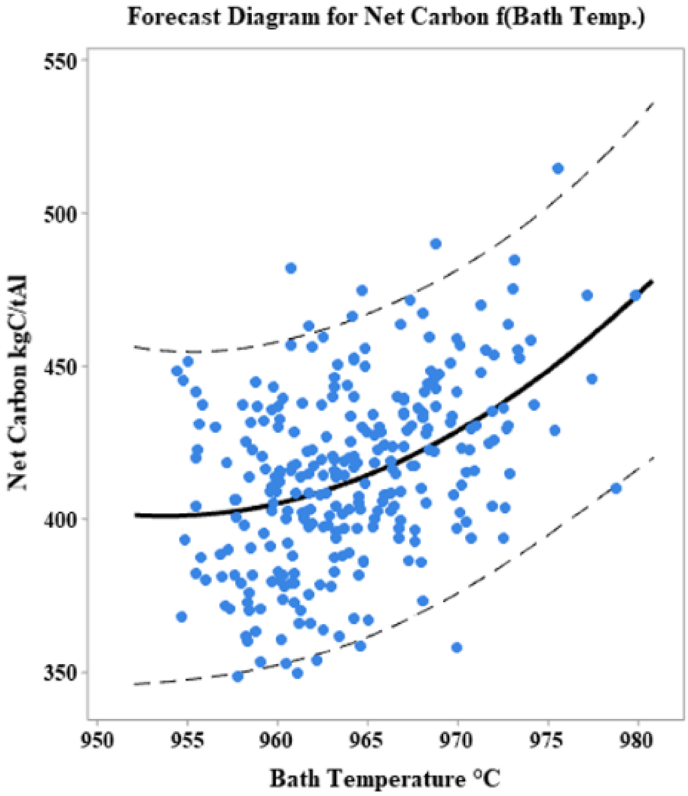

Figure 10. Net carbon forecast vs bath temperature.

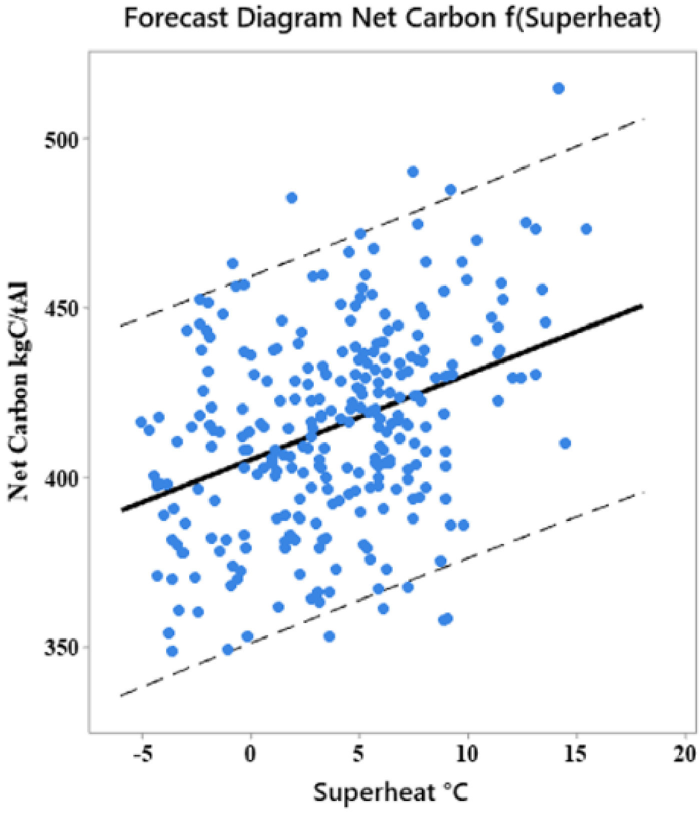

Figure 11. Net carbon forecast vs superheat.

As can be seen in Figures 10 and 11, the forecast diagram for net carbon as a function of bath temperature is exponential, whereas the prediction diagram as a function of superheat is linear. The statistical data shows a significant correlation between the two causal factors.

2.3.5 Initial Business Case

Increasing frequency of pot tending does not require any investment. However, Aluminium Dunkerque Electrolysis Plant is already operating with a reduced workforce, with 17 operators working 8 hour shifts to operate the 264 pots.

The resulting workload cannot be immediately transferred to current workforce, and it is probably planned to increase the number of operators by 2 per shift, around 10 additional operators in the Electrolysis department.

Gains in net carbon obtained on test group were guaranteed by auditing pot tending operations on each test and reference pots each time they were carried out. It will not be possible to maintain these audits in addition to those carried out for the entire potline.

Extra carbon mass of the butts (+22.5 kg), does not necessarily mean that the carbon department will be able to recycle all this additional material without incurring a loss of quality in the anodes produced. Sodium content could be affected in the production of new anodes and therefore carbon reactivity of anodes and consequently an increase in net carbon.

For the first economic study, we therefore chose to moderate the gain achieved in the trial by -50 % (5 kg decrease in net carbon instead of the 9.8 kg measured). The OPEX takes into account the additional two operators per team, i.e., +10 operators over the year for the plant.

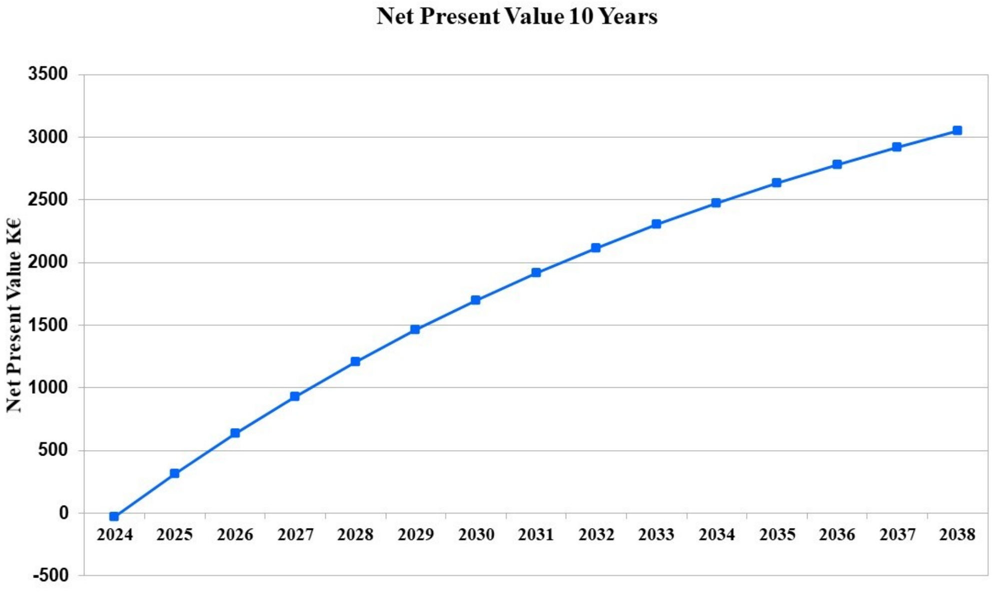

Figure 12. Net present value for increased frequency of pot tending.

It can be seen that by selecting only 50 % of net carbon gains obtained during trial period, net present value (NPV) remains positive and the project payback is 1 year. A profit of 3 MEUR is generated after 10 years.

2.3.6 Conclusions for Solution A

Major potential gains can be made by changing frequency of pot tending when greater than 5 days cycle. Given observations made during the test period on anode cover quality, it is uncertain that such gains can be obtained by going below pot tending frequency of 5 days.

It is important operations can be audited on a regular and sustained basis to guarantee maximum net carbon gains.

Net carbon gain makes it possible to reduce input of raw materials in carbon plant if recycled content can be increased from 1.5 to 2.0 % in the paste without reaching threshold limits. In the negative, provisions must be made regarding the size of the anodes to limit the % of recycled material in the paste or recycling material can also be sold.

Progress can also be made by intervening more quickly on pots outside their thermal limits. Average temperatures > 970 °C are particularly to be avoided in medium and long term. Action needs to be taken quickly to detect this type of pots and treat them to restore desired thermal balance. Usually, the number of pots being in this condition is low and ranges between 2 to 3 % of the potline.

3. Solution B – Anode Coating to Prevent Oxidation and Carboxydation

3.1 Description of the Coating Product

Coating product used by Aluminium Dunkerque in this trial came from an established Chinese source offering a product already tested on technologies in China. The product must be applied in two separate coats, either with a spray gun or directly with a paint roller. The latter type of application was chosen for the test.

Coating product is mainly alumina-based (50 %); first coat is applied to the carbon to be protected using a reference quantity between 1.5 and 2.0 kg/m^2, depending on grain size of the anode surface. Second coat is applied 30 minutes after the first one, also using a reference quantity of 1.5 kg/m^2.

Surface area required to protect Aluminium Dunkerque's anodes is 2.3 m^2, covering the 4 sides of the anodes as well as the upper part (at the level of the pin holes). Quantity of product required to treat one anode assembly (2 anodes) at Dunkerque is therefore 7 kg.

The cost of the product, excluding transport, is 3 000 USD/t; 3 t were used to carry out the test on 2 pots during three anodic cycles. (120 anodes sets in total).

3.2 Test Protocol

The test period covered 3 complete anode cycles on 2 test pots. Only one reference pot was selected part of the same group of test pot anode changes. The same anode number was changed on all 3 pots at the same time. The anode production batches are identical in all three pots (test and reference).

Metal pad measurements were carried out on the three pots during 3 months of testing in order to calculate an accurate current efficiency for each pot.

The level of impurities in the metal produced was also measured on Si, Na, Fe and Ca components. The anode cycle of the three pots was 76 shifts of 8 h at the time of the trial.

Reference Pot: A004, Test Pots: A005 & A006.Figure 13 shows the coated anodes.

Figure 13. Anodes ready to be used after coating.

3.3 Measurement Results

3.3.1 Normality Test

Figure 14 shows the results of normality test. The data measured shows a normality in its distribution and can be used for statistical comparison.

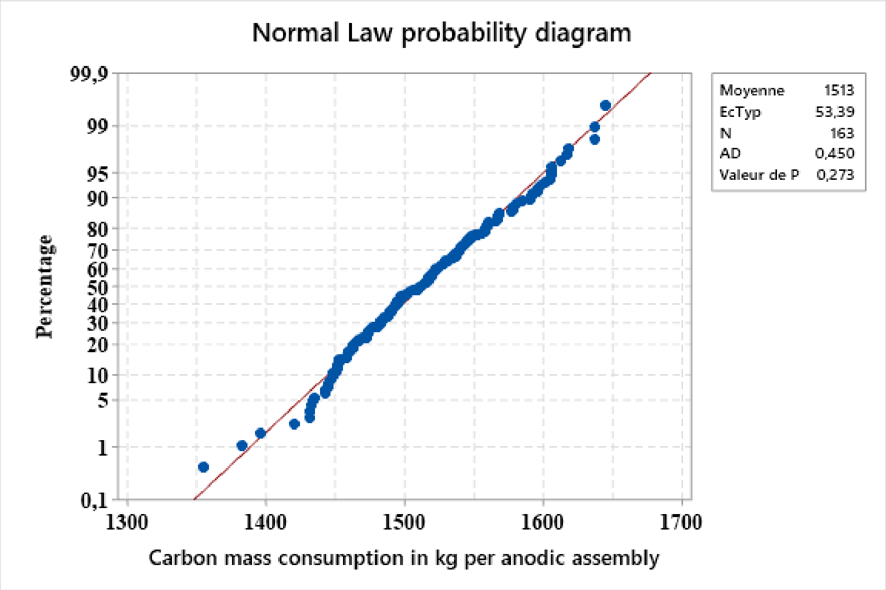

Figure 14. Normality test.

3.3.2 Comparison of Anode Mass Consumed

As Figure 15 shows, there is no significative difference between reference pot and the two test pots in terms of the mass of carbon consumed during the anodic cycle.

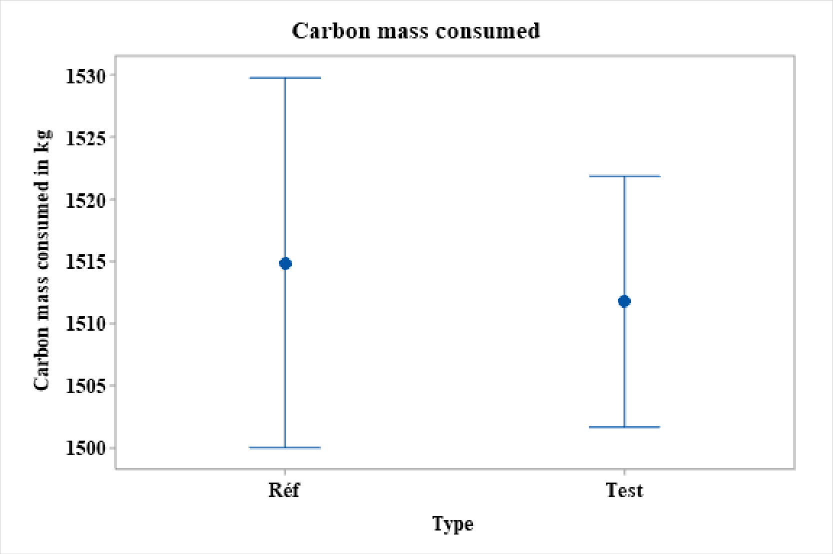

Figure 15. Carbon mass consumed on anodes in kg Ref. pots vs Test pots

3.3.3 Net Carbon Comparaison

Net carbon consumption is shown in Figure 16.

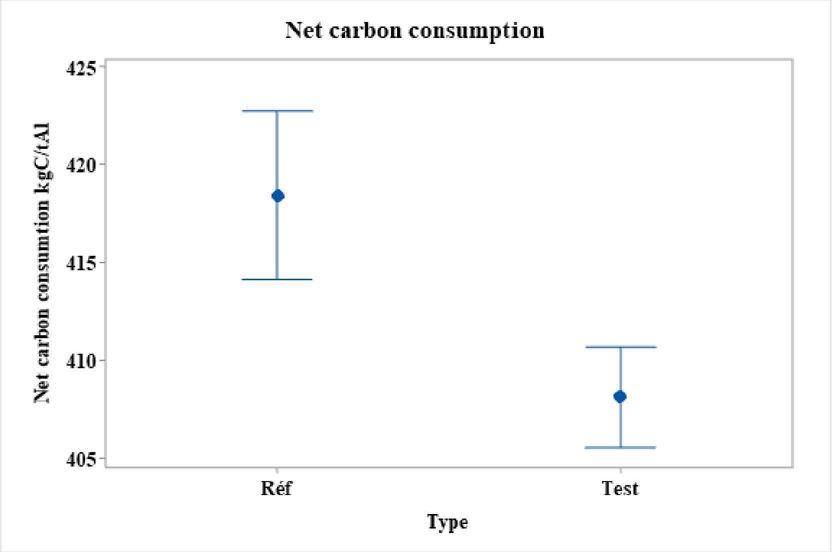

Figure 16. Net carbon consumption reference vs test pots.

Unlike results obtained for new anode mass, net carbon consumption shows a significant difference. Net carbon is calculated from current efficiency obtained from tapping weight calculations and evolution of the metal pad mass of the pots. Metal pad mass is calculated through results of copper additions within the considered pots. The result is therefore fairly accurate over a three-month trial period. The difference in consumption is -17 kg C/t Al in favour of the pots that received the coating on anodes.

This can be explained by a clear current efficiency difference between the test pot and the reference pots as shown in the graph in Figure 17.

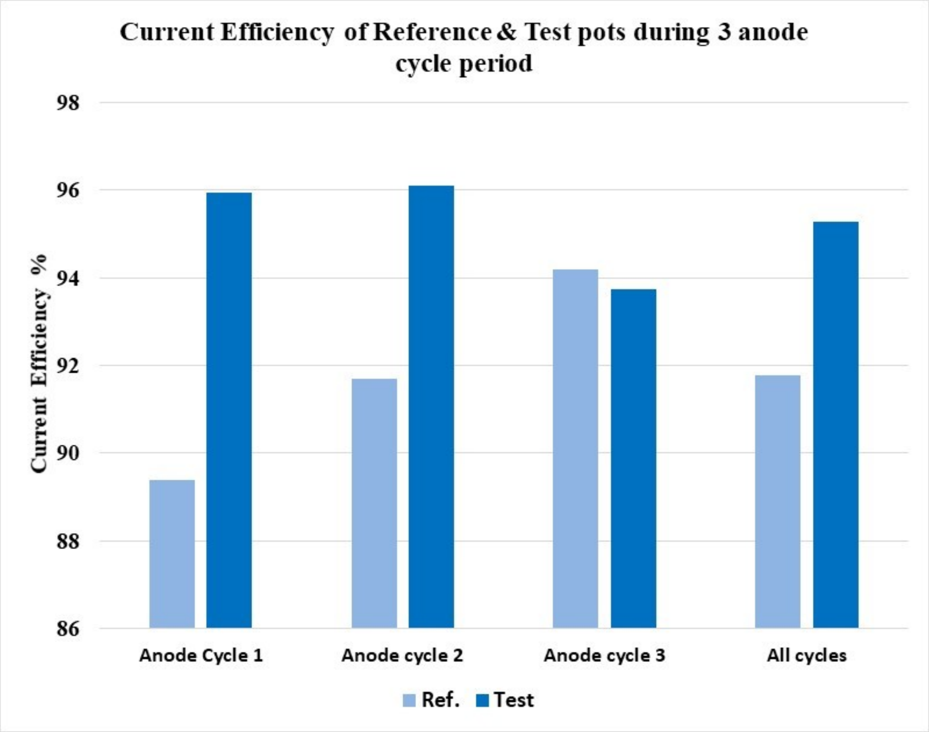

Figure 17. Current efficiency on reference and test pots through trial period.

Lower current efficiency of reference pot is confirmed by a lower sodium level and a lower number of alumina shots. If trial periods are broken down by pot and anode cycle, Figure 18 shows that with similar current efficiencies, net carbon level becomes similar between pots. (P3 anode cycle)

A004 being the reference pot, A005 and A006 being test pots with coated anodes. Periods P1-P2-P3 represent the three-anode cycles that were carried out during trial period.

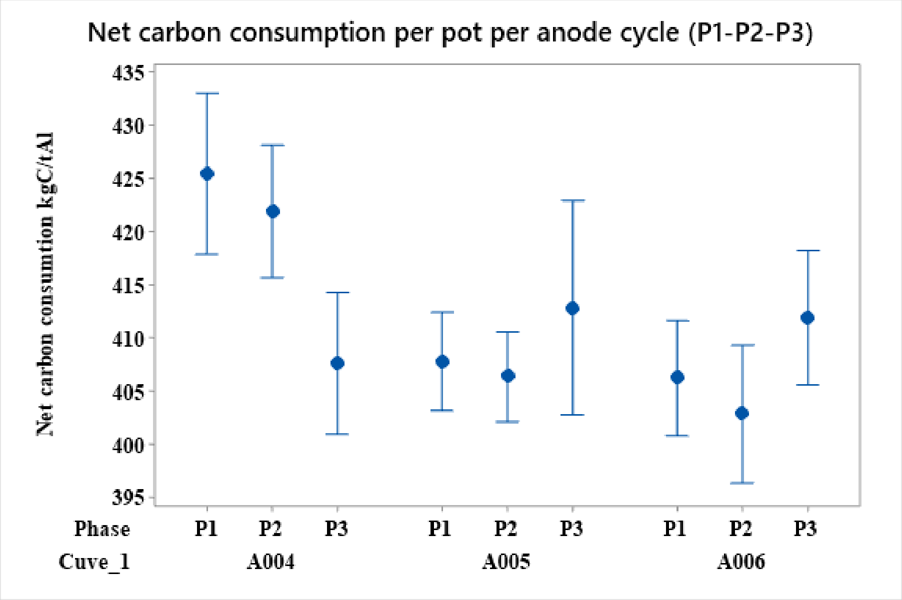

Figure 18. Net carbon by pots and anode cycles during trial period.

3.3.4 Laboratory Results

Before carrying out the tests on pots, carbon samples that had been coated were tested in the laboratory furnaces. The cores underwent joint tests for oxy-reactivity at 550 °C and carboxy-reactivity at 960 °C. These tests gave excellent results, as shown in the Table 1.

Table 1. Test results.

Measurment type	Average results of non coated samples (%)	Results of coated samples (%)
O_2 residu	76	98
O_2 lost	20	0.2
O_2 dust	7	0.2
CO_2 residu	90	97
CO_2 lost	8	1.2
CO_2 dust	2.7	0.6

3.3.5 Impact of Coating on Metal Quality

Of the four impurities measured, Si, Fe, Na and Ca had no undesirable impact on quality of the metal. All impurities did not change over time. It is difficult to compare impurities between reference pots and test pots. The test pots had higher sodium values due to higher current efficiency on these pots.

3.3.6 Initial Business Case

The implementation of coating on a complete potline requires an estimated investment of 2 MEUR for installation of an automatic coating machine on the sealing lines. A significant Opex is also required for the coating product, which has an annual cost of 2.5 MEUR.

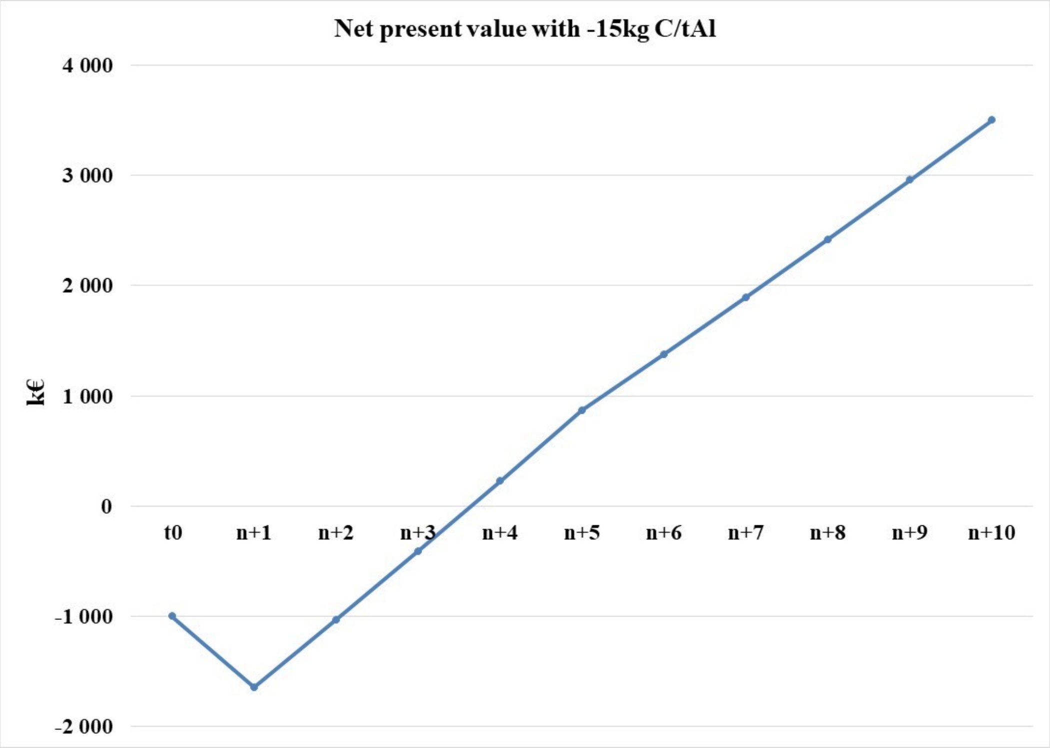

Figure 19. Net present value with -15 kg C/t Al.

The main gains will be made in terms of the cost per tonne of CO_2 eq avoided (CO_2 eq cost set at 80 EUR/t CO_2 eq) and the savings on coke and pitch raw materials (150 kEUR per year per tonne of net carbon). Under these conditions, the project is interesting from a gain starting at 15 kg C/t Al in net carbon. Below this value, the business case quickly deteriorates. With a gain of -17 kg C/t Al measured in this test, we believe that guaranteed results have not yet been achieved to industrialize the technology and that there is still a risk for this type of project. An extended industrial test needs to be performed as risk removal before industrialisation.

3.4 Conclusions on Solution B

The anode coating solution is promising but needs to be validated on a larger scale before it can be implemented on a complete potline. Results obtained do not sufficiently guarantee that the minimum necessary gain (kg C/t Al) will be achieved. The best results obtained on the test pots in terms of current efficiency could not be attributed directly to the coating because they remained within the average level of performance of the potline at the time of the trial.

Automatic spraying of coating product also needs to be closely monitored and may involve additional Opex in terms of maintenance and cleaning of equipment. The product dries relatively quickly, and frequent cleaning of the spray nozzles should be considered in a workshop that does not work 24 hours a day.

The next stage would be to test the protective coating on anodes over a longer period and on a larger number of pots.

4. General Conclusions and Next Steps

In Aluminium Dunkerque case, deployment of Solution A remains a priority with significant potential for gains without major investment. The number of additional staff required to carry out additional pot tending tasks will not be used at 100 % and could also be dedicated to other tasks creating additional added value.

For smelters already on a frequency level of 5 days or lower between each pot tending operation, it is recommended not to decrease this frequency, which will have a direct impact on the net carbon consumption. A further increase in the frequency of pot tending could undoubtedly lead to an additional gain, but the observations made on quality of the cover will not allow for a linear progression in the gain.

Aluminium Dunkerque will soon be switching its pot tending frequency on a large section of the potline and would like to equip itself, beforehand, with an automated system for weighing new anodes and butts; this will enable it to accurately monitor changes in net carbon consumption.

Solution B for coating anodes needs to be tested on a larger scale as well, to validate and guarantee future results in terms of net carbon gains. Development of less expensive coatings is also required to improve profitability of the project and reduce risks. Following the change in the frequency of pot tending, Aluminium Dunkerque will carry out additional, larger-scale tests to confirm carbon reduction measures and assess indirect impact on current efficiency through better anode surface retention and reduction of carbon dust.

5. References

1. Tapan K. Sahu and Najeeba Al Jabri, Improving Net Carbon Consumption at EGA with the Support of Anode Tracking and Butt Analyser, *Proceedings of 35th International ICSOBA Conference*, Hamburg, Germany, 2-5 October 2017, *Travaux* 46,743-755.
2. Ali Jassim and Najeeba Al Jabri, Innovative Anode Coating Technology to Reduce Anode Carbon Consumption in Aluminum Electrolysis Cells, *Light Metals* 2019, 745-752.
3. Bibhudatta Mohanty and Mayukh Ghosh, Coating of Anodes to Reduce Air Oxidation, *Proceedings of the 39th International ICSOBA Conference*, 22-24 November 2021, Virtual, *TRAVAUX* 50, 743-754.
4. Boyi Wang and Bo Hong, Application of Nano-Ceramic Anti-Oxidation Coating on Anodes of Aluminum Reduction Pots, *Proceedings of the 41st International ICSOBA Conference*, Dubai, UAE, 5-9 November 2023, *TRAVAUX* 52.