Anode Centre Modifications to Accommodate Potroom Amperage Increase – A Review and Practical Experience

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Abstract

As anode consumption is proportional to aluminium production, an increase of amperage for more aluminium production requires an increase in anode production. This increase can be in the number of anodes, anode size or anode density. This usually means substantial modifications in the anode centre. There are large numbers of possible modifications to increase carbon anode production. Each modification arrives with its advantages and disadvantages. This paper presents most modifications that can be made in an anode centre to increase anode production, with an overview of consequences on equipment, process and inventory. This review paper is motivated by the first author's experience of over 25 years with the modifications in an anode centre, made to accommodate amperage increases.

Keywords: Aluminum electrolysis, Carbon anodes, Anode center modifications for increased production, Anode size increase.

1. Introduction

There are two main directions in potline operation, depending on economical conditions and objectives: maximum metal production, and minimum power consumption. The former is profitable in regions with abundant power and low energy cost, the latter in regions with high energy cost and limited power. In general, high metal productivity pots operate with high anode current density and low anode-cathode distance (ACD), and low energy consumption pots with low anode current density and high ACD; in the same technology, the two modes of operation are also possible, each at different amperage [1].

In this paper we focus on smelters that are maximizing metal production, and we explore the consequences of increasing the metal production on the anode production.

Metal production increase in an existing smelter can be achieved by:

1) Increasing amperage in existing pots: This involves pot operation strategy changes, and pot design changes to compensate for increased heat generation in the pots [2].
2) Adding pots to existing potlines [3]. The number of added pots is usually limited by available space and maximum rectifier voltage.
3) Adding one or more potlines to an existing plant (greenfield expansion) [4, 5].

From these three methods, the first one, amperage increase in existing potlines, is the most profitable because capital cost is minimal as long as existing spare capacities of potrooms, anode plant and casthouse facilities are used. Amperage increase potential for smelter productivity increase in existing smelters was recognized in the 1990s [6–7]. Some smelters started to increase amperage at the very startup of a potline [4].

Whatever method used, anode centre has to follow, because higher metal production requires more carbon anodes since net carbon consumption per tonne of aluminum stays essentially the same. Table 1 gives an example of carbon anode production needs for amperage increase from 360 kA to 410 kA [8]. Production of carbon anodes is a manufacturing process quite different from aluminium electrolysis. Implications of producing more carbon for aluminium pots can become very challenging when anode centre operation is pushed to the maximum of its capacity. Table 2 gives some challenges that, among many more, will be discussed in detail in this paper.

Table 1. Required anode production increase for amperage increase from 360 kA to 410 kA [8].

Anode requirement	Unit	Now	Future	
Amperage	kA	360	410	
Aluminium production	t/y	600 000	680 000	
Baked anodes required	t/y	335 000	380 000	
Baked anode weight	kg	980	1070	
Baked anode length	mm	1550	1650	
Baked anode height	mm	625	650	
Anode current density	A/cm^2	0.893	0.956	
Green paste production	t/y	375 000	420 000	
Green anode weight	kg	1030	1120	
Green mill throughput	t/h	2 × 33	2 × 36	
Specific mixing energy	kWh/t	8.5	7.8	
Anode baking furnace		6	6 fires	7 fires
Production per fire per year	t	55 800	66 300	54 300
Tonnes per section	t	188	180	180
Fire cycle time	h	29.5	24.9	29
Total heat-up time	h	177	149	174

Table 2. Anode production increase: some challenges [8].

Green anode production bottlenecks	Baking furnace
• Ball mill production capacity • Preheating of dry aggregate • Insufficient specific mixing energy • Paste cooler capacity • Vibroformer availability and process control • Mold must be changed for longer anodes • Vacuum compaction to increase anode density • Green anode cooling capacity • More butts: butt storage, cooling, cleaning, crushing, cast iron stripping • Rodding: Faster rodding cycle, more cast iron to be melted, conveyor speed, higher/longer anodes – check clearances	• With 6 fires, total heat up time 149 h is not enough • Increased waste gas volume increases pressure drop in the flues, which leads to a lack of oxygen in the fire zone (soot) Solution: • Add one fire • Increase flue height (check clearance for crane) • Investment required: Extension of the furnace building, refractory, firing equipment, anode transport, handling and slotting equipment, crane capacity and adjustments for anode handling

This paper will overview the different methods used to increase carbon anodes supply to potrooms and will look at consequences of changing some of manufacturing parameters and anode supply logistics. It as a long checklist of things to consider. It adds to numerous papers already written on the subject [8–13].

2. Putting More Carbon in Pots

There are three ways to supply more carbon when potrooms produce more aluminium (Figure 1):

- Supplying more anodes, either by producing them locally, getting them from another anode plant within the company or buying on from the open market;
- Increasing anode size: length and/or width, height;
- Increasing anode density, putting more carbon in the same volume [14–6].

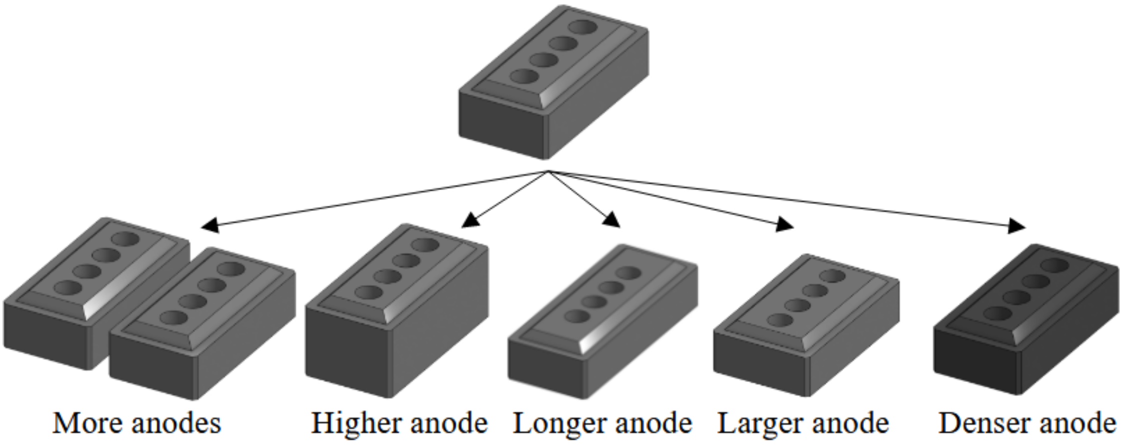

Figure 1. Ways to put more carbon in pots to cope with amperage increase.

It should be mentioned that these ways can be used alone or in combination. It can end up supplying more, bigger and denser anodes. Each solution has its own challenge. While each solution involves consuming and treating more raw materials, some consequences are common.

2.1 Manufacturing More Carbon Paste

Whatever means are used to supply potrooms aluminium production increases (except when buying baked anodes), it always involves producing more carbon paste, to produce more blocks, bigger blocks or denser blocks. Paste plant is the first part of the anode plant to be impacted by more production.

2.1.1 Raw Materials

Raw materials supply has to be increased to be able to produce more carbon paste. Usually, transportation and unloading can cope with a small increase in quantity of raw materials increase, usually for a small amperage increase or a few more added pots. Capacity has to be reassessed if it involves one or more potrooms, in the smelter.

If raw materials come by boat, it is usually not a problem, because harbours usually have idle time between vessels. If harbour is blocked by ice during winter, more storage may be required, or ice class vessels are to be rented to supply during winter. If raw materials come by railcars, this may mean a significant rise in railcars traffic within the plant. Unloading of coke railcars usually does not have a problem of capacity. Unloading of pitch may be impacted by the lack of heating capacity in rail cars. Check if heating capacity is adequate or if it should be increased to deal with larger numbers of pitch railcars to be heated.

2.1.2 Paste Plant

Crushing may be an issue, specifically ball mills. Throughput may be limited. It may be countered by crushing coarser. But tendency is to crush finer to fill voids in anode structure more efficiently [17–19]. Check with manufacturers to see if throughput may be increased with balls mill modification, if throughput is a problem.

Using aggregate and binder faster, with same size silos and reservoirs, lowers safety buffers for equipment problems in paste preparation. Improving preventive maintenance may be necessary to reduce unnecessary down time due to equipment breakdowns.

Dosing is usually not a problem, but the capacity should be checked.

With higher throughput, aggregate preheating time may be shorter, which results in less uniform aggregate temperature. Some preheaters may be adjusted to compensate.

Paste mixing may be a bit shorter. It may be countered by increasing energy input in paste. But this will result in faster wear of the mixing tools. A more efficient or a thicker wear-resistant coating on mixing tools may avoid faster wear.

Paste cooling, if present, may be shorter too. Cooler adjustment may keep paste temperature at the target. But this may result in more cooling air to be treated in tar fumes scrubber. Check if tar fumes scrubber can take it. If cooler uses water for cooling, more water flow may be used to adjust final paste temperature. Resulting excess of water vapour may condense in places not design for, causing tarry water spillage. Check if the dew point may be adjusted in duct flow, by heating airflow, to increase water vapour transportation capacity.

2.2 Anode Forming

2.2.1 Producing More Anodes

Increase in anodes blocks production will require a faster production rate or longer production time.

On a hydraulic press, it is difficult to run faster. It is possible to cut a few seconds on some actions, but overall, it is difficult to make a hydraulic press hurry. In this case, increasing production time may be an option if there is time available.

A vibrocompactor offers more possibilities. It is possible to cut a bit the vibration time and to compensate by increasing vibration energy, by modifying eccentrics adjustment. Just keep in mind that total amount of energy provided to the anode block by vibration has limits. Too much energy may end up cracking the block [20]. Correction strategies are available if required.

Check if conveyors at forming equipment can cope with faster production rate.

Producing anode blocks at a faster rate will also have an effect on green anodes cooling [21]. Air cooling would require more space. Check if there is any available. Water cooling by total immersion will also be affected. Total heat transfer to water will increase. The water-cooling system has to have extra capacity or should be upgraded. Water spray cooling offers more flexibility. Water spraying time may be increased to cope with a shorter period in cooling area. Be aware that too drastic cooling may cause lens shape cracks inside carbon blocks, undetectable from outside.

Producing more anodes also implies that storage areas, if not increased in size, will provide a smaller protection time buffer.

2.2.2 Producing Bigger Anodes

Producing bigger anodes does not increase production time, except for a bit longer filling time of forming equipment.

On a hydraulic press, production of higher anodes is usually not an issue. Producing wider or longer anodes requires, if design of mould does not allow it in the beginning, replacement of mould and top former by new ones. Depending on press design, this may even lower press rated capacity, because mould walls would be thinner, hence less resistant to pressure.

Vibrocompactor, like a hydraulic press, usually allows for higher anodes without problems. Producing wider or longer anodes may be possible if mould design allows adding spacers. If not, mould has to be replaced with a mould with new anode dimensions. As width of mould is usually the position where hydraulic latches lock mould with vibrating table, attention should be given to hydraulic latches to fit correctly with new mould. New mould may require modification on vibrating table for fitting between both of them to be correct.

Counterweight also has to be modified for the top of anodes to fit with new anode design. It also has to be adjusted in weight to keep the ratio of counterweight to vibrating table + mould + anode weight around one.

Conveyors following forming equipment have to be checked for interferences with height, width and length of anodes. This includes cooling trays.

Producing bigger anode blocks will have an effect on green anodes cooling. Effects will be similar to those described in the previous section. Trying to cool faster may result in internal cracks of anode blocks. These cracks are invisible from outside. This may create out of schedule anodes in potrooms. The anodes will split in two parts in pots.

Packs of heavier green anodes handled by stacking cranes may surpass stacking cranes weight capacity. Check with manufacturers of handling cranes. Cranes may be retrofitted with sturdier handling equipment to compensate for heavier loads. Bigger anodes may require to modify stacking configuration to take care of larger dimensions. This may end up with smaller storage capacity, and smaller protection time buffers.

2.3 Anode Baking

2.3.1 Baking More Anodes

There are four ways to bake more anodes in an anode centre.

The first one, the most widespread, is to speed up firing cycle [22]. It is inexpensive in capital, but have some drawback. Faster baking cycle gives a less uniform baking. The coking value of pitch also lowers a bit and gives a little bit less dense anode. This is usually not an issue. It also supplies a little bit more fuel from anodes, the part of pitch that does not coke in anodes. Better flue wall design can partly or totally alleviate non-uniform flue gas distribution.

More fumes have to be treated at fumes treatment centre. Fumes treatment centre may be limited. This may be partly countered by switching from bag filters to cartridge filters. This adds airflow and adds filtering surface if fumes treatment centre is not already on cartridge filters.

Cooling time would be shorter. Cooling time may be used more efficiently by increasing cooling air throughput in flues. But this may result in more packing coke oxidation through degassing slots infiltration. Packing coke oxidation causes reheat, instead of cooling, and also causes CO and SO_2 production from packing coke. This tendency would be increased further because of higher levels of nickel and vanadium, two well-known oxidation catalysts, in packing coke over last decades. Levels of CO and SO_2 in furnaces building requires use of respiratory protection. CO poisoning may occur with crane operators in their crane cabins, causing heavy headaches. CO monitoring devices start to be installed in crane cabins.

Water injection in flue walls has already been tested and used for some time [23]. This results in improved anodes cooling. But using water injection in flue walls also results in flue walls degradation, specifically by causing thermal shock in bricks, and large vertical cracks, on each side of water injection position.

A second option is to increase baking furnaces capacity, in same concrete shell, by removing head walls [24]. This option is not widespread, but can be looked at. This allows more anodes in pits, not requiring faster baking cycle.

A third option, more capital intensive, is to lengthen an existing baking furnace. This means adding one more fires in the same furnace. There should be enough place, in line with existing furnace building to increase furnace length. Baking treatment centre should have enough capacity to handle extra baking fumes added by an extra fire. Otherwise, the scrubber has to be upgraded to handle it. Cranes should have enough time to handle extra anodes. Otherwise, an additional crane should be added. Green and baked anodes conveyors have to be able to handle extra anodes traffic.

A fourth option, a lot more capital intensive, is to add a brand-new baking furnace.

2.3.2 Baking Bigger Anodes

Bigger green anodes will be heavier. Lifting capacity of furnace cranes may limit weight of green anodes pack to be handled. Check grabs weight capacity to be sure not to surpass it. Check girders capacity in all axes to make sure not to go over their rated capacity. If weight is excessive, contact crane manufacturers to assess if cranes can be upgraded to lift heavier packs

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Check also stacking crane lifting capacity.

Higher anode blocks is the easiest change to cope with in baking furnaces. Stacked blocks position in pits stays essentially the same (Figure 2). Except for blocks to flue walls distance. It is not a problem when this distance is above approximately 60 mm. Below approximately 60 mm, two problems may occur:

- Tar fumes may be released from blocks before temperature inside flues is above auto-ignition temperature of tar fumes. Tar fumes will not burn and will condense in exhaust manifolds, ventilation ducts around furnaces and even in scrubbers. This may cause a fire hazard. Two solutions have been tried with some success:

  - Decrease flue walls side bricks width, so total width of flue walls in thinner. This works, but flue walls are more sensitive to bowing. More tie bricks may help raise flue wall rigidity.
  - Reduce flues width inside flue walls. This reduces the flue wall thickness, at the expense of a higher air flow resistance.
- Packing coke will start coating flue walls surface, and sometimes blocks. This is caused by tar fumes coking in packing coke. This may end up blocking degassing slots, so furnace fumes may come out in furnace building, and interfere in loading or unloading anode blocks packs. Scraping flue walls may help. Equipment was designed and built to do that. Or it can be done manually. If packing coke coating is not removed, it tends to become harder, as more tar cokes inside coating, thus increasing removal difficulty.

With higher anodes, the height of stacked anodes in the storage area will also rise. Clearance between the top of stacked anodes and stacking cranes may become too small, cause interference and occasional bumping, which will cause packs to collapse. Number of stacked anodes rows may have to be lowered to get higher clearance, which will lower safety time margin significantly. Modifications on stacking cranes may be required to keep the number of stacked anodes the same.

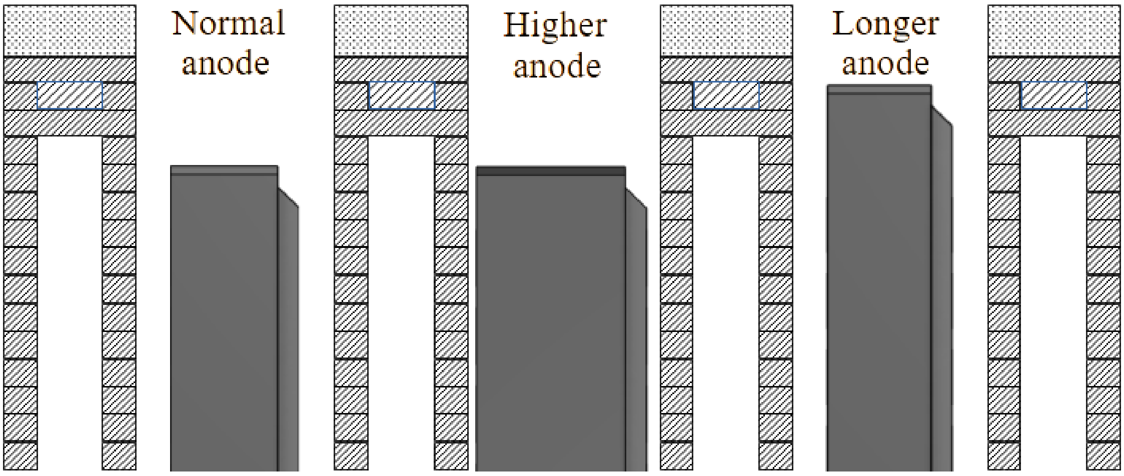

Figure 2. Effect of change of dimensions on anode piling in furnace pits.

Larger anodes do not influence the heat transfer. The larger anodes mean longer anodes pack to be loaded. Cranes grabs may have difficulty to handle longer packs (Figure 3). This also means smaller distance between packs and headwalls. There may be an interference with suction pipes and filling pipes. It is possible to manufacture thinner suction and filling pipes, but they will bend more easily. That can result in higher repair rate.

In storage area, wider anode packs may be difficult to handle by stacking cranes, depending on how grabs take anodes packs. This may require to modify or change grabs. Larger packs in storage may not fit in existing storage space. This may require removing an anode from the pack to fit.

Longer anodes packs do not change anything for furnace cranes. But piling longer anodes packs may result in top pack being outside heating zone of flue walls (Figure 2). This will increase temperature variations in baking. The top row of anodes may even degas inside furnace building. This may be compensated a few ways:

- Non heating zone of flue walls top may be shortened by making the solid top of the flue walls thinner.
- The bottom of the pits may be modified to lower it a bit, but not too much, or else this will cause another non-heating zone [25].

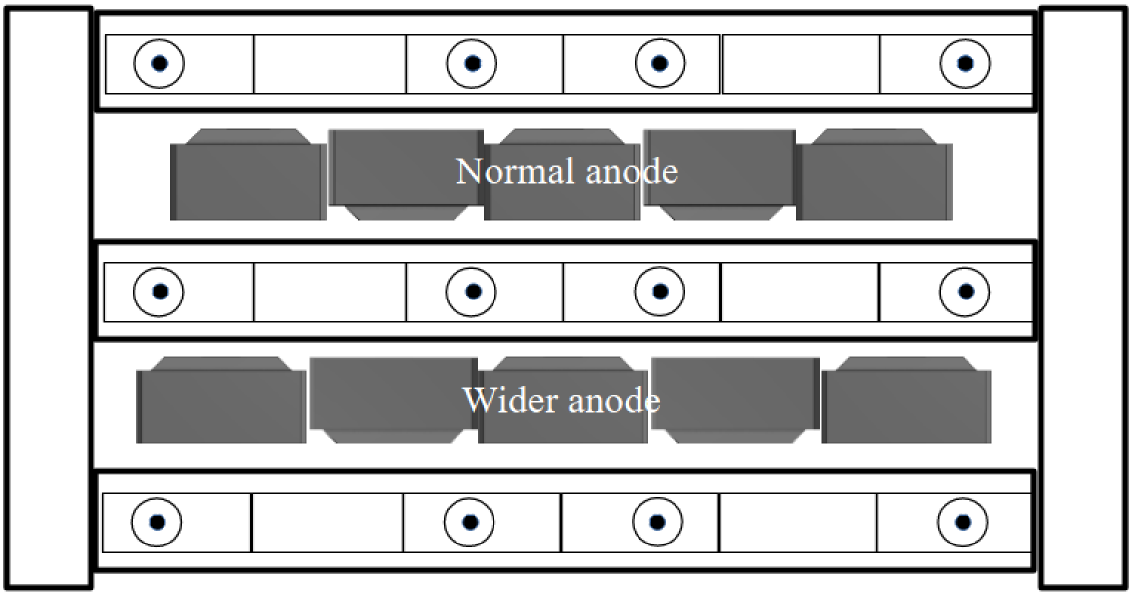

Figure 3. Effect of anode width on end gaps used for the anodes and packing coke handling in furnace pits.

- Packing coke bedding at bottom of pits, if present, can be reduced or completely removed. To avoid anodes sticking to bottom tiles, a layer of cardboard may be added as bedding instead of packing coke.
- The top row of anodes may be installed sideways instead of vertically. This implies modifying crane grabs or having another way to handle this layer of anodes.
- If clearance between crane tools and the top of the furnace is large enough, the top of the furnace may be raised to enlarge heating zone of flue walls [25]. This means higher flue walls. Changing all flue walls may take a long time if this is done on a replacement basis. Complete change of flue walls is costly. Modifying existing flue walls by adding a few rows of refractory bricks may be considered. But some flue walls may be damaged during conversion. Modifications and repairs may be extensive for some flue walls.

Again, in storage area, longer anodes packs may be difficult to handle by stacking cranes, depending on how grabs take anodes packs. This may require to modify or change grabs. Longer packs in storage may not fit in existing storage space. This may require changing anode packs arrangement to fit. And this usually results in a reduction of storage capacity.

2.4 Anode Rodding

2.4.1 Buying Anodes from an Outside Suppliers

If internal production of carbon blocks is not sufficient, buying carbon blocks from outside suppliers may be an option. Buying from outside suppliers involves:

- Receiving anodes: This is usually done by boat, when there is a harbour nearby. If not, railway maybe an option. Great care should be taken to avoid exposing carbon blocks to humidity during unloading and transportation to storage, to avoid possible explosion when rodding with molten cast iron.
- Storing anodes: If delivering is not done on a just-in-time basis, storage of a large quantity of carbon blocks is required. If entering outside anodes was not thought of at carbon plant design, there may be no space inside carbon plant to store large quantity of anodes. A

storage place outside carbon plant may be rented, bought or built and a regular transportation system devised to feed carbon plant on an as-needed basis.

- Feeding anodes to anode plant: Anode plants may not have been designed to receive anodes from outside sources. Receiving facilities may be absent or lacking. This requires a lot of thinking to see how to receive these anodes without disturbing current carbon plant operations.

Keep in mind that receiving anodes may be required for other reasons than amperage increase. Green mill maintenance or upgrade, or baking furnaces rebuild are the most common reasons to receive anodes for anode plants use. This may also involve building inventory of green or baked anodes for reasons described earlier. Import installations may be used to export anodes first. So having this type of installation may be interesting and they should be maintained or moth-balled, not dismantled, even if they are not used.

2.4.2 Rodding More Anodes

Producing more rodded anodes involves either producing more time within a week, if there is some available, or producing faster. This later case means shortening production cycle by shortening equipment cycle and/or increasing conveyors speed. Both cases involve contacting equipment suppliers to see if cycle time and/or speed can be increased. If not, equipment may have to be modified or replaced.

Both cases imply producing more cast-iron. If capacity of induction furnaces crucibles allows it, increasing batch size may be possible. Cast-iron level should stay in active heating zone of induction furnace.

Melting cast iron faster is also an option, by increasing the power transfer to cast iron if induction furnaces power supplies allow it. This will cause more turbulence in melting furnaces. That may shorten refractory life spans and requires faster induction furnace refractory rebuild.

Number of cast-iron batches can be increased if time allows it. This will not cause a faster wear of refractory, but producing cast-iron batches faster will require faster induction furnace refractory rebuild.

Rodded anodes storage may have to be increased. If not, buffer time to take care of rodded shop problems and maintenance will shorten. Think of upgrading maintenance crew and maintenance equipment. Think also of keeping bigger spare parts inventory or keep them nearer to the plant.

2.4.3 Rodding Bigger Anodes

Rodding bigger anodes does not require more cast-iron.

Bigger anodes mean heavier anode assemblies suspended on power and free conveyors. These conveyors may not have been designed for such a mass, especially in accumulation zones. Design with new weight should be submitted to engineering firms or manufacturers for verification.

The bigger anodes again mean heavier weight on rodded anode trays and heavier weight to be handled by tray transporters. Design with new weight has to be checked.

Higher anodes mean lower anode assemblies bottom on power and free conveyors. This may interfere with some equipment and/or rodded anode tray filling. Adjustments may have to be made to eliminate problems.

Larger anodes are usually not a problem. But check if rodded anode trays will be able to take it.

Longer anodes may cause problems if their length is longer than power and free chariots. The problem will be specifically in accumulation zones (Figure 4). This may require to lengthen power and free chariots.

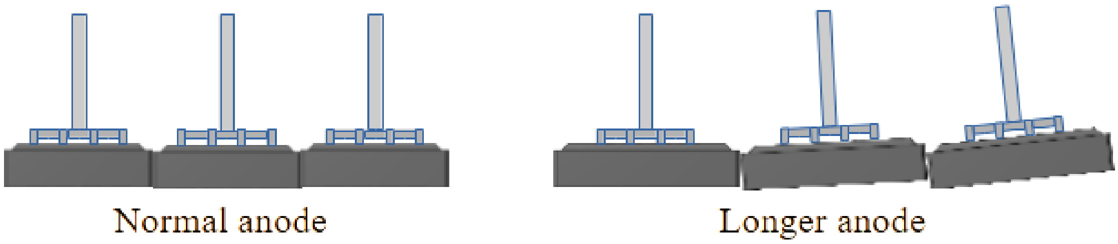

Figure 4. Effect of anode length on rodded anode placement if power and free conveyor chariots are not adjusted for the new anode length.

Again, check if longer anodes will cause problems when filling rodded anode trays.

2.5 Butt Treatment

2.5.1 Treating More Butts

More butts to treat means more butts to cool, hence more fluorinated fumes evolving to the atmosphere. If a fluorine treatment centre is present, check if its capacity will be sufficient. If no fume treatment centre is present, check local regulation to see if new level of emissions will not be higher than what regulation allows.

With more butts to cool, it may be required to add butt storage. If storage is not increased, buffer time for butt treatment problems, break down and maintenance will shorten. In this case, think about upgrading maintenance crew and maintenance equipment. This may also require to have more spare parts available locally to shorten repair time.

If butt storage cannot be enlarged, this may result in shorter cooling time for butts. Hot bath is harder to remove. Bath removing equipment may have difficulty to cope with it. If this is problematic, look into improving bath cleaning equipment.

Hot bath on rubber conveyor belt may cause fire. See if fire extinction system on conveyors is adequate to cope with it. If not, think about improving existing one or install one if not already present.

Bath crushing system may have difficulty to handle more bath and/or hotter batch. It would be wise to check its capacity for both throughput and temperature.

More butt-cleaning waste will be generated. See if it is possible to dispose of it safely and in a way that comply with local environmental regulation.

Tonnage of cast iron to be cleaned will also increase. Cast-iron cleaning system should be able to take extra without lowering cleanliness of cast iron. Or else, there will be more slag shovelling on top of molten cast iron and shorter refractory life of cast-iron melting furnace, both because of sodium from bath. Because sodium will lower refractoriness of furnace lining.

Butt crushing system should be able to take extra tonnage. If it is a unique equipment, its maintenance will become even more crucial. If crushed butt storage is not increased, buffer time between green mill and butt treatment plant will lower and may cause shut down because it is empty or full. Manage it carefully.

2.5.2 Treating Butts of Bigger Anodes

As the number of butts to be treated will not change significantly, butt treatment centre should not be impacted. But bigger out of schedule anodes may be an issue that has to be looked at, to see if butt treatment equipment is able to cope with it.

3. Special Cases

There are a few cases that are not considered putting more carbon in pots that should also be considered. They are not common, but some users may encounter them:

- Asymmetrical anodes;
- Having to enlarge steel stub diameter on anode rods;
- Having to add new steel stubs on existing anode rods.

In cases of anode rods modification, plants have to use existing green and baked anodes inventory before implementing changes

3.1 Asymmetrical Anodes

Asymmetrical anodes are longer anodes designed to exploit unused pot space to fill it with carbon and reduce anode current density. Some unused space is usually in central passage of the pot. Using the available space in the centre channel, and the same amount in the sidewall channel, keeps the anodes symmetric. Any additional length can be added only in the sidewall channel, which makes anodes asymmetrical with respect to anode rods. Great care should be taken to allow enough space in the centre channel for breaker-feeder operation. There are limits also in the side channels; too narrow side channels, may cause difficulties in positioning of new anodes as anodes may sit on the freeze, but in any case, too narrow side channels are prone to accumulation of carbon dust and crust which can cause anode spikes at outer edge of the anodes. Anode yoke can also be made asymmetrical to distribute the current more uniformly in the anode. Figures 5–7 show examples of asymmetrical anodes and yoke.

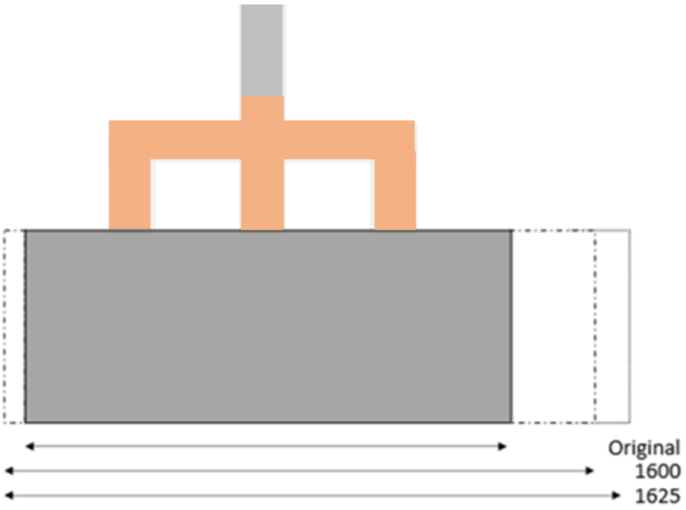

Figure 5. Asymmetrical anode design at TRIMET with the original yoke and stubs [26].

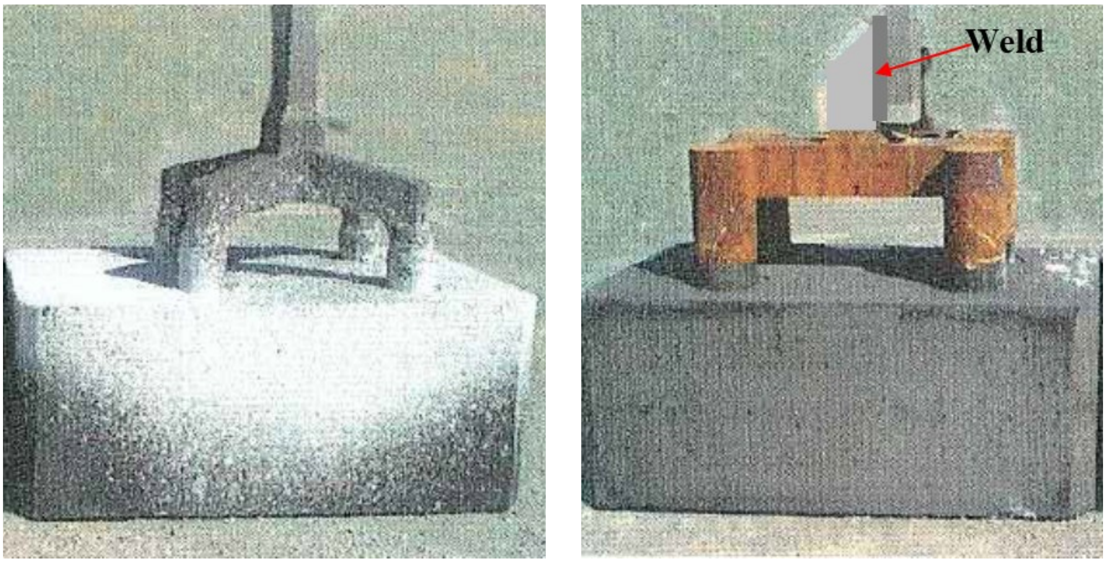

**Figure 6. Asymmetrical Sumitomo anode at Boyne Smelter Limited (BSL).
Left: symmetric yoke and asymmetrical anode before upgrade.
Right: symmetrical anode and asymmetrical yoke after upgrade [27].**

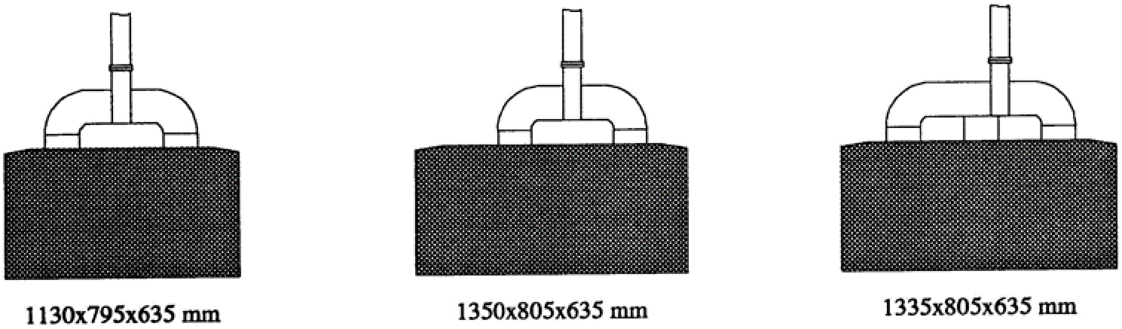

Figure 7. Original anode (left), asymmetrical anodes with original yoke (centre) and with asymmetrical yoke (right) [28].

Manufacture of asymmetrical anodes in green mill and baking is quite straightforward. It is similar to longer anode, except for stub holes position on the anode.

There are two types of equipment to be added because of eccentricity of stub holes. An anode turner has to be added before rodding, to present the anode always in the same position at rodding station. And an anode rod turner has to be added at butt reception, again, to present butt in same position at cleaning and stripping equipment. Asymmetrical anodes present some challenges in potrooms, when anodes have to be inserted in pots, in correct position. Large asymmetry of anode block with respect to the yoke is susceptible to breaking off the outer, longer part on anode butts. Also, the introduction of longer and asymmetrical anodes may cause other problems in pot operation [26].

3.2 Changes on Anode Rods

If current density through stub holes is too high, this may cause overheating of steel stubs and carbon surrounding stubs. This generates heat at a place where it is not desired. To reduce ohmic resistance, current density should be lowered. Two ways can be considered:

- Increasing steel stub diameter;
- Increasing number of steel stubs.

Both solutions require changes in anode stub holes and substantial modifications to steel part of anode rods.

As described earlier, all inventory of previous design anodes should be consumed before implementing new anode rod design.

3.2.1 Bigger Diameter Steel Stubs

Clearance between steel stubs and carbon side of stub holes has to stay within a range that does not cause thermal expansion problems, causing out of schedule anodes [29].

And during the interim period, rodding department will have to produce a significant amount of cast iron to fill the larger gap between steel stubs and carbon side of stub holes. This interim period would last a bit more than an anode change cycle in potrooms, approximately a month. This may cause productivity problem in production of cast iron and this would slow down production during that time. And after the interim period, rodding plant will be stuck with a significant excess of stripped cast iron. Plan for reuse or responsible disposal.

As stub diameter will be bigger, equipment using steel stubs one way or another during cleaning and stripping, will have to be modified for bigger steel stub diameter.

3.2.2 More Steel Stubs

Adding steel stubs to anode rods requires to add more stub holes on anodes [29]. During interim period additional stub holes will have to be filled to avoid significant sodium contamination of butts by bath and more reactive anodes. To solve this problem, best choice is to fill unused stub hole(s) with a filler. Calcined petroleum coke does fine. Although there is some bath infiltration through calcined coke, it is an economical solution, easy to implement. Other fillers may be considered that may do best, each plant has to assess their situation to choose what fill the best their needs.

During the interim period, quantity of cast iron will not change. When new anode rod design starts being implemented, a larger amount of cast iron will have to be produced. During implementing period, a large amount of new cast iron will have to be bought and melted. After implementation, more cast-iron will have to be produced on a permanent basis. See if existing cast-iron production equipment and personnel will be able to follow. See Section 2.4.2 Rodding More Anodes for modifications in cast-iron production that can be looked at.

4. Increasing Anode Density

Another way to put more carbon in pots is to increase anode density. This implies to optimize the production process, mostly in green mill, to pack more carbon in the same volume. The following list of possible actions will be obvious to most experienced process engineer.

4.1 Green Mill

4.1.1 Aggregate

Starting with dense particles is an obvious step to make a dense anode. There are roughly three possible actions to increase density through particle density:

- Buy dense coke if available;
- Classify coke to keep dense particles as aggregate and send light particles to ball mills to be crushed, eliminating porosity. This step requires to use one or two coke density classifiers [30];
- Use more butt, if it is possible to get some. Just keep in mind that butt is usually polluted with sodium coming from the bath. Anode densifies at the expense of carbon dioxide reactivity. If bath pollution is low, overall, the deal may be positive [31].

A current trend is to use finer fines to get some density [17–19]. But this can be taxing for ball mills. The finest the final fine product, the smaller the throughput of ball mills. Final throughput may not be sufficient to supply existing or future needs of paste plant.

4.1.2 Binder

It is possible to use binder with a higher coking value. High softening point may be used for this purpose [32]. But, as its name specify, high softening point softens at higher temperature. This requires more heating to unload, to convey and to store pitch. Aggregate has to be heated at higher temperature, mixing and forming also have to be made at higher temperature. The heating system of paste plant has to be able to work at higher temperature than normal softening point pitch.

4.1.3 Process – Binder

Running paste manufacturing at optimal binder level ensures highest density. Three strategies may be used to run at optimal binder content:

- Raw material properties equations, an equation is devised to relate some raw material equation with optimal binder level. After that, regular measurements of these properties allow plants to set optimal binder level. This strategy works only with slow variations of raw materials properties, single binder sources and a single or a mix of two stable proportions calcined coke [33].
- With a large inventory of raw materials, an evaluation of optimal binder level can be achieved and be kept for the duration of inventory of tested raw materials.
- With rapid variations of raw materials and/or rapid variations of proportions of mixed raw materials, a real-time binder optimization algorithm can be used. This strategy is not widespread, although it is used successfully for a long time in at least one plant [34].

4.1.4 Process – Mixing/Cooling

Mixing and cooling may increase paste density by adding more energy per tonne of paste [35]. Energy is transferred through higher shear force on the paste in mixers or coolers. Higher shear can be achieved by increasing shear in paste, like by using rough surfaces on mixing tools. Rough surface ensures that paste will not glide on tool surface. Paste sticks to rough surface causing increased shear on paste, which promotes better packing of particles.

4.1.5 Process – Forming

For hydraulic press, raising forming pressure on the anode block is possible, but risky. Cracking may occur if pressure produce stresses in the anode that exceed retaining forces induce by binder [20]. Adding vacuum to hydraulic press improve density and allows for higher forming temperature.

For vibrocompactor, there are four ways to improve density:

- Increase in energy, by increasing vibrating table asymmetrical forces;
- Increasing energy transfer to block by increasing vibration time;
- Add vacuum, this increase density and allows for higher forming temperature;
- Add counterpressure on counterweight.

Again, if internal stresses, induced by forming, exceed retaining forces induced by binder, cracking will likely occur.

4.1.6 Process – Baking

Fast baking tends to lower anode baked density, not by much, but enough to be measurable

To increase baked density in baking, one should bake slowly, to allow time for binder to coke inside the anode. If not larger part of binder will evolve as volatile.

Be aware that very high green density anode may crack in baking. This is caused by internal pressure created by binder coking. If there is not enough open porosity to allow volatile evolving from binder cooking to come out of the anode, there is pressure buildup inside anode leading anode to crack to create pathways for volatiles to escape. Volume of volatiles produces by a cubic metre of the anode is surprisingly high. Ballpark estimate gives an idea. If all volatile come out as CH_4, a cubic metre of anode gives about 76 m^3 of CH_4 (Tables 3a and 3b). If all volatiles come out as H_2, it gives about 610 m^3 of H_2 (Tables 3a and 3c). As part of volatiles comes out as tar fumes, real quantity of volatiles is probably between 50 m^3 to 100 m^3, a significant quantity of volatiles to evacuate in a relatively short period of time, even if estimate is rough. So open porosity should be provided to help with volatiles escape. See reference [36] for an example of changes in anode composition to produce more open porosity.

Table 3a. Volatile weight evolving at baking.

Anode green density (g/cm^3)	Weight 1 m3 anode (kg)	Binder level (%)	Plant coking value of binder (%)	Volatile evolving from binder	Weight volatile (kg)
1.615	1615	13.5 %	75 %	25 %	54.5

Table 3b. Volatile volume if 100% is CH_4.

Molecular weight of CH_4 (g/mol).	Volume* of CH_4 per mol (L)	Weight volatiles, from Table 1a (g)	Volume* of CH_4 (L)	Volume* of CH_4 (m^3)
16	22.4	54 500	76 300	76.3

** Under normal temperature and pressure conditions, 0 °C and 101 325 Pa*

Table 3c. Volatile volume if 100 % is H_2.

Molecular weight of H_2 (g/mol).	Volume* of H_2 per mol (L)	Weight volatiles, from Table 1a (g)	Volume* of H_2 (L)	Volume* of H_2 (m^3)
2	22.4	54 500	610 400	610.4

** Under normal temperature and pressure conditions, 0 °C and 101 325 Pa*

5. Conclusions

To allow potrooms to produce more aluminium, either by current increase, additional pots or potlines, anode centre should increase its production by either production of more anode blocks, bigger anode blocks or/and denser anode blocks.

This requires additional raw materials and may require more production time or faster production rate. This may also ask for modifying existing equipment to produce, convey, store, bake, rod more, bigger or/and denser anodes and clean and strip more or/and bigger butt.

This requires careful assessment of existing plant equipment to see if it is fit to handle new requirements. If not, it has to be determined if it can be modified to fit new requirement. If not, it may be necessary to replace it with new equipment designed to fill the new requirement.

This process is rarely simple. It requires time, expertise and adequate funding, especially if the anode plant was not originally designed to be upgraded.

6. References

1. O. Martin, R. Gariepy, G. Girault, APXe and AP60: The new references for low energy and high productivity cells, *Proceedings of the 11th Australasian Aluminium Smelting Conference*, Dubai UAE, 6-11 December 2014, Paper 40Th9.
2. Abdalla Al Zarouni, Lalit Mishra, Nadia Ahli, Marwan Bastaki, Amal Al Jasmi, Alexander Arkhipov and Vinko Potocnik, Energy and mass balance in DX+ cells during amperage increase, *Proceedings of 31st International Conference ICSOBA and 19th International Conference "Aluminium of Siberia"*, 4-6 September 2013, Krasnoyarsk, Russia, *Travaux* 42, 494-499.
3. Abdallah Abdelrahman Rahbar et al., Potlines extension project at EGA Al Taweelah smelter, *Proceedings of the 40th International ICSOBA Conference*, Athens, 10 - 14 October 2022, Travaux 51, 1029-1038.
4. Michel Reverdy et al., The successful implementation of DUBAL DX+ technology at EMAL, *Light Metals* 2016, 307-311.
5. Abdulla Habib and Jean-Francois Riverin, Commissioning and start-up of Alba Line 6 Project using EGA DX+ Ultra Technology, *Proceedings of the 37th International ICSOBA Conference and XXV Conference «Aluminium of Siberia»,* Krasnoyarsk, Russia, 16 – 20 September, 2019, *Travaux* 48, 831-841.
6. Claude Vanvoren, Jean-Michel Peyneau, Michel Reverdy and Jérôme Bos, The Dunkirk Smelter, From 216 to 257 kt/Year Through 10 Years of Technology Creeping and Continuous Improvement, *Light Metals* 2003*,* 185–192.
7. K.J. Driscoll and D.L. Moison, Capacity Creep - The Hidden Potential Growth of Aluminium Smelting Capacity, *Light Metals* 1997, 259–264.
8. Jean-Claude Fischer, Raymond Perruchoud, Markus Meier, Werner Fischer, René Von Kaenel, Jacques Antille, Louis Bugnion, Anode management Options during Smelter Capacity Creep, *Proceedings of the 11thAustralasian Aluminium Smelting Technology Conference,* 6-11 December 2014, Dubai, UAE, Paper 38Key8.

9. Dave Glover, Capacity Creep Considerations for a Typical Carbon Plant*, Proceedings of the 8th Australasian Aluminium Smelting Technology Conference and Workshop,* 3-8 October 2004, Yeppon Australia, Paper 6.03.
10. Bill Woodworth, Vis Naidoo, Jessica Rouse and Lloyd Butler, Overcoming challenges presented by production creep to carbon baking, *Proceedings* of the 10th Australasian *Aluminium Smelting Technology Conference,* 19-14 October 2011, Launceston Australia, Paper 2d1.
11. Bénédicte Champel and Nicolas Monnet, Maximizing Creeping Value through Rigorous Methodology, *Light Metals* 2013, 641–646.
12. James Anson, René Trudel, and Bertrand Vincent, The Impact of Increased Anode Size and Amperage Creep on Anode Management, *Light Metals* 2017, 1385–1394.
13. Christophe Bouché, Bertrand Somnard and Pasquale Calo, Opportunities and Challenges Associated to Green Anode Plant Upgrade for Smelter Amperage Creeping, *Light Metals* 2018*,* 1425–1432.
14. Paul Harry and Alan Tomsett, Electrode Plant-Larger Anode Assembly Project, *Light Metals* 2017*,* 1015–1020.
15. Khalil Khaji and Hameed Abbas, Baked Anode Density Improvement through Optimization of Green Anode Dry Aggregate Composition, *Light Metals* 2010, 1027–1030.
16. Bienvenu Ndjom et al., Improving Baked Anode Density and Air Permeability through Process Optimization and Coke Blending, *Light Metals* 2013, 1105–1110.
17. Francisco E.O. Figueiredo et al., Finer Fines in Anode Formulation, *Light Metals* 2005, 665–668.
18. Alireza Fardaru, Mohsen Ameri Siahooei and Borzu Baharvand, Study Finer Fines in Anode Formulation (Case Study: Almahdi Hormozal Aluminium Smelter), *Light Metals* 2019, 1345–1350.
19. Frank Cannova, Mike Davidson, Roberto Marquez and Barry Sadler, Influence of coke source and calcining technology on superfines and blended coke grindability, *Proceedings of the 11th Australasian Aluminium Smelting Technology Conference,* 6-11 December 2014, Dubai, UAE, Paper 05M3.
20. Yvon Menard, Prebaked Anodes Cracking at Forming - Reasons and Solutions, *Proceedings of 35th International Conference of ICSOBA,* 2-5 October 2017, Hamburg, Germany, *TRAVAUX* 59, 665–672.
21. Werner K. Fischer, Marcus W. Meier, and M. W. Lustenberger, Cooling of Green Anodes After Forming, *Light Metals* 1999, 547–554
22. Alan D. Tomsett, Increasing Anode Baking Furnace Throughput, *Proceedings of the 9th Australasian Aluminium Smelting Technology Conference,* 4-9 November 2007, Terrigal, Australia, Paper 36.
23. Don N. Holdner and André L. Proulx, Water Additions to the Cooling Sections of Horizontal-Flue Ring Furnaces, *Light Metals* 1981, 597–610
24. Arnaud Bourgier et al., Development of a New Baking Furnace Design Without Headwall to Increase Anode Production Capacity, *Light Metals* 2019, 1257–1268
25. Pragasan Palavar et al., Baking Furnace Rebuild Strategy at DUBAL to Improve Productivity, *Light Metals* 2015, 1109–1114.
26. Matthias Dechent, An Anode Crisis – The Pitfalls of an Anode Length Increase, *Proceedings of the 41st International ICSOBA Conference,* Dubai, 5 - 9 November 2023, *Travaux* 52, 1375-1385.
27. Paul Harry and Alan Tomsett, Anode plant – Larger anode assemblies project, Light Metals 2007, 1015-1020.
28. M. R. Dunn, B. Allison and T. W. Hall, Three Stub Anode Retrofit, *Light Metals* 1993, 671–675.
29. M.D. Ohlswager, G.E. Goeres and R.W. Peterson, Anode Cast-Iron Thickness Optimization, *Light Metals* 1990, 499–503.

30. Marie-Josée Dion, Cyril Gaudreault, and Yvon Ménard, Calcined Petroleum Coke Density Separation Process: Solution to Maintain Anode Quality with Degrading Coke Density, *Light Metals* 2015, 1039–1044.
31. Binuta Patra, Studies on Influence of Recycled Anode Butts on Properties of Prebaked Anodes used in Aluminium Electrolysis, *Proceedings of 39th International ICSOBA Conference, Virtual,* 22-24 November 2021, *TRAVAUX* 50, 605-613.
32. Thomas A. Golubic, Stacey A. McKinney, and Robert H. Wombles, High Softening Point Pitch as Anode Binder Pitch, *Light Metals* 2010, 909–912.
33. André L. Proulx, Optimum Binder Content for Prebaked Anodes, *Light Metals* 1993, 657–662
34. Alexandre Gagnon, Yvon Menard et al., Determining dosing of binding agent for combining with particulate material to produce an electrode, *Word Property Organization Patent Application* WO 2016029306 A1, filed 25 August 2015, published 3 March 2016.
35. P. Stokka, Green Paste Porosity as an Indicator of Mixing Efficiency, *Light Metals* 1997, 565–568.
36. Bienvenu Ndjom et al, Challenges and Opportunities of Vacuum Compaction: Lessons Learnt from Retrofitting EGA-JA Paste Plant to Vacuum Compaction, *Light Metals 2019*, 1213–1220.