ANODE BAKING: THE UNDERESTIMATED HUMAN ASPECT

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Abstract

In the framework of carbon plant auditing R&D Carbon Ltd. had the opportunity to investigate the operation of many different anode bake furnaces. As a striking result significant differences in the performance of bake furnaces with similar design were identified. Avoidable direct annual losses of one million USD and more per 100.000 tons of baking capacity have been identified. These direct costs do not take any indirect losses in the smelter into account, which result from substandard anode quality and which can easily be two to three times higher than the direct losses.

Most of the problems creating financial losses could have been avoided. The key question, therefore, is why were these opportunities not explored?

We identified four main reasons creating these losses:

- No well-defined objectives and goals set.
- Persisting errors regarding the anode baking process and misunderstanding of cause-effect chain.
- Organizational and motivational aspects underestimated.
- Inadequate data and information presentation.

Propositions are made, how losses can be avoided and how management can react in order to optimize bake furnace efficiency while minimizing cost.

Introduction

In the framework of carbon plant auditing our company was in the opportunity to investigate and to compare the operation of a number of anode bake furnaces. As an unexpected and striking result we identified significant differences in the performance of bake furnaces with similar physical properties. Standardized on a furnace with a capacity of 100.000 tons per year we identified an annual avoidable cash drain in the order of magnitude of one million USD per year. This figure includes only direct costs and does not take into account any collateral damage in the electrolysis, caused by substandard anode quality triggered by poor anode bake furnace operation. Unsatisfactory anode quality can easily generate extra losses in the order of 2 – 3 million USD per 100.000 tons bake furnace capacity per year. In analyzing the situations encountered, it could be shown that most of the cash drain could be stopped on short notice and at a reasonable cost. The key question is now why these business opportunities are not explored by the plants in question. In analyzing the available information we identified four main reasons responsible for not curing substandard bake furnace operation:

- No well-defined objectives and goals set.
- Persisting errors regarding the anode baking process and misunderstanding of cause-effect chain.
- Organizational and motivational aspects underestimated.
- Inadequate data and information presentation.

This paper will provide the information required for assessing furnace operation against best figures reached over extended periods of time in smoothly operated furnaces.

Bake Furnace Targets

The targets will be given for an open top, gas fired ring type furnace, (Figure 1) built for the baking of carbon anodes in a weight range of approximately 1000 – 1500 kg, with petroleum coke as packing material.

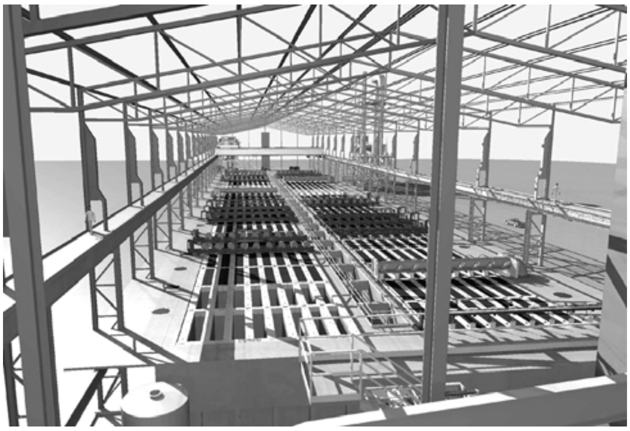

Figure 1: Artist's impression of an open top ring type furnace as defined for the targets to be given

For optimum furnace operation two different categories of targets have to be considered:

- Targets linked to the anode quality
- Targets linked to the bake furnace operation and maintenance

Ranking of the two categories regarding importance is as shown in the listing. Any anode quality deficiency offers the greatest risk regarding collateral damages through sub-optimum smelter operation. Operational deficiencies will mainly result in collateral damages in the fields of energy consumption, production losses, environmental impact and plant safety.

The categories mentioned are not completely independent of each other. As an example, furnace design has an impact on anode quality, on furnace operation and on furnace maintenance as well. Furthermore, it may make sense to accept sub-optimum anode bake furnace operating conditions if the related disadvantages are overruled by advantages in reduction plant operation. After all, what counts is minimizing metal production cost, and not anode baking cost minimization.

Even taking these difficulties into account, it makes sense to establish a set of targets defining an ideal anode bake furnace operation. If in a given situation one or more targets have to be modified then this can at least be done based one decision on purpose.

Two sets of targets will be presented and as far as possible quantified:

- Anode quality targets.
- Bake furnace operation and maintenance targets.

Anode Quality targets

To a certain extent, anode quality is a function of the raw materials used. With typical anode grade petroleum coke processed in a properly operated furnace, anode quality targets as shown in Table 1 can be reached.

Note that for all anode properties not only the *average* but the *variation* has to be considered as well. Experience has shown that in bake furnace operation focusing on anode properties *variation* may be a smarter and cheaper approach in improving anode quality than undertaking efforts in pushing the *average* or mean value. Furthermore, baked anode quality is also a function of green anode quality. If baked anode quality is substandard, it is always worth checking if “garbage in – garbage out” might be one of the reasons. Summarizing, not reaching all targets as given in Table 1 for the mean as the 2σ should always be a reason for starting an investigation.

Bake Furnace Operation Targets

Once the quality targets have been agreed upon, it is the job of operation to realize all the goals regarding production quality, quantity, environmental impact and cost. It is in this field where the human aspect plays an important role. Through investigations, furnaces similar in each and every aspect as, e.g. design, firing and anode handling equipment and process automation level were identified. Yet significant differences in bake furnace performance have been identified. In the paragraphs below, targets are listed based on shortcomings observed that will hamper optimum furnace performance. The list may not be exhaustive; however these targets have to be fulfilled anyhow if optimum bake furnace operation is the goal. An overview of the operation targets will be given in Table 2.

Fire Change Execution Targets. The following goals have to be achieved:

- All fire changes to be executed exactly according to the instructions given and executed within a time window of ± 30 minutes of the scheduled time.
- Cumulated delay less than 10 hours per fire per year.

Anode Loading Operation Targets. The following goals have to be achieved:

- All Anodes are to be set symmetrically in the pit; with a maximum sideway deviation of 2 cm from the ideal position.
- For undisturbed operation, as a minimum, the section just downstream of an exhaust manifold has to be loaded with green anodes and the required packing material at all times.

Table 1: Baked anodes, worldwide range and targets for good anodes

Property	**Method**	**Unit**	**Worldwide ranges**	**Targets for good anodes**	
				Mean	**2σ**
Apparent Density (baked)	ISO 12985-1	kg/dm3	1.50 – 1.62	≥ 1.58	≤ 0.02
Spec. el. resistance	ISO 11713	μΩm	51 - 74	≤ 55	≤ 4
Flexural strength	ISO 12986-1	MPa	4 - 14	≥ 12	≤ 3
Compressive strength	ISO 18515	MPa	30 - 65	≥ 45	≤ 12
Static elasticity modulus	RDC-144 *)	GPa	3.0 – 6.5	5 – 5.5	≤ 0.4
Coefficient of thermal expansion	ISO 14420	10-6K-1	3.6 – 4.6	≤ 4.1	≤ 0.4
Thermal Conductivity	ISO 12987	W/mK	3 - 5	4.2	≤ 0.5
Density in Xylene	ISO 9088	kg/dm3	2.05 - 2.10	≥ 2.08	≤ 0.02
Air permeability	ISO 15906	nPm	0.3 – 8	≤ 0.9	≤ 0.9
CO2 reactivity:	ISO 12988-1				
Residue		%	75 – 96	≥ 92	≤ 4
Dust		%	0.2 – 14	≤ 2	≤ 2
Loss		%	4 - 15	≤ 6	≤ 3
Air reactivity:	ISO 12989-1				
Residue		%	55 – 95	≥ 80	≤ 10
Dust		%	1 – 12	≤ 3	≤ 4
Loss		%	4 - 35	≤ 15	≤ 6
*) R&D Carbon Ltd. instrument number					

Anode Unloading Operation Targets. The following goal has to be achieved:

- All baked anodes to be unpacked at all times. Re-baking anodes already baked a second time will cause serious process disturbances, loosing baking capacity and thus wasting money.

Fire Monitoring and Operation Targets. The following goal has to be achieved:

- Performing a soot free furnace operation at all times. This means that the CO level in the combustion gas, measured at the exhaust manifold should be kept at a value of less than 100 ppm_v and the O_2 value > 7 % at all times. The Bacharach soot figure should be 0 with a maximum of 1 in exceptional cases.

Bake Furnace Maintenance Targets:

As with operation targets, developing an exhaustive list of maintenance targets is possible for a given plant only. Note also, that the targets are related to breakdown maintenance. For preventive maintenance, activities will be scheduled in such a way that no negative impact on furnace operation will occur.

Mechanical Maintenance Targets. All mechanical breakdown maintenance to be executed within such a time frame that no negative impact on bake furnace operation occurs. Key areas of mechanical maintenance are the anode handling system including the furnace cranes and the bake furnace equipment. As a first indication, the acceptable downtime may be in the order of magnitude of four hours maximum for any breakdown incident related to the anode transportation system and two hours for breakdowns related to the baking furnace equipment.

Electrical Maintenance Targets. As with mechanical breakdown maintenance, all electrical breakdown maintenance to be executed within such a time frame that no negative impact on bake furnace operation occurs. As a first indication, goals may be a downtime of one hour maximum for sensors and fuel valves, two hours for coolers, exhaust manifold gates and similar equipment and four hours on the anode handling equipment.

Refractory Maintenance Targets. Refractory maintenance to be executed in such a way that a flue wall service life of more than 150 fire passings can be guaranteed. This will typically require that the refractory of each and every section is inspected, cleaned and repaired after every fire passing, with emphasis on expansion joints, packing material sticking, flue wall deformation as well as flue wall and headwall repair if required.

Financial Impact of Sub-optimum Furnace Operation

As stipulated earlier, related to 100.000 tons of annual baking capacity, avoidable cash drain of up to one million of US$ on direct cost has been observed. As an example only, the range of flue wall service life found on similar open top furnace was not less than 60 – 300 fire passings, equal to a service life of three to 15 years. Based on a furnace with 32 sections and 8 pits (9 flues) the total number of flues equals to 288. With typically 20 fire passings per year per section, with a service life of 60 fire cycles, all flues have to be replaced after 3 years, or after 15 years with a service life 300 fire cycles. Replacement cost is therefore either for 96 flues per year or 19 flues per year or a difference of 77 flues. The plant reaching 300 fire passings did so only by inspection and where required repair of all flue walls after each and every fire passing. Based on *replacement cost* of US$ 15,000 and estimated refractory *repair cost* of US$ 3,000 in the case of the plant with a flue wall life cycle of 300 fire passings, a difference of US$ 12,000 times 77 flues per year alone would already be responsible for a cash drain of nearly one million US$ per annum, not even taking into account any production loss and extra energy consumption in the case of the furnace with the poor flue wall service life.

Taking into account the financial impact of sub-standard furnace operation, actions to improve the situation can easily be justified.

Optimizing Bake Furnace Operation

Several methods as, e.g., the Pareto analysis and the Cause & Effect analysis (Fishbone Diagram) can be used as tools for process optimization. Although a widely accepted approach, in the field of bake furnace optimization we observed disappointing results. Applying the methods mentioned allowed identification of organizational shortcomings as, e.g. insufficient stocks of spare parts or insufficient funds for proper maintenance.

Table 2: Bake Furnace operation targets overview

Criterion	**Target**
Fire change execution	Always within ± 30 minutes from scheduled time
Cumulated delays	< 10 hours per fire per year
Anodes to be set symmetrically in the pit	Deviation < 2 cm from ideal position
Section downstream of exhaust manifold loaded with anodes	Always
Baked anodes not unloaded	Never
Soot free combustion	CO < 100 ppm_v upstream of exhaust at all times O2 level > 7 % upstream of exhaust at all times Bacharach smoke figure max. 1 at all times
Mechanical/electrical maintenance:	
Downtime anode transportation system	Max. 4 hours
Downtime bake furnace equipment	Max. 2 hours
Electrical maintenance:	
Downtime fuel valves and sensors	Max. 1 hour
Flue wall service life	Min. 150 fire passings
Deviations from given procedures	None

However, even if such causes are eliminated or considered as non-existing, still unsatisfactory furnace operation can be observed. Identifying and curing these hidden aspects is then the challenge. Analyzing the results of a number of anode bake furnace audits we realized that underestimating the human aspect plays a paramount role in unsatisfactory furnace operation.

The Underestimated Human Aspect

Motivation Deficiencies

In auditing anode plants we sometimes observed the striking fact that the operation of the green anode plant was much smoother with operators better motivated than in the bake furnace. As external aspects can be excluded, there must be an unidentified internal flaw triggering unsatisfactory bake furnace operation. Most probably the motivation differences can be explained as follows: in the paste plant, as long as there is no breakdown, production is automatically on the desired level. As soon as there is a breakdown, production is stopped and everybody is motivated to restore normal operation as soon as possible. In most plants, green anode weight and height are recorded and displayed in real time. If these values remain within their limits, and a visual inspection of the green anodes show no deficiencies it can be assumed that the green anode production process is under control.

In contrast, operators on the anode bake furnace have virtually no feedback about the quality of their work. As any feedback is missing and the consequences of substandard actions are often not realized, the willingness for implementing improvements either proposed from plant process engineers or from third party experts is limited or nonexistent.

From our observations and discussions we observed that this fact in quite some plants has never been realized with as a result that no actions will be undertaken to cure the situation. Analyzing the situation in more detail we identified mainly two causes for disappointing results in furnace operation:

- Cause-effect relationship not well understood.
- Deficiencies regarding the man-machine interface.

Cause-Effect Relationship Not Well Understood

Analyzing the cause we concluded that insufficient knowledge regarding the anode baking process background was responsible for inability in problem solving through this system. Cause-effect analysis in the field of bake furnaces is often difficult as a consequence of the fact that the effects show up after several days or weeks only. Linking the effects to the correct causes is then often not performed correctly, with sometimes dramatic consequences. Heavily investing in training for process engineers and operators and/or calling for third party support may be the most efficient way to solve this problem. The following examples may serve to depict the problem:

Anodes Loaded Asymmetrically in a Pit. Accepting anodes loaded in the pit asymmetrically makes life easier for the crane driver, as no time is required to position the anode pack in such a way that the packing material layer has the same thickness on both sides of the pit. Not loading the anodes properly will have a negative impact on the pitch volatile matter combustion and will increase the risk of rejects as a consequence of too high heat-up rates at the side where the anodes touch the flue wall. The result will only be seen after unpacking the anodes. In most cases it will be impossible to link the extra amount of rejects to the real cause.

Fire Change Delayed. Any delayed fire change requires slowing down the fire, by squeezing the under pressure applied to the system. This operation may in turn create soot, with a risk of fire incidents and with a negative environmental impact. A fire incident may be triggered at the execution of a fire change, and this may well take place one shift later, again with a chance that the link between slowing down a fire and the fire incident is not realized.

Baked Anodes Not Unloaded. In the case of a shortage in green anodes it is sometimes decided not to unload the bottommost layer of baked anodes in an attempt to keep the process going. As a consequence, the contribution of these anodes regarding supply of pitch volatile matter to the process is missing when heating up the section in question. This will reduce furnace output and will significantly disturb the process, with the risk of producing off-specs anodes.

Exhaust Temperature Too High: If for whatever reason a fire change is delayed, higher temperatures than usual will be observed at the exhaust. Operators sometimes open peepholes in the pitch burn area to “cool down” the combustion air. What happens in the first time is cooling down the nearest thermocouple, fooling the control system and thus disturbing seriously the process.

Anode Target Temperature not Reached: Sometimes management asks for a certain anode temperature to be reached prior to the execution of a fire change. Anode temperature, or more precisely packing material temperature in the pit is an unsuited property for bake furnace control. The response on energy input is slow and the inaccuracy of the measurement is high. Arranging the thermocouple a few centimeters lower in the pit is sufficient to increase the temperature display to the desired level – and that is what the operator will do. In fact, what we see here is a combination of two mistakes. First, the management giving orders incompatible with the instructions of the control system supplier, second, the operators fulfilling the targets by fooling the temperature measurement.

Summarizing it can be said that the negative impact of not operating a furnace exactly according to the instructions is all too often heavily underestimated.

Man-Machine Interface Deficiencies

It would not be fair to blame the shift supervisors and furnace operators for all the mistakes observed in auditing furnace operations. If an operator has to observe several furnaces with their off-gas cleaning installations, an information overflow may well be the result. Considering the fact that new huge smelters are likely to be built in the near future, searching for improved man-machine interfaces will be required to give the operators tools allowing smooth furnace operation monitoring.

Regarding process optimization through information available on screen in the control room, three options exist:

- Presenting all available information to the operator, as a basis for decision taking by the operator (Figure 2, Figure 3).
- Analysis of the available information by the system and displaying proposed actions to the operator.
- A combination of the approaches mentioned above.

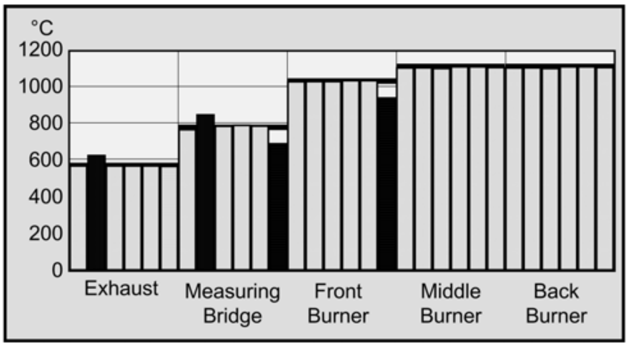

Figure 2: Screen display, showing the actual temperature situation on the furnace

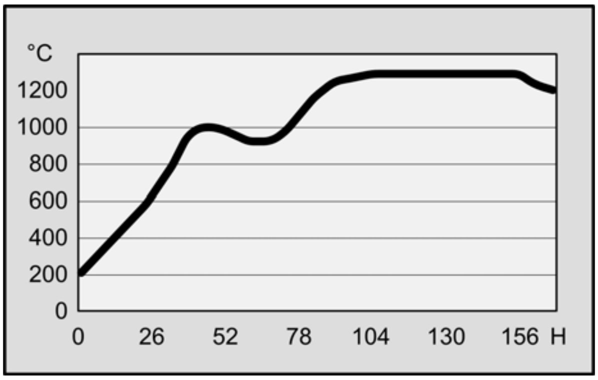

Figure 3: Simplified screen display, showing the historical temperature trend over the last completed fire cycle

In a well documented system, instructions how to react can be found in the system's operating manual. If presenting the actual furnace parameters only, we suppose that the operator knows all the instructions given in the manual. He should then be able to take a smart decision even in an emergency where a fast decision is required.

To help the operator, sometimes the decision about the action to be undertaken is delegated to the process control system, delivering "How-to-do" instructions to the operator in real time. Although this approach will help the control room operator about how to react, the approach is not without risks. If all possible events are not properly analyzed and implemented it may happen that a given irregularity results in a wrong or even dangerous counteraction. Presenting a kind of "multiple choice" proposals rather than just one instruction how to handle and analyzing the suggestions given by the system during an extended period of time will be required to make this approach to a success story.

Furnace optimization goals overruled by smelter optimization goals

Last but not least we have to realize that sometimes management decides deliberately for sub-optimum bake furnace operation. The most common chain of events is as follows: Smelter process optimization asks for bigger anodes. Accommodating such anodes is usually possible by jeopardizing packing material layer thickness. The increased anode volume will produce more pitch volatile matter, to be burnt in the flues of unchanged dimensions. As a consequence, it might well happen, that the reject rate will increase and that soot free combustion is not possible any more. Needless to say, that such a decision may be justified, as the final goal is the lowest possible metal price. The advantage of decreased metal production cost may easily overrule the disadvantages observed in the furnace. Of course it is then not fair to blame bake furnace staff for not being able any more to maintain all earlier goals, taking into account the changed boundary conditions.

Concluding remarks

At this time, several companies are investigating possibilities for new big smelters with metal production levels up to one million tons of aluminum per year and more. For an efficient anode supply, big furnaces with six or even eight fires may well be the way to go. Operating such units efficiently and trouble free means that mistakes hampering optimum operation may have much more severe consequences than in existing small furnaces with two or three fires only. The authors hope that the information given in this paper will help to operate furnaces in such a way that the required anodes can be produced smoothly in good quality, at lowest possible cost and at the lowest possible environmental impact.

Identifying clear targets, investing heavily in training and improving the man-machine interface will be the main activities required for an optimized operation of furnaces with four and more fires. Of course, the same activities will help to optimize operation of existing furnaces as well.

Acknowledgements

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