Prolonging the Economic Lifetime of GTCs and FTCs

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Abstract

After decades of operations of environmental systems such as GTCs and FTCs, operating conditions may have changed such that severe pressure is exerted on the remaining economic lifetime. Capacity drift of the constituting components is an additional factor that may weaken the prospects for the systems. As a consequence, investment requirement may become acute or operational limits may be imposed on the associated production plants (smelter and anode baking furnace, respectively). This article describes approaches towards improving performance and stretching the economic lifetime of such systems at optimized capital expenditure. It describes a structured approach to debottlenecking, accommodating all objectives in terms of cost, capacity and energy and emission limitations. The result is an optimum with respect to CAPEX and OPEX, whereby solutions are evaluated based on investment per unit of capacity. In addition, the article presents a project that was executed at Aluminerie de Bécancour with the described objective of prolonging the economic lifetime of the FTC at minimum investment. Process conditions (increased fume volumes, altered pitch burning conditions, pet coke impurities, etc.) had changed significantly since the commissioning of the system in 1985 and during this project, the conditioning tower was replaced with a new and improved design.

Keywords: Environmental systems; GTC capacity; FTC capacity; GTC lifetime; FTC lifetime; debottlenecking.

1. Introduction

Usually, the conclusion that a GTC or FTC is reaching the end of its economic lifetime can be deducted from operational indicators showing that the system 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. For example in the case of an FTC, 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).

Escalation will obviously compromise the associated primary production process (smelting and anode baking respectively), which is unacceptable. Replacement or overhaul of the underperforming system comes at a substantial and possibly prohibitive CAPEX penalty and debottlenecking or partially upgrading the system is usually more attractive. For optimized performance and capital allocation, there is a structured, step–wise strategy towards this debottlenecking process.

2. Equipment Capacity vs. System Capacity

For obvious commercial reasons, during a system's 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. With any industrial system, there is operational margin which is unevenly distributed over the system. Figure 1 illustrates how for such a system, in new and "as built" condition, system design capacity and capacities for individual pieces of equipment are related. The margin in capacity distributed across the system is the system's creep potential.

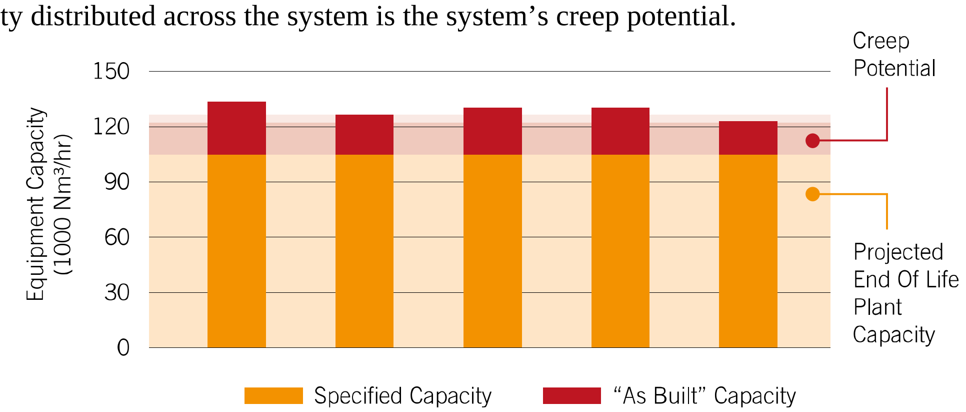


Figure 1. System capacity (new plant, Note: Y–axis is generic).

During the system's operational life, capacity creep is commonly implemented as a strategy to increase the system's capacity without investment. Capacity creep is the process of adjusting operations in minor steps to find the limit imposed by the capacity of the piece of equipment with the least margin or headroom in terms of capacity. Once operating on this limit, capacity creep may continue if further improvements can be unlocked at minor cost. 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.

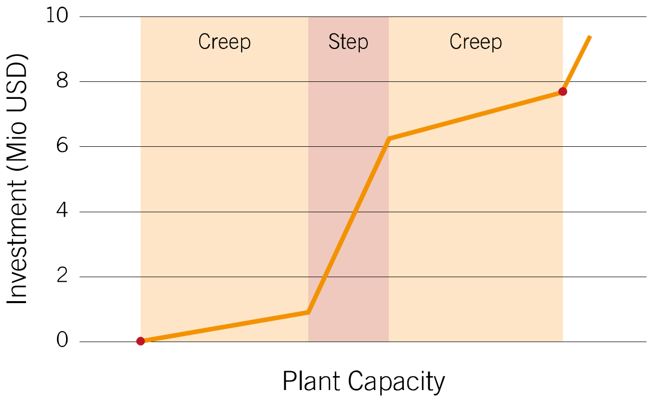


Figure 2. Capacity vs investment: Creep phases and step change (Note: Y–axis is generic).

As the system approaches the end of its technical lifetime, capacities of individual pieces of equipment (regardless of whether a capacity creep strategy has been implemented) will have drifted away from their nameplate capacities in many cases and a similar analysis of individual equipment capacities versus desired and actual system capacity can be made.

When at this time, a system is driven towards the boundary of its overall capacity, controllability may be jeopardized. In the case of GTCs or FTCs, this does not only apply to the system itself but also to the associated primary process. All equipment is operated running flat out with, e.g., all control valves fully open. This situation is undesirable and an indication that if there is any additional (downward) capacity drift, the situation becomes unacceptable.

3. The Structured Approach

3.1. Establishing a baseline

The process of debottlenecking the GTC or FTC is kicked off by establishing the actual baseline of the system. Operations are audited and evaluated to determine how operations are 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 audit 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.

3.2 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. 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 operations, which are in turn based on other upstream operational scenarios. These include longer term projected smelter output, expected raw material compositions 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.

3.3 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 system. 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 the revised objectives since energy consumption is a good overall indicator of the plant’s OPEX. Although reducing energy consumption may not be the primary objective of a modernization or debottlenecking process, it may offer guidance since a GTC’s or FTC’s 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.

There may be many options available and as an example, one could consider one of the following options/alternatives to increasing the capacity (example applies to an FTC):

- Reducing conditioning tower pressure drop,
- Inlet gas cooling,
- Variable frequency drives on fans,
- Pleated bags,
- Dry bottom cooling tower,
- Full pitch burning system.

Boundary conditions to take into account are as follows:

- 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.

3.4 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 are identified.

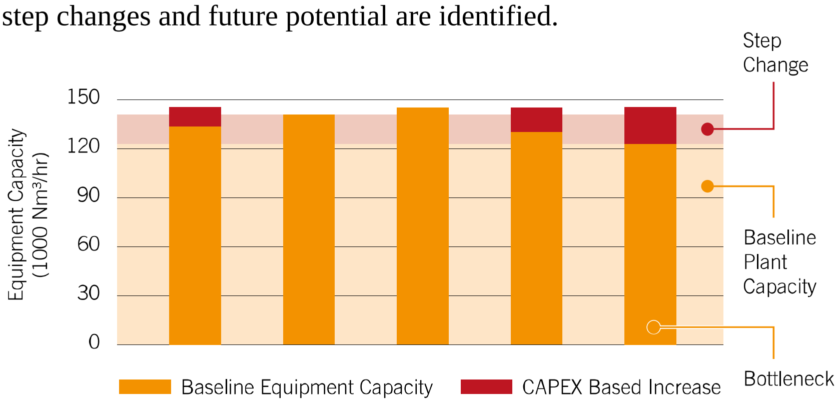


Figure 3. Determining baseline and future changes (Note: Y–axis is generic).

This process may produce findings that dictate a sequence for any set of 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.

3.5 Implementation: Capacity versus cost

Having summarized modernization options for each piece of equipment and ranked them for investment as well as operational cost versus delta capacity and ease of implementation, a cost curve is generated giving delta capacity versus investment cost (see Figure 5). The example in and scales in the graph are obviously generic.

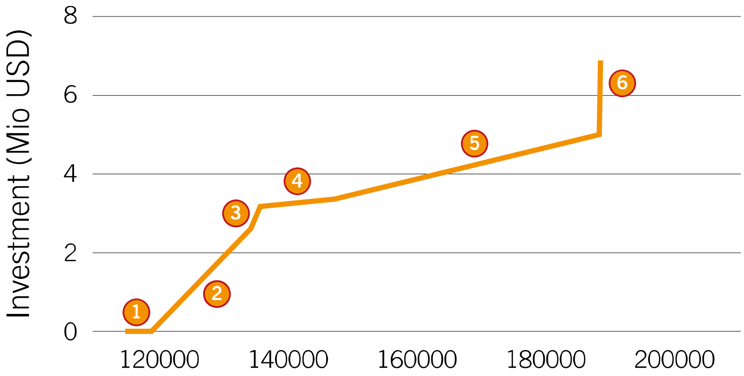


Figure 4. Capacity versus cost.

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 on major and minor bottlenecks. Clearly, the proposed modernization or debottlenecking project will bring the system towards at least the first step beyond the desired capacity but more importantly, any low investment capacity steps will be included in the suggested minimum sequence; the project will find its natural limit directly before the first next high investment capacity step beyond where the desired capacity is reached.

4. Case Study: FTC Modernization at Aluminerie de Bécancour

The Aluminerie de Bécancour (“ABI”) smelter is located along the Quebec shores of the St. Lawrence River and has a reputation of being energy and environmentally conscious. Over the course of three decades, the cooling tower of the FTC at ABI experienced severe corrosion due to deteriorating equipment continuously operating in a harsh industrial environment. In the same period, the process conditions for which the cooling tower was to service, had changed significantly. The raw ABF fume had an increase in vanadium and sulfur concentrations due to change in recipe and pitch burning practices. The FTC clearly did not meet the ABF requirements and modernization was required. Minor debottlenecking activities were of course investigated but the new targets could not be met without implementing the major modernization step of replacing the existing conditioning tower with one of a modern design to manage the increased fume volume and change in fume composition.

4.1 Historical development

During the initial startup in 1986, the cooling tower was designed to accommodate approximately 220 000 actual m^3/hr of fume with a temperature of 140 °C. The tower was fabricated from mild steel, thermally insulated and was essentially an empty vessel designed to cool the fume through evaporation of water. In 1991, the smelter expanded in capacity by 50 % with the addition of a new potline and a new (smaller) bake furnace. It was decided to reuse the existing FTC to treat fumes from the new furnace. Filtering capacity and induced draft fans were added to the existing FTC but the cooling tower remained unchanged. Over the years ABI would further ramp up production levels as the demand for the light metal increased; a common practice within primary aluminium industry. Hence, the original cooling tower experienced an increase in operating parameters and was eventually servicing fume volumes of approximately 310 000 actual m^3/h at temperatures of 150 °C by the year 2009 (Figure 6).

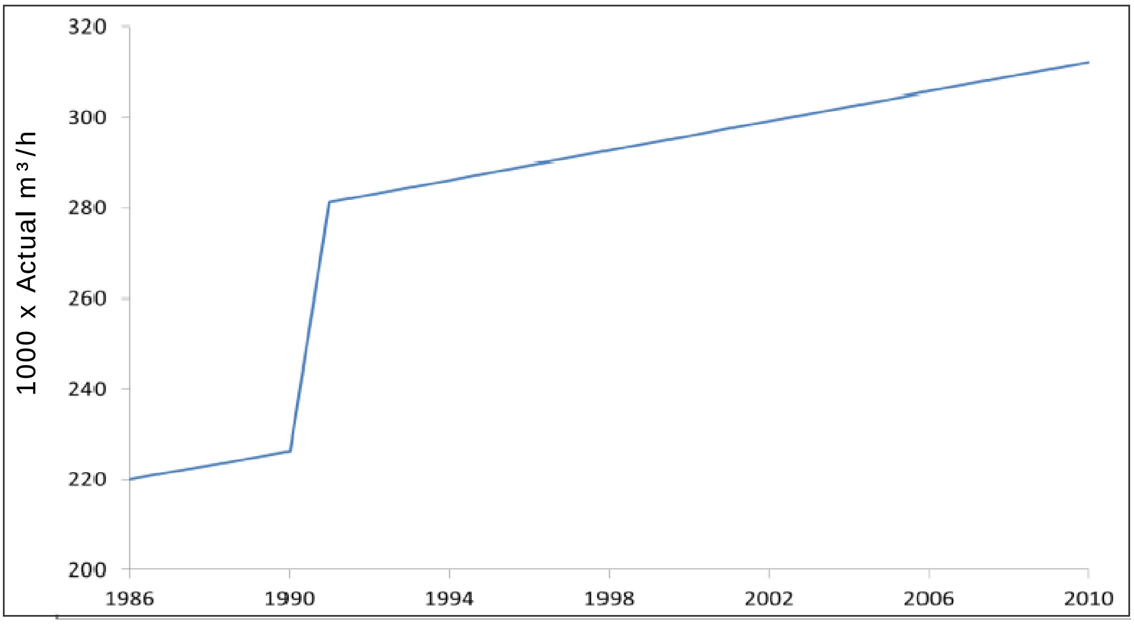


Figure 6. Fume volume increase from original startup date.

The higher gas volume and increased temperature accelerated wear and corrosion within the tower to the point where it was not performing reliably and showed signs of degradation.

4.2 Process design of the new conditioning tower

The function of the Conditioning Tower is to continuously and consistently maintain an outlet temperature of 105 to 110 °C regardless of the range of inlet flows, temperatures and composition indicated in the tables 1 and.2

Table 1. Conditioning tower inlet conditions.

Condition	Flow Actual m^3/h	Temperature °C
Minimum	72 000	110
Normal	360 000	150
Future operation	414 000	160
Maximum heat load	360 000	220

The fume flow rate of 360 000 actual m^3/h during maximum heat load is approximately 60 % greater than the original design condition of the old cooling tower.

Table 2. Conditioning tower inlet fume composition.

Parameter	Concentration mg/Nm^3
Gaseous fluorides	0 – 50
Total particulates	0 – 500
Condensable Tars	0 – 150
Sulphur Dioxide, SO_2	0 – 400
Sulphur Trioxide, SO_3	0 – 25
Moisture	3 % by volume

The system achieves this through evaporative cooling of atomized water droplets which are blended into the fume stream via custom spray lances at the top of the tower. These are vital components because they lower the fume temperature to promote the condensation of aromatic hydrocarbons (Figure 7) that would otherwise pass through the system in their gaseous state. Once the hydrocarbons condense, they can be removed from the system through inertial separation and filtration on alumina downstream of the Conditioning Tower. As indicated below, virtually all of the heavy hydrocarbons are condensed when the temperature is reduced to 100 °C.

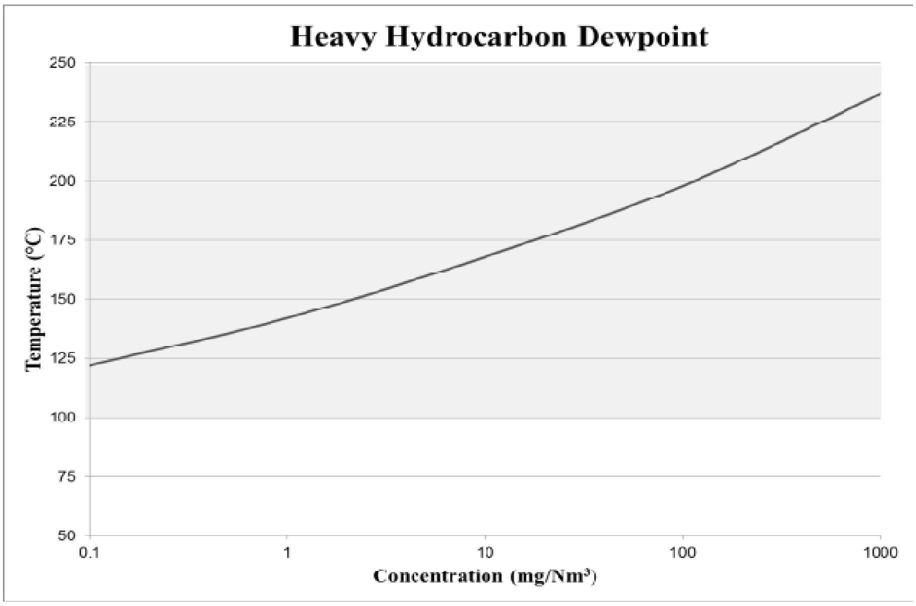


Figure 7. Condensation temperature of heavy hydrocarbons.

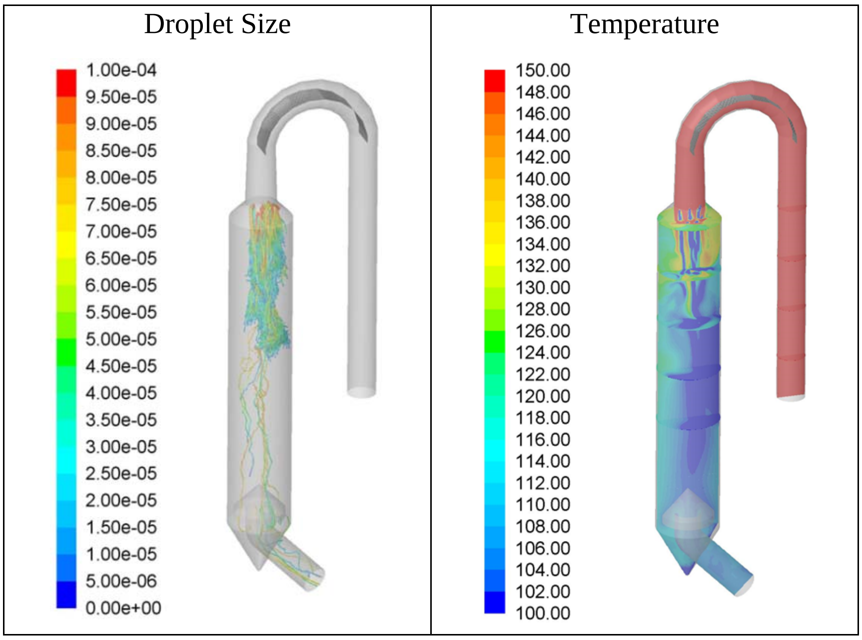
The number of lances in operation can be manually varied such that an extremely broad range of water flow can be atomized with high pressure compressed air. The heat load is dependent on the number of fire groups in operation and massive deviations are not expected in short term operation. Therefore, the number of lances in operation remains a manual process to maintain simplicity and economics. The control system monitors and maintains the desired outlet temperature to within ± 2 °C through all cycles of the ABF. Each complete spray lance was fabricated from Hastelloy body and nozzle for a robust and healthy lifespan. Each lance was equipped with a water flow switch which provided online feedback to the operator as to which lances were in operation. The switch provides online confirmation that the lance is receiving water from the valve rack. This is critical because the Conditioning Tower has to provide a balanced spray pattern for optimum performance.

The proprietary spray lances can maintain a water droplet size less than 100 μm over a wide range of fume inlet temperatures with no deterioration of water droplet size. The droplet size is maintained through a constantly regulating supply of compressed air from the valve rack. Danieli Corus prepared equipment specifications and the valve rack was provided by ABI in accordance with the functional requirement. The valve rack was supplied with fully redundant air and water racks, booster pumps, valves and instruments as required.

The Danieli Corus conditioning tower is commonly accepted in the industry as a very efficient and proven means of treating the fumes from the anode bake furnace. The tower was generously sized to allow eight seconds residence time for the water droplet to completely evaporate and ensure it operates with a dry bottom. A fixed inertial separator was located in the coned discharge of the conditioning tower; a component that was not included in the original tower design in 1985. The separator was designed to remove a substantial portion of the condensed tars and particulate which would otherwise short circuit to the inlet plenum like the original tower. This component is included to ease the maintenance requirements associated with cleaning of the inlet plenum and therefore improves system online availability. The particulate separated from the fume collects at the bottom of the Conditioning Tower and discharges through a double dump airlock valve into a collection bin.

4.3 Computational fluid dynamic verification/validation

As added assurance of the performance, a Computational Fluid Dynamic (CFD) model of the riser duct and Conditioning Tower was performed using FLUENT 14.5 software. The objective of the modelling was to confirm dry bottom operation under all inlet conditions and to check that water droplets do not collide with the internal wall. The modeller established boundary conditions, mesh sizes and convergence theories based on significant experience with evaporative cooling simulations. Using a known set of fixed parameters, the model tracked the water droplet size, the fume velocity profile and the thermal fields (Figure 8). Ultimately, the CFD modelling confirmed completion evaporation and no water contact with the internal walls to the satisfaction of all parties.



Droplet Size

Temperature

Figure 8. CFD modelling of Conditioning Tower.

4.4 Making it happen: Tie–in and commissioning

After the fabrication and site erection (which are not covered in this article) were completed, the modernization project finally came to be materialized when the new conditioning tower (Figure 9) was tied in into the existing FTC. The mandate from ABI was to minimize tie–in duration since it would require the FTC and ABF to go offline. In addition, having the furnace unheated for extended periods would allow it to cool. Restarting the chilled furnace could cause disruption in anode quality and spikes in hydrocarbon emissions. Therefore, due to environmental legislation and process risk in the ABF, the tie–in duration was not to exceed forty–eight hours.

As the team prepared for the tie–in, ABI ramped up production on the bake furnace to increase inventory. During the outage the surplus of baked anodes would be consumed normally within the pot room ensuring that smelting remained uninterrupted. The site team diligently planned a safe and efficient tie–in schedule which included an extensive list of pre–work to minimize the tasks that had to be performed during shutdown. To ensure minimal downtime and a fluent tie–in, the site team confirmed all existing components against their final location. All loose material such as duct supports, bracing and expansion joints were accounted for and moved to a location for easy access. Existing insulation and lagging was removed nearby the tie–in locations and where possible some of the existing fasteners were removed from the flanges on the riser duct and inlet plenum. Scaffolding was erected below the existing cooling tower as the entire cone was to be cut out to allow installation of the new ducting. Finally all areas were cleared of potential congestion and the tie–in was to proceed as scheduled on 24th March, 2015.

During the tie–in, the existing inlet ducting was removed and the new riser duct with lobster back was installed in single lift. The alignment was near perfect and one crew immediately bolted the bottom flange while a second crew began welding out the top splice connection. Once the load could safely be removed, the crane was no longer required and packed up. The inlet plenum and expansion joint connection was performed at grade with small wheeled crane. The flawless tie–in was performed safely in less than forty hours and the bake furnace was brought back online early morning of 26th March.

It was the end of March but cold wintery conditions were still present during hot commissioning. Shortly after the fires were restarted on the ABF in the early morning, the fume flow was directed to the FTC with all eyes on the performance of the Conditioning Tower. Ironically the excitement subsided because the inlet fume temperatures were very low and the enormous heat sink of the tower absorbed whatever heat came in. As the temperatures slowly rose throughout the morning, to everyone’s surprise water began pouring out the bottom of the tower at an alarming rate. The spray water pumps were confirmed off and a check at the spray lance platform confirmed that no water was entering the tower. It was a jolt of comic relief when it was realized that the water was generated from melting ice in the tower. Since the tower was erected in early winter and stood with an open top for almost four months, snow and ice were allowed to accumulate in the bottom.

As the temperature rose throughout the morning, the amount of water from the bottom slowly dwindled to a stop. Nearly half a day later, the fume temperature from the Conditioning Tower reached a point where water injection was required and the control software was trialled. After some fine tuning of the control logic, the FTC was left to operate overnight with the commissioning team on call for the operators. The following morning the tower was inspected and a large amount of dry carbon granulate was discharging from the dump valve – a sign of a very healthy conditioning tower. The addition of the inertial separator in the bottom cone of the tower was new to the operators and they were not expecting that degree of removal.

Once the system was stabilized, the unused spray lances were removed from the process to prevent carbon and soot accumulation in and around the nozzle. The temperature control loop was monitored and tuned as the operators and technical staff became familiar with the operation.

After commissioning, there was barely a hiccup in the bake furnace operation and fugitive emissions were held to a minimum to the satisfaction of all parties involved. After more than 15 000 working hours there was no reported injury.

Figure 9. New conditioning tower alongside existing tower.

The conscientious approach to the project kept the costs in check by re–using existing equipment where possible and the site team was able to make progress with the installation throughout the Quebec winter to meet the March start–up date. Careful preparation and planning allowed for a smooth transition from the old cooling tower to the new Conditioning Tower measuring almost double in size. The performance stability of the new tower has been recognized by ABI and all parties are very satisfied with the installation.

5. Conclusion

A structured approach is presented for modernizing and debottlenecking industrial systems based on establishing current and future operating points, identifying operational bottlenecks and evaluating options for modernization and debottlenecking for individual pieces of equipment making up the system. The modernization and debottlenecking is 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 system. This strategy by its nature and origin can also be applied to larger units such as primary smelters to arrive at the most economical solutions.

Turning theory into practice requires solid experience in brownfield modernization and optimization, since these working situations induce practical and operational conditions entirely different to situations such as expansion projects or operations where associated plant equipment is decommissioned for the tie–in of new equipment.