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Structured Approach to Modernization of Fume Treatment Centers

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Abstract

Although a Fume Treatment Center (FTC) is designed for the end of life performance of the anode baking furnace, aspects such as changing anode dimensions, increasing production or drifting quality of green anode materials are likely to drive the FTC towards the boundaries of its capacity and henceforth impose limits upon the anode baking furnace. A structured approach to debottlenecking the FTC has been developed, accommodating the owner's and operator's objectives in terms of cost, capacity and energy and emission limitations. The result of this approach is an optimum solution with respect to both CAPEX and OPEX, found by setting targets for overall pressure drop to meet capacity and energy consumption requirements, while maintaining environmental performance. Solutions are evaluated based on investment per unit of additional flow capacity. This article discusses the debottlenecking concept, illustrated by a practical case study as well as major technology step changes that were developed during this process.

Introduction

At some point in the life of a carbon bake system, operations will likely indicate that the FTC is on the limits of its capacity. More likely, this conclusion will be made apparent by a growing list of shortfalls in production as well as rising maintenance costs. Typical signs are:

- Tar blockages of spray lances and in ducts or even bags
- Frequent deluge of the ducting
- Excessive filter bag wear
- Control valves fully open (loss of control)

Before long, management reports will chronicle rising costs and declining performance of the anode baking system. As in most cases, it is not long before management demands a recovery plan. This paper will describe a structured approach to arrive at a strategy to increase the plant capacity and optimize operations and running cost. Before going into the details of the approach, we first will highlight some debottlenecking principles which have proven very successful in other industries [1]. At the end of the paper, a case study is presented based on an actual installation.

Creep vs. Step Change or Minor Cost vs. Major Cost

Capacity creep is a natural phenomenon in existing plants. For obvious commercial reasons, during the design phase, engineers do their utmost to calculate equipment size to suit nameplate capacity. Subsequently, during the procurement phase for reasons such as standardization, guarantees and the like, larger equipment is selected. This process implies that there is room for capacity creep in the installation. However, this margin is unevenly distributed over the system. As a result, one component in the system will limit the plant performance. Capacity creep is the process of adjusting operations in minor steps to find this limit. Once operating on this limit, capacity creep may continue if further improvements can be unlocked at minor cost.

Figure **1** illustrates how a set of equipment, once the plant is built, allows for this capacity creep at zero and minor cost respectively.

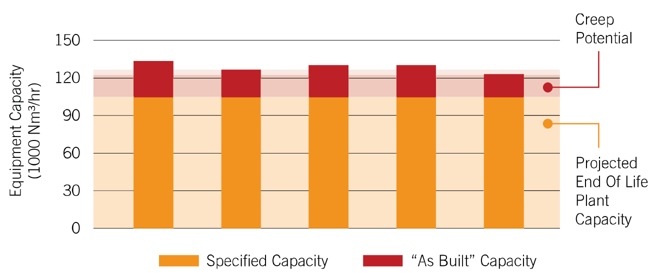

Figure 1 - Capacity Creep Potential (New Plant)
Note: Y-axis is generic

For further plant capacity increase, more substantial investment may be required to remove the bottleneck. Once such a step change is made, cost to capacity ratios dictate that the capacity creep process continues in order to arrive at the next optimum for plant capacity at any given bandwidth of cumulative expenditure.

Figure **2** illustrates how capacity creep and step changes take place against their respective cost: optimum operating cost structures for production are always at those operating points directly before a step change is required.

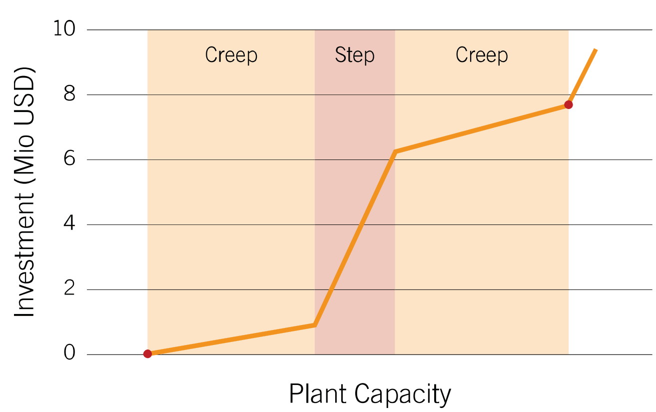

Figure 2 - Capacity vs Investment: Creep Phases and Step Change
Note: Y-axis is generic

Remaining in Control

When the FTC is driven towards the boundary of its capacity for whichever reason, controllability of not only emissions but also the baking process may be jeopardized. In these situations, all equipment is usually running flat out with all control valves fully open. This eliminates part of the control over the bake–oven firing system performance, e.g. moving away from full pitch burning towards excessive tar formation. As an additional consequence, plant availability will be undermined through the increased maintenance requirement and extra cost will be brought about by the need to remove the tar.

Design and Construct in Parallel, Operate in Series

Because of the nature of the fume treatment center, in particular the requirement for high or even full availability, it employs a combination of parallel and series equipment.

As with any repair or modification to the FTC, removing bottlenecks comes with the requirement that the unit shall remain in operation for as much as possible to avoid costly downtime and of course the release of untreated fumes to the atmosphere.

The task of considering the optimum solution for a given capacity requires one take into consideration the project schedule, in particular the construction schedule and the constructability itself. Modifying existing equipment leads to longer downtimes than building parallel equipment and allowing for shorter durations for tie–ins. During this planning process, all operational and financial factors should be taken into consideration. In some cases, the operational cost penalty of installing a financially more attractive alternative for an improved piece of equipment may outweigh the price difference with the more expensive option that allows for parallel construction and quick or even on–line tie–in.

The Structured Approach to Modernization: It starts with the Baseline

The process of debottlenecking the FTC is kicked off by establishing the actual baseline of the unit. Operations are audited and evaluated to determine how operations have moved ahead or potentially started lagging behind the original design. This can be done during a visit by a specialized, external design team.

It may not be immediately obvious why an external resource would be used for such a task; however the following benefits add weight to the audit, which may not be available internally:

- Independent, non-biased view without the burden of being related to day-to-day operations;
- Dedicated, focused effort without the possibility to be diverted by operations;
- Benchmarking against findings across the globe;
- In depth experience with inspection and condition monitoring techniques; and
- Immediate reporting to operational management if findings dictate that immediate action is taken.

During the visit an actual and thorough plant test run will be made. This test run will be used as a base for mapping potential capacity creep and eventually the guaranteed and measurable performance of the implemented changes. In addition to identifying minor and major plant bottlenecks, the audit process and the test run will identify, which equipment is not meeting up to its original specifications and is in need of repair or replacement; as mentioned above, such cases can be reported immediately and outside of the debottlenecking and modernization processes.

Step 1: What Capacity?

Now that the baseline and the apparent bottlenecks in the system have been identified, a sequence of future target capacities for the unit can be determined.

It goes without saying that there is a limit to what can be achieved with an existing installation. The ultimate capacity step would consist of building a parallel system. In general, as technology matures over time, the designers will allow less design margins as the performance of the equipment becomes more predictable. In short: there will be less fat to cut.

In determining and evaluating alternatives, any scenario should be benchmarked against the reference point of the total replacement cost of the unit. This benchmark should, once again, take the operational cost penalty of downtime into consideration and compare operational performance and hence value in use of the new plant against that of the modernized, old equipment. In addition, since maintenance cost will, by nature, increase over the lifetime of the plant and its equipment. The differences for this operational cost component in scenarios may be significant.

Basic requirements for the sequence of capacity targets will be set by upstream bake furnace operations, which are in turn based on other upstream operational scenarios. These include longer term projected smelter output, expected raw material compositions for especially the anode production process and e.g. development of the parameters of the environmental permits. These capacity requirements are matched by the debottlenecking and modernization scenarios drafted in the next steps.

Step 2: Available Options

Based on the technical and operational findings of the baseline audit, the next step is to draft a long list of upgrades and modifications to the FTC. These may be motivated by the requirement to eliminate operational shortfalls, reduce maintenance cost or simply increase the capacity of a piece of equipment.

Along the way, identifying possibilities for reducing the energy consumption may be very useful to, in turn, identify possible solutions for meeting new plants objectives since energy consumption is a good indicator of the plant’s overall OPEX. Although reducing energy consumption may not be the primary objective of a modernization or debottlenecking process, it may offer guidance since OPEX is largely determined by the power consumption of the extraction fans that is related to the overall pressure drop over the system, which will be low with well-functioning equipment.

For an FTC, there may be many options available and as an example, one could consider one of the following options/alternatives to increasing the capacity:

- Reducing conditioning tower pressure drop
- Inlet gas cooling
- Variable frequency drives on fans
- Pleated bags (Ad–Flow™ bags)
- Dry bottom cooling tower
- Full pitch burning system

Boundary conditions to take into account:

- Acceptable velocities in ducts and piping
- Fans curve and plant resistance curve

During this step, the long–list of options should be drafted based on the technical and operational merits of the options; if technical or operational aspects prohibit the implementation of an option under consideration, it should be eliminated during this step.

Step 3: Economic Target

In the first step we have established what we need; in the second step what must be done to achieve it. During this third step, options are put into perspective in scenarios and their economic viability is evaluated. Scenarios are compiled out of the long–list of options, their capital requirements, capacity increases or maintenance cost reductions and with respect to operations, their individual benefits and interdependencies. Figure **3** illustrates roughly how bottlenecks, step changes and future potential for capacity creep are identified.

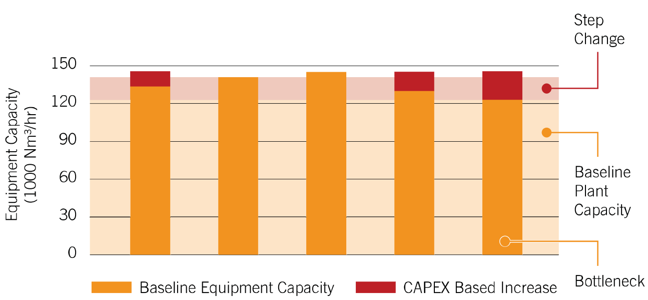

Figure 3 - Determining Baseline and Future Step Changes
Note: Y-axis is generic

This process may produce findings that dictate a sequence for any set debottlenecking or modernization options. Ultimately though, the drafted scenarios and sequences of options are evaluated for their economic viability.

Mapping the scenarios in diagrams based on their capacity increase and investment requirement may once again serve as an ideal management tool for deciding upon capacity against cost. It will help optimize the scenarios and help match them against the capacity requirements found in Step 1 at minimum cost.

In an ideal case, the new capacity based on the step changes and capacity creep steps reaches the required capacity, but in many cases a comfortable head room in terms of capacity and hence operating flexibility and level of process control can be achieved at a minor extra investment.

Case Study

This case study is based on an existing installation running at 115% of its nameplate design capacity. Because of increased anode production, firing times had been reduced and the valves controlling the pressure at the ring main were found to be 100% open. This resulted in incomplete combustion and high tar/pitch levels in the fumes to the FTC. In turn, this resulted in liquid tar deposits in the ducts and conditioning tower and short bag life.

In order to meet the production targets, debottlenecking was proposed in two phases: on short term to 150% and on the longer term to 200% of the design capacity. The first part of the expansion was to meet current demand and the second to meet the expected demand as result of a planned capacity creep of the associated potline.

In addition to the practical observations mentioned above, the audit process of the first step also indicated some additional complications:

- Excessive tar formation was found even downstream from the conditioning tower in the inlet plenum, filter bags, etc.
- A high pressure drop over the entire system was found
- The conditioning tower was operating at a 1800 Pa pressure drop, where 400 Pa is advised
- The condensation tower was under–dimensioned
- Collecting ducts were long and had many bends
- Filter bag life was observed to be much shorter than the going minimum of three years

After having established the base line and the production targets several options were identified to increase the capacity, such as, but not limited to:

1. Reduce plant pressure drop in installing a new enlarged conditioning tower
2. Adapt the pressure control system from loops in series to parallel loops.
3. Change the bag pulsing system from time set–point to pressure drop set–point with individual cell measurement and control.
4. Replace the reactor with a new vertical radial injector
5. Add filter cloth area in the existing filter bags
6. Add parallel new bag houses
7. Add/replace exhaust fans

For reference, also the costs of a new FTC were taken into account. Each of the options was detailed with respect to contribution to the plant capacity, capital cost and (ease of) implementation and required downtime.

The contribution of item 1), new condensing towers strongly depends on the operating point of the exhaust fan. The pressure drop of the Danieli Corus design condensing tower was approximately 30% of the existing tower at current conditions and even more at elevated capacities. Because the operating point of the fans were at a relative steep slope of curve, a significant increase could be made in capacity whereas this is less likely if the operating point would have been on a flat part of the operating curve see Figure **4**.

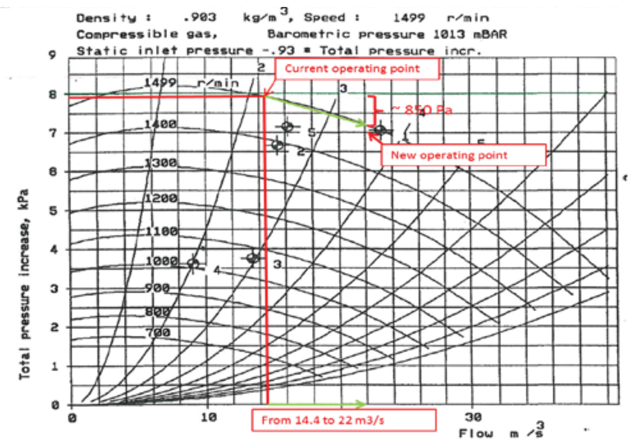

Figure 4 - Fan Operating Points

The effect of inlet gas cooling for capacity increase is balanced. On one side capacity is won because of the lower gas volume, on the other side a heat exchanger would add to the pressure drop over the system. Because of this and the lack of industrial references this option has been not further pursued.

Frequency control (variable frequency drives) of exhaust fans are an interesting option in the case where one is looking for a small increase is flow. The over–speed option will provide an additional 5–10% capacity depending on the type of fan and motor. Overtime, going from start to end of life time of an anode bake furnace, frequency control is an interesting option with respect to energy savings.

In the first instance with this example at hand, the main bottleneck was not the bag filters themselves. Even at the 115% capacity, the air–to–cloth ratio and filter velocities were such that more capacity could be handled without modifications. However this overdesign capacity was not sufficient to meet the intermediate and final capacity targets so alternative options such as pleated bags and additional modules were explored.

In case the alumina handling system is a bottleneck, either by capacity in the FTC itself or because of quality problems such as high attrition, changing over the reactor to the system using the VRI reactor could enable the capacity creep. This is allowed for by the VRI's high once true scrubbing efficiency, reducing the recycle rate from approximately 1 to 40 in conventional systems to 1 to 5 [2].

Capacity versus Cost

Having taken into account all the above options and ranked them for investment as well as operational cost, delta capacity and ease of implementation, a cost curve is generated giving delta capacity versus investment cost (see Figure **5**).

This graph is an excellent tool to determine if the required capacities can be reached and to which capacity the plant should be expanded/debottlenecked to reach its best economic investment capacity taking into account the rules presented earlier in the paper on major and minor bottlenecks.

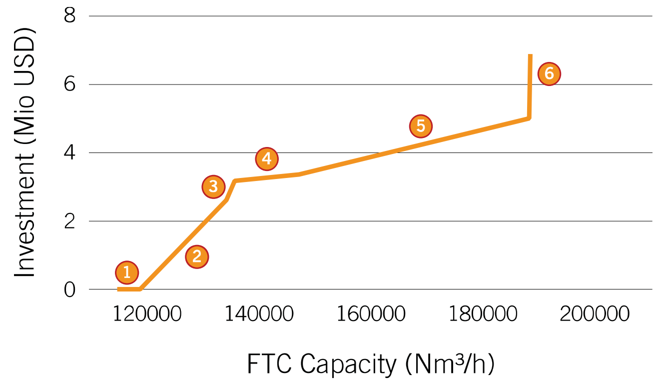

Figure 5 –Capacity versus Cost

As a final recommendation following the ranking of suggested modifications based on economy vs. capacity ranking process, the proposed steps in the presented diagram were divided into a Phase 1 and a Phase 2, the first of which being a set of modifications to equipment as well as the process taking away the bottlenecks in current operations as well as eliminating existing process mishaps. These bring the FTC to the required capacity for existing ABF operations at the required reliability, availability, maintainability and health, safety & environment standards. The second phase would bring the FTC to the required capacity for envisaged future ABF operations.

Phase 1 consists of the following four steps:

1. Modified under pressure control

In the existing situation, under pressure distribution over the ABF's two kilns was controlled with two valves. At zero cost, one of these can be eliminated without losing the ability to control and balance under pressure, while reducing pressure drop through the elimination of the valve. The first step hence brings the operator an additional 1,500 Nm^3/hr capacity.

2. Replace conditioning tower

The existing conditioning tower could be replaced not only to gain capacity, but improve the following process aspects:

a) Reduce the overall pressure drop over the system
b) Regain control over the ABF combustion system
c) Eliminate tar deposits downstream
d) Lengthen the on–stream time of the FTC
e) Achieve a lower carbon loading for the reacted alumina
f) Achieve dry discharge of carbon

Especially through the reduced overall pressure drop, this step will debottleneck the system by nearly 15,000 Nm^3/hr, with reduced power consumption per volume of treated fumes as a side effect.

3. VRI reactor in the existing baghouse

With the objective of improved scrubbing, the existing fluidization reactor can be replaced with a VRI. Since this would require modification, the relatively limited capacity creep would come at quite high cost. Process–wise however, this step is essential since the reduced attrition of alumina is beneficial for potroom performance as is the reduced dust loading for the filter modules.

4. Installing Ad–Flow™ filter bags

Inherent to their pleated design, Ad–Flow™ filter bags offer a strongly increased cloth area per required area of tube sheet. This reduces the pressure drop over the baghouse, while the modification is simple. The additional capacity offered by this step may be over 10,000 Nm³ and requires no modification to the existing fan configuration. So far, references for this type of filter bag are only available for applications in GTCs, not FTCs.

The following table illustrates how the installation of this type of bag reduces the filter velocity and the can velocity in both N and N–1 operations in the current situation and with the increased FTC capacity in this stadium of the debottlenecking process.

Table 1 – Process conditions with Ad–Flow™ filter bags

Situation	**Filter Velocity (cm/s)**		**Can Velocity (cm/s)**	
	N	N-1	N	N-1
Existing	1.48	1.98		
Upgraded	1.83	2.43	153	203
With Ad–Flow	1.01	1.35	132	176

This step provides the milestone capacity increase bringing the FTC to its set capacity for current operations and eliminating the problems that were found during the fact finding phase, thus completing Phase 1 of the debottlenecking/expansion program that was suggested.

Table 2 presents the step by step capacity increase of the FTC as also presented in Figure 5, albeit in more detail. It also presents the required capacity of the main exhaust fans in terms of electrical power. This clearly shows that while the improved filter bag design suggested in step 4 brings a substantial capacity increase, it does so at *decreased* power requirement.

Finally, the specific (electrical) energy requirement per volume of fumes indicates the contribution to reduced operational expenditure for each step. Overall, this very relevant OPEX component reduces by nearly 20% through the steps suggested for the first phase.

Table 2 – Proposed capacity increase (“Phase 1”)

Step	**Description**	**Flow (Nm³/hr)**	**Required fan capacity (kW)**	**Specific energy cons. (kJ/Nm³)**
—	Existing situation	114,120	158	4.98
1	Underpressure control	115,620	158	4.92
2	Conditioning tower	129,500	160	4.45
3	VRI	131,000	161	4.24
4	Ad–Flow™ bags	141,000	158	4.03

As a final set of steps designated “Phase 2”, capacity could be brought to its final target to match the plant’s future production scenarios by the upgrade of the main exhaust fans (step 5) and the addition of an extra bag house (step 6) in order to add the required filtration area to accommodate the added flow.

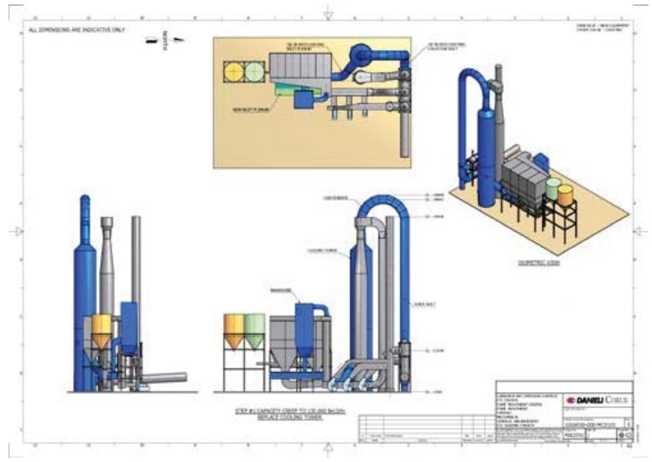

Figure 6 - Suggested Equipment Upgrade

The final, debottlenecked FTC after the steps constituting phase 2 of the program is illustrated in Figure **6**.

Conclusions

A structured approach is presented to establish the current operating point for a fume treatment center and its bottlenecks. The approach must be looked at from different angles, including required capacity, technical possibilities, investment cost and feasibility of installation/construction to arrive at the most efficient expanded capacity of the FTC. This strategy by its nature and origin can also be applied to large integrated units such as primary smelters to arrive at the most economical creep solutions.

References

[1] V. Kaiser, R. Di Cintio, and M. Piccotti ., *Ethylene plant energy analysis*, presented at AIChE Spring National Meeting April 1993, Houston, Texas, 1993.
[2] Erik Dupon and Peter Klut, *Experiences in FTC Design, Operation and Development,* Light Metals 2012, p 1181.

Note

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