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CONSIDERATIONS REGARDING HIGH DRAFT VENTILATION AS AN AIR EMISSION REDUCTION TOOL

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Abstract

High draft ventilation is an effective technique for reducing emissions from electrolysis cells while panel covers are removed to perform maintenance. In recent years, many new smelters have implemented high draft ventilation as one of the tools to further reduce air emissions from potrooms. In this paper the principles of high draft ventilation are discussed followed by a presentation on its impact on smelter performance. Practical observations are provided concerning the implementation of high draft ventilation in greenfield and brownfield smelters.

Introduction

Primary aluminium smelter operations continuously seek improvements for higher production efficiencies, for lower costs, to achieve better working conditions and to reduce emissions. This paper is focused on reduction of fluoride emissions from potrooms, more specifically, on the use of high draft ventilation in cells.

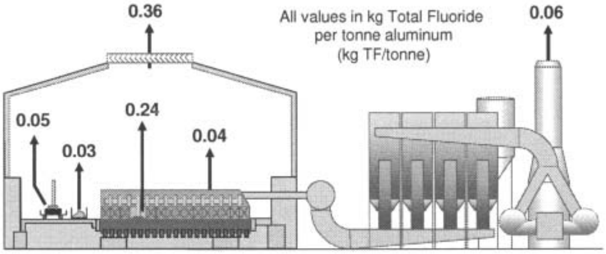

Figure 1 - General distribution of fluoride emissions in a modern prebake smelter

High draft ventilation is a tool to reduce emissions into the potroom and it all starts at the electrolysis cell. See Figure 1. When a cell operates normally and all panel covers are closed, background fluoride escapes into the potroom through gaps and other means (0.04 kg TF/tonne). Most fluorides are actually contained by the ventilation system and transported to the gas treatment center. There the HF is scrubbed and the particulate fluoride caught on the filters. The residual fluoride in the stack is approximately 0.06 kg TF/tonne. In the potrooms the temporal fluoride emissions peak during anode changing. Opening the covers to access the bath and anodes causes a loss of draft and the average contribution of these emissions are 0.24 kg TF/tonne. Then, the spent anodes, covered with hot anode crust, can come into immediate contact with humidity from the ambient air. This creates an emission that is estimated to be 0.05 kg TF/tonne. Lastly, the excess hot crust/bath material that is removed from the cell also comes in contact with the air. This is perhaps a less intense emission source, but still provides for approximately 0.03 kg TF/tonne.

After the introduction of GTCs, stack emissions have been reduced to a very low level, assuming that the evolved fluoride load to the GTC is maintained below 85% of the saturation level of the alumina [1]. Therefore, in order to achieve further reductions the next most productive target is the emission from cells during anode changes. Here is where high draft ventilation is most effective.

While there are different approaches to high draft ventilation, in this paper we focus on the so-called 'dual duct' type of high draft ventilation system. This system uses a separate (thus 'dual') but smaller diameter ventilation duct that runs parallel to the main ventilation duct. Depending on the situation, the extra flow from the high draft system is taken to the GTC or (in case there is no spare capacity in the existing GTC) taken to a smaller, separate GTC.

For each project it is recommended that during the planning phase several, often plant-specific, options are evaluated first. This is what happened in the early phase of the addition of Line 3 of the Alumar smelter in Brazil. Here a total of five options were developed and for each option comparisons were made of the total cost to install and the cost to operate.

Alcoa operates three smelters with high draft ventilation systems (Deschambault, Alumar and Fjarðaál) while a fourth smelter (the Ma'aden JV) is in the design phase. While it is an accepted practice to include high draft ventilation in the design of new smelters, very few existing smelters have actually been equipped with a high draft ventilation system. The smelter in Deschambault is a rare example of where a full dual duct high draft system has been retrofitted during full production.

Principles of High Draft Ventilation

In principle, high draft is the same as normal draft except for the flow rate of air drawn from a cell, which is a factor X higher. Under normal draft a particular vacuum is maintained under the closed hoods. This is sufficient to keep the gas collection near 99 percent during periods of no open cover panel activity.

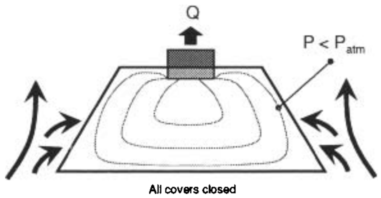

Figure 2 - Indicative pressure profiles during normal draft and all covers closed

The issue is that once covers are removed or doors are opened that the vacuum changes such that the tipping point from vacuum to positive pressure moves upwards inside the superstructure so that more of the cell gases can escape through the opening. In Figure 2 the normal situation is sketched while Figure 3 shows the effect of opening one or more covers (on one side only).

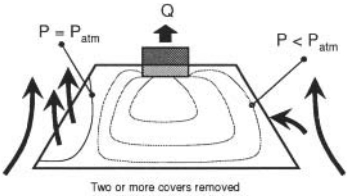

Figure 3 - Indicative pressure profiles when 2 or more covers are removed

After a cover is removed the pressure inside changes, especially around the area that is now open. Two important effects occur: First, the buoyancy of the cell gases is now strong enough that it overcomes the internal pressure and drives the gases outside the cell, and second, the natural draft of air around the cell (and from floor vents) creates a stack effect that further pulls the cell gases from the cell into the potroom [2].

To prevent the cell gases from escaping from the cell when one or more covers are opened the profiles must be restored so that the cell remains under a light vacuum. Dernedde [3] defined the flow under these conditions as the minimum ventilation flow Φ_M where the flow is just enough that all cell gases remain captured. From data taken from tests on a prebake cell, Dernedde subsequently developed a mathematical model that presents a relationship between the actual ventilation flow and the minimum required ventilation flow.

$$E = \frac{100}{1 + \left(\left(\frac{\Phi_M}{\Phi} \right)^{0.50} - 1 \right)^{1.50}}$$

With: E = gas collection efficiency, %
Φ = Applied ventilation flow, Nm^3/s
Φ_M = Minimum ventilation flow for E = 1, Nm^3/s

In this equation the minimum ventilation flow Φ_M is a function of how the cell is configured. Dernedde evaluated the draft under different cell configurations vs. the buoyancy of the cell gases and derived the following relationship for Q_M:

$$\Phi_M = (C_D \cdot A)^{0.67} \cdot \left(\frac{Q_H \cdot H \cdot g}{\rho \cdot c_p \cdot T} \right)^{0.33}$$

With: Φ_M = Minimum ventilation flow for E = 1, Nm^3/s
C_D = Orifice coefficient
A = Open area, m^2
Q_H = Heat released from the crust, W
H = Vertical height of one cover plate, m
g = gravity constant, 9.81 m/s^2
ρ = density of air, kg/m^3
c_p = heat capacity of air, J/kg.K
T = temperature of the air into the hood, K

Using these equations, engineers can design the ventilation system for normal draft and for high draft ventilation. The impact of this is summarized in Figure 4 where point 1 represents the case when all covers are closed and point 2 the case when 3 covers are removed. From the data in Figure 4 it is clear that under normal draft the gas collection efficiency is reduced once covers are opened. Under high draft the point where the collection efficiency starts to deteriorate is pushed away to the right allowing up to 3 covers, for example, to be removed with minimal impact on cell losses.

Please note that sometimes high draft ventilation is also referred to as 'double suction' ventilation. While some applications have shown that the high draft ventilation flow is twice the normal ventilation flow, one has to be careful that the high draft ventilation depends on a number of factors and needs to be evaluated case by case. For the purposes of this paper we shall refer to the use of 'high draft ventilation'.

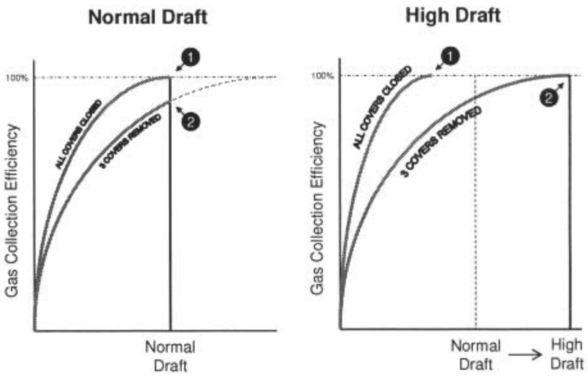

Figure 4 - The gas collection efficiency as function of the applied ventilation flow

Next, two important questions must be answered in the design phase:

- For how many removed covers must the ventilation flow be able to provide for 100 percent gas collection?
- How many cells (per GTC) will be under high draft ventilation at the same time?

With this, the high draft ventilation of a single cell is configured plus the complete system now starts to takes shape. The answer to question 1 will result in the design flow for high draft ventilation. A margin for error is needed (this is not exact science – the engineer will apply a safety factor) so that the design flow under high draft conditions exceeds the minimum calculated flow Φ_M.

Question 2 is a very practical question. Operators often need to split their activities and movements between cells and in some occasions they will work on one cell and open the covers on the cell that is next in line. In some cases this can be as many as three cells that have a number of covers removed. In this case the answer is three. In any case, this answer leads to the total flow under high draft conditions that need to be taken to the GTC either through the dedicated high draft duct or through the main duct.

Dual Duct High Draft System Design

The design for a high draft ventilation system in a new smelter is different from the design of a system in an existing smelter. Implementation in an existing plant is a considerably more complicated exercise. This is further explained in the following sections.

New aluminum smelters (Greenfield application)
In this case we refer to the installation at Alcoa's Fjarðaál smelter in Iceland. For this smelter the emissions limits are very low (≤0.35 kg TF/tonne Al) and the high draft ventilation is used here as a tool to achieve consistent low emissions from potrooms.

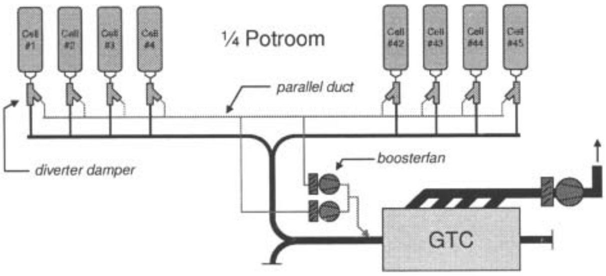

Figure 5 - Schematic of one section of high draft ventilation in a new smelter

Because the ventilation air flow from a cell in this system is redirected to the parallel duct, a diverter type of valve is installed (Figure 6). When the operator engages the high draft ventilation mode (also referred to as *maintenance* mode) this valve moves its position and enables the parallel duct to ventilate the pot gases at the high rate.

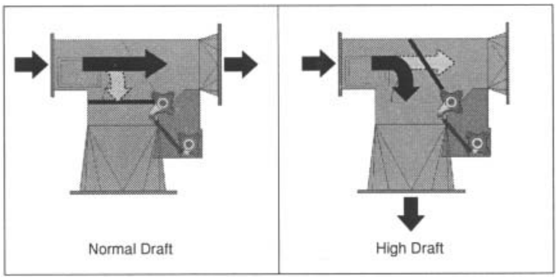

Figure 6 - Diverter damper

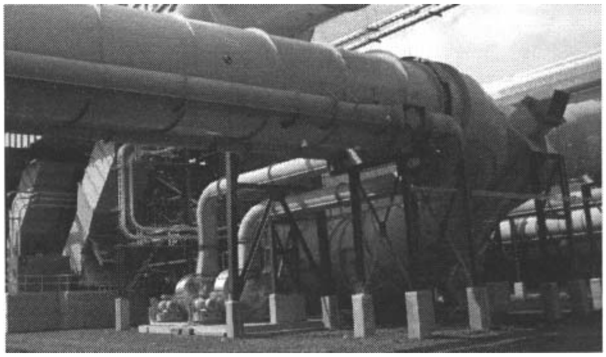

Figure 7 - High draft boosterfans at the Alcoa Fjarðaál smelter (Photo courtesy of Solios Environnement)

In order to create the high ventilation flow a lower negative pressure must exist in the parallel duct. Detailed pressure loss calculations will determine what this pressure is but it is inevitably different from what the main fans deliver. Therefore dedicated booster fans are used (See Figure 5 and Figure 7). Each has double the capacity for high draft ventilation so that the second booster fan can be stopped for maintenance, for instance. This way there is sufficient redundancy while capital costs are optimized.

In a new design the extra ventilation flow is incorporated in the total flow that is treated in the GTC. Sufficient filter compartments are provided and the main exhaust fans are sized properly to work optimally in the design points.

Existing aluminum smelters (Brownfield application)
There are several considerations for a smelter to install a high draft ventilation system:

- Tighter regulatory standards or working within a unit mass per unit time permit restriction
- Creating better working local conditions in the potroom during anode changes
- A considerable reduction of total fluoride emissions is required
- Over time several line amperages increments have occurred, thereby increasing open pot work and emissions into the potroom so that more flow under normal draft is required.

One of the major constraints is that the GTCs are likely to run at 100 percent of their capacity. It is not a common practice that GTC operations are adjusted to changes in the potline such as line amperage increases. In other words, the normalized ventilation flows remain unchanged over time. However, higher amperages generate higher heat losses to the ventilation air and the average gas temperatures increase to a point the GTC operation and performance are negatively impacted. Higher temperatures push the air-to-cloth ratios and can also cause increased fluoride emissions from the GTC.

Figure 8 - Dual duct high draft ventilation at Alcoa Deschambault with at the right the smaller, dedicated GTC to handle the extra flows

- If there is no room to accommodate the flow requirements for high draft ventilation then an alternative solution must be found. One solution that has successfully been applied is to add a small GTC besides the exiting GTC, as shown in Figure 8 and Figure 9.

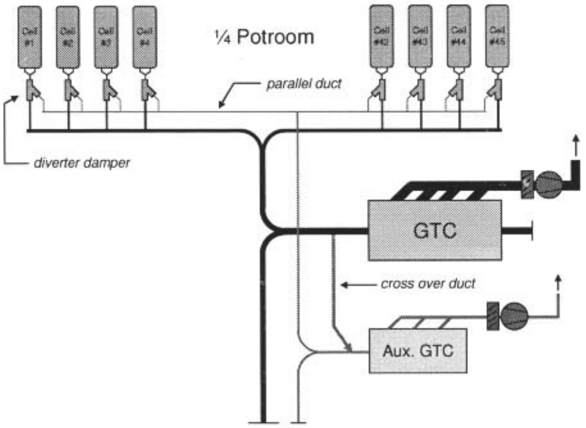

Figure 9 - Schematic of one section where high draft ventilation is applied in a Brownfield application

What needs special attention is the challenge of installing a high draft system while a potline is in operation. Each cell needs a tie-in by removing a piece of existing ductwork and replacing this with a diverter damper. This operation needs to be done very quickly. During the change over all draft is lost and emissions escape freely. However, this installation must also be executed very carefully because of the imminent electric dangers that exist while working on parts that connect directly to the superstructure. This meant that during the project in Deschambault special installation tools needed to be developed to safely install all different shaped ducts and pieces without any injuries.

Benchmarks without High Draft Ventilation

The case for high draft ventilation, in specific using a dual duct system, has been put forth as a means to achieve lower levels of fluoride emissions primarily during anode change. Many smelters in the world regard this technology to be the price of admission to attain total fluoride emission rates of less than 0.40 kg TF/tonne. However, this is not necessarily the case. Emission rates below 0.30 kg TF/tonne Al have successfully been attained at some Alcoa smelters without the use of high draft ventilation.

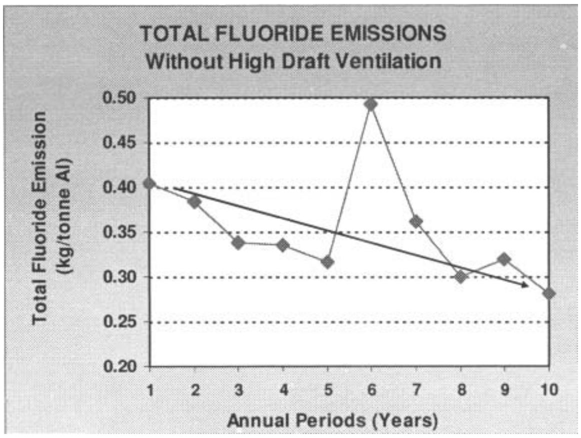

Figure 10 - Total fluoride emissions without high draft ventilation

As illustrated in Figure 10, the total fluoride emissions (combined pot room roof emissions and the GTC stack emissions) can be sustained at, or below, 0.30 kg TF/tonne as an annual average. In this case it should be noted that hot butts have been removed from by transport vehicles to an area of fume capture and treatment for more than 20 years.

There are multiple factors that contribute to this success. Dedication and commitment of the work force is essential. This includes the proper management of draft on pots using a single duct system with dampers at each cell. When the operator puts the pot into a status that requires covers to be removed, the system automatically goes into the high draft mode for that pot. After a certain number of minutes the system times out and is returned to the normal damper position.

The dual duct system provides significant improvement of capture of emissions from the pot as compared to single-duct dampered systems that rely upon manual placement into the proper drafting position. The greatest shortcoming of this approach is that pots that are left in the improper draft position can greatly detract from overall emission performance of other pots and the potroom.

The location that achieved the impressive result shown in Figure 10 has taken extra measures to assure that the overall system is tightly sealed to prevent in-leakage between the main fans and the reduction cells. They also place strong emphasis on regular checks of the system balance of flows from each cell.

What is most significant to the steady decline in the emissions baseline observed in Figure 10 has to do with how normal, or low, draft is managed. As equipment, pot covers and work practices were improved it became possible to reduce the normal drafting of the cell to levels below what is typical for modern technology. In effect this is a reduction in Derneddes's open area factor, A, that is used to estimate minimum cell ventilation.

When combined with the other efforts to prevent in-leakage and to balance the system, this allows a pre-existing system to deliver greater suction and exhaust flow when it is needed at a cell. Exhaust rates may then be increased by >50% at every reduction cell when it is needed during anode change or other operations.

This more efficient use of exhausting is not unique to this location, but it is somewhat uncommon in our industry. There are multiple advantages to be gained by placing focus on low draft that is indeed low and high draft that is at a maximum when needed. Most of these advantages are in costs, but there are process control benefits as well.

With this example given it is possible to reset some of the common perceptions around dual duct systems. They do open the door to lowering rates of fluoride emission. However, the absolute threshold is closer to <0.30 than 0.40 kg TF/tonne Al with a single duct system.

Benchmarks with High Draft Ventilation

Examples have been given in this paper on the reduction of fluoride emissions that are achievable with the installation of high draft ventilation systems. These systems can greatly reduce emissions provided they are designed, maintained and used properly.

Residual fluoride emissions will primarily exit the pot room roof during anode changing, which is shown in Figure 1. If the gas treatment center (GTC) is not followed with wet scrubbers there will also be a few one-hundredths of a kilogram per ton of emissions from the stacks of these systems as well.

Figure 11 shows what might be expected after the installation of high draft ventilation and other world class technologies and practices are implemented and maintained. These are annual average values for the best smelters in the world in the year 2008. Most, but not all, of these top performing smelters use dual ducts.

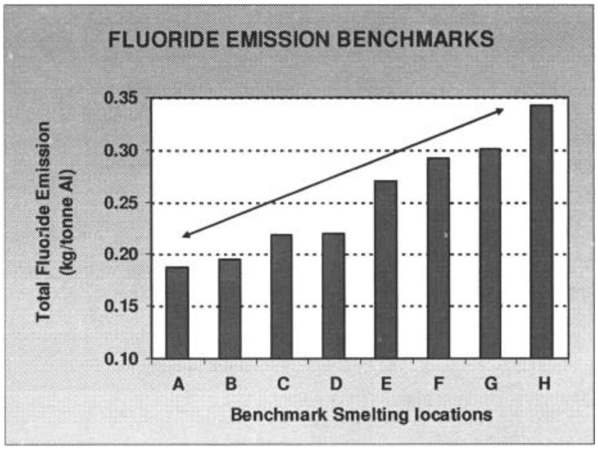

Figure 11 - Total fluoride emissions from benchmark smelters

Benchmark performance beyond this graph has been recently identified at 0.16 kg TF/tonne Al and at 0.13 kg TF/tonne Al at one smelter that had exceptionally good performance over a nine month period.

Figure 11 gives examples of fluoride emission performance that can be achieved using high draft ventilation systems at smelters with extremely demanding emissions limits and air quality standards. It will also apply to mega-smelters that strive to have no significant impact upon sensitive vegetation beyond the buffer zone around the facility.

So far, the data presented in this paper shows overall results of what smelters can achieve. However, there was a rare occasion where it was possible to capture the overall impact of a dual duct ventilation system. This is associated with the start-up of the dual duct system in Alcoa's Deschambault smelter during the fall of 2002. Here it was possible to collect total fluoride emissions data from roof monitors prior to and after the start-up. This data is shown in Figure 12. Please note that during 2001 the plant also started using enclosed pallets to transport spent anodes and bath. This lowers the HF part of the total fluoride emissions and is included in the trend in Figure 12.

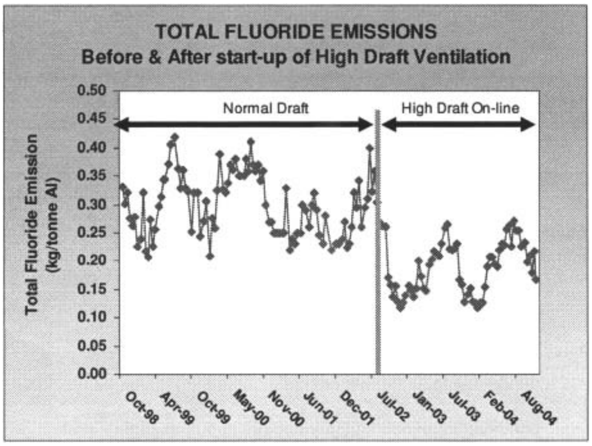

Figure 12 - Fluoride emissions recorded on roof monitors before and after the start-up of the high draft system in Alcoa Deschambault

It can be clearly seen that the total roofline fluoride emissions have been reduced after start-up of the high draft system. Moreover, the variability in the emissions (outside of variations in emissions due to the seasonal variation in ambient conditions) was greatly reduced once the high draft system was on-line. This is another important aspect for operations.

The geographical location of a smelter will impact any seasonal trends observed in monthlyemission performance. Deschambault has cooler, shorter summers than a smelter in the Middle East, for instance. The seasonal trending shown in Figure 12 clearly reflects this impact.

Future considerations

High draft systems are being used but there is still limited long term experience available. Some of the current experience is that to keep the full benefit of the system one has to maintain it well. Furthermore, improvements are needed to increase the consistency. For instance, flow detection should be considered in all high draft connections to ensure the right amount of draft is established. This is not always evident.. Also the position of the valve should be monitored more closely.

Other considerations relate to the increasing temperatures of the ventilation air. The use of high draft ventilation is also a good tool when both temperatures and emissions need to be reduced. Presently, temperature reduction is not a key design factor but can be in future designs of systems for existing smelters.

Conclusions

Dual duct-based high draft ventilation systems present an important, technology based option that, when combined with practical measures such as enclosed spent butt and bath pallets, enable smelters to achieve world-class levels (~ 0.2 kg TF/tonne Al) of fluoride emission performance. These systems are rapidly becoming cost-of entry mandates for greenfield smelters.
It is a tool that can be considered in existing smelters but then, based on the experience gained from the Alcoa Deschambault project, planning and installation must be done very carefully.

At this point it is not certain how reductions of the last 0.2 kg TF/tonne Al will be addressed or achieved. If pot tending machine technology is somehow modified to capture fumes during work activities it will very likely be tied in to the gas treatment systems or use portable, crane-mounted "capture stations." While "triple duct" technology is unlikely, additional ducting from gas treatment centers to capture and control point sources of fugitive emissions (other than from cells) may be the way of the future beyond dual duct technology.

Cost-effective methods for continuously monitoring the status and "health" of the ducting systems presents an option for minimizing periods of sub-standard ventilation flow.

The practical limit for existing locations installed with single ducted systems is <0.30 kg TF/t Al.

For locations with dual ducted high draft ventilation systems the practical limit has been demonstrated to be <0.20 kg TF/t Al.

Current world benchmarks for annual averages of total flouride emissions from the pot room roof plus dry scrubbing systems typically in cooler climates, are in the range of 0.15 to 0.20 kg TF/t Al. Less than 1% of our industry currently attains this standard of performance.

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