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Factors Influencing Cell Hooding and Gas Collection Efficiencies

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Abstract

In modern aluminium electrolysis cells the hooding and gas collection efficiencies are important design parameters to improve productivity and reduce environmental pollution. Hooding efficiency is the result of a variety of design parameters for the anode superstructure. The factors that determine the gas collection efficiency are described by simple physical models. Measurements of HF emission rates into the potroom were made with our self-developed HF monitor. Forced gas suction rate during cell operations will in general reduce the HF emission from the potroom. By optimising the gas suction rate and operational routines it may be possible to reduce emissions from the anode changing operation by approximately 75%. Ventilation rates through the potroom were found to have a significant influence on the emission level, depending on the suction rate employed in the cells.

Introduction

When the Norwegian aluminium smelters were built, they were located close to the electric power station, because transport of electricity over long distances in those days would inevitably lead to considerable losses. So far all the electric power production in Norway has been hydro electricity, and the smelters were located at the end of a waterfall in narrow valleys surrounded by high mountains.

With such a location of the aluminium smelters the fluoride emissions from the electrolysis cell operation could pollute the local environment. Norwegian smelters therefore have focused on emission control.

The fumes produced during operation of aluminium electrolysis cells consist mainly of gaseous and particulate fluoride-containing compounds. They exit from the cell into the main gas duct system and are transported to the dry scrubber, where fresh alumina is used to remove the pollutants from the fumes. This "reacted" or "secondary" alumina is then transported to the electrolysis cells and is used as ore or feed material to the molten electrolyte for production of aluminium. The major improvements made in dry scrubbing technology have now resulted in the capture of more than 99.5 % of the fluorides evolved from the cells.

The fumes from the cells are initially contained within the cell enclosure or shielding system, which is mounted on the cell superstructure. For prebake anode cells in Hydro Aluminium this shielding consists of separate covers that can be moved or removed from the cells. The majority of gaseous fume losses occurs when the covers are removed during normal cell operations, especially anode changing. However, even when the covers are closed, there may be significant losses of fluorides into the potroom atmosphere. Because of the high efficiency of modern dry scrubbers, the major fluoride losses from modern smelters now originate from emissions escaping through the potroom roof.

Hydro Aluminium has developed its own aluminium electrolysis cell technology for about thirty years now. The fluoride emission regulations from the Norwegian environmental authorities, together with our increased knowledge about nature's own tolerance for pollution, have had direct impacts on our cell design. This has been an incentive for incorporating an efficient and functional hooding of the cells. Thus, the anode superstructure has been redesigned to increase both the hooding efficiency and the gas collection efficiency of the cells.

For Hydro Aluminium's newest technology a hooding efficiency of 99.5 % and an overall gas collection efficiency from the potroom of 99.5% should be achievable.

Definitions

The gas collection efficiency is defined as the ratio of the amount of gas and dust that is collected and transported to the dry scrubber, divided by the corresponding total evolution from the cell, and is given in per cent. This implies that the gas collection efficiency is also a measure of the total amount of emissions per unit of time, and thereby it directly influences the maximum number of cells and the total production capacity of the aluminium smelter with respect to the tolerance of the local environment for fluorides and other emissions.

Thus, it is important to make the shielding of the cell superstructure as gas tight as possible. The definition of the hooding efficiency is the ratio of the amount of the hooding surface area that is open from the cell superstructure to the surrounding atmosphere in the potroom when the covers are in position, and the total surface area when all the covers are removed. The hooding efficiency is then a measure of how gas tight the shielding of the cell is. A high value also increases the gas collection efficiency and thereby causes less pollution and gives a better working atmosphere for the potroom operators.

Factors influencing the hooding and gas collection efficiencies

In the literature little has been published concerning the factors that affect the hooding and gas collection efficiencies (1, 2). The purpose of this paper is to discuss our efforts to reduce the cell emissions from the prebake anode cells in our smelters. Particularly, the work to improve the hooding and the gas collection efficiency will be described in detail.

The number of potential parameters influencing the gas collection efficiency is extensive. Here is a list of some of the most important ones:

- Gas exhaust flow rate, or gas suction rate (in a closed cell, and also during manual work on the cell when one or more covers are removed)
- Draft (pressure) inside the cell superstructure
- Shielding and cover design (width of the covers relative to the distances between the anode rods)
- Hooding efficiency
- Space or openings between the covers of a closed cell (with all the covers on)
- Space in the hooding during manual operations on the cell
- Shield and cover maintenance
- Constructional tolerances of the superstructure and the covers
- Space between the anode rod and the superstructure
- Number of covers removed during an anode change
- Carbon anode dimensions (surface area)
- Number of anodes changed simultaneously
- Working routines (performance and duration)
- Ventilation along the pot shell and through the gratings between the cells and up through the roof of the potroom
- End-to-end or side-by-side cell design
- Cell cavity and hooding design

Forced suction system

Hydro Aluminium's gas collection system has two different operational modes. A normal suction rate, 5000 Nm^3/h per cell, is used when there is little or no manual work done on the cell. Little activity here implies that maximum one cover is removed from the cell.
A forced suction rate of 15000 Nm^3/h per cell is used when there is high working activity on the cell. High activity here implies that more than one cover, but never more than three, are removed. Forced suction is used in connection with manual operational routines like anode changing, covering of newly set anodes with alumina, anode effect quenching, and cell redressing.

Both the system for forced suction and the main gas duct system are divided into groups of 12. Each forced suction group has its own fan that is set in operation when manual work is done on the cells. Not more than one cell in a suction group is to be serviced at the same time, due to the system characteristics.

When the forced suction system is activated, the duct for the normal suction is closed by a flow damper, and the fan is started. The process gases are then led through the forced suction duct. This means that the main suction system is affected only to a minor degree when the forced suction system is in operation, and the fumes are then led into the main gas duct to the dry scrubber.

Theory

Simple models to explain how hooding, suction and ventilation influence emissions from HAL 230 kA cells

In Hydro Aluminium the model program FLUENT is one of the tools used to design new cell superstructures. The suction rate from the cell, the hooding and the ventilation around the cell are simulated in order to maximise the gas collection efficiency. The influence of the factors that determine the gas collection efficiency may be described by simple physical models.

The effect of hooding efficiency and gas suction rate on the under-pressure in the anode superstructure

The anode superstructure is modelled as shown in Figure 1. A volume or mass flow (M) of gas is sucked out of the cell, and heat (Q) is added to the gas. Air is flowing in through open areas where covers have been removed, or through small openings between the covers when the cell is closed.

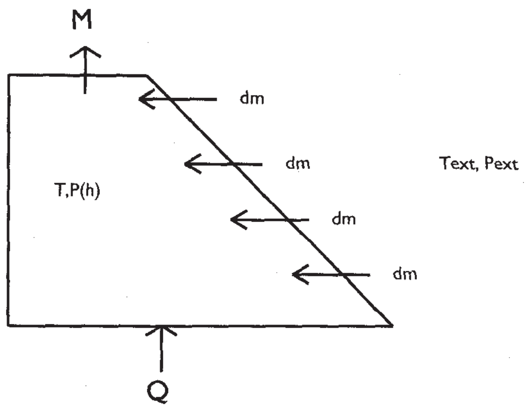

Figure 1. Factors influencing hooding, suction rate and under-pressure in the cell superstructure

M	Mass flow	(kg/s)
Q	Heat loss from the cell to the gas	(W = Nm/s)
T	Temperature	(K)
P	Pressure	(Pa = N/m^2)
h	Height (h = 0 at the deck plate)	(m)
dm	Incremental mass of air	(kg)

The temperature inside the anode superstructure of the cell is given by the equation:

$$\Delta T = \frac{Q}{M \cdot C_p} \quad (1)$$

where:

C_p Heat capacity of air (J/kg/K)

At each height increment (dh) an incremental mass of air (dm) flows into the cell, which is described by the equation:

$$dm = B \cdot dh \sqrt{\frac{2\rho}{C_d}} \cdot \sqrt{P_{ext}(h) - P(h)} \quad (2)$$

where:

B Width of the opening at a height increment dh (m)

ρ Density of air (kg/m^3)

C_d Dimensionless constant describing pressure loss over the opening

The pressure difference over the opening at height h is given by the equation(3):

$$P_{ext}(h) - P(h) = \Delta P - \left(P_{0(1atm)} \cdot g \cdot h \cdot \frac{M_d}{R} \cdot \left(\frac{1}{T_{ext}} - \frac{1}{T} \right) \right)$$

Where:

g	Gravitational acceleration	(9.82 m/s^2)
ΔP	Draft (pressure) at h = 0	(Pa = N/m^2)
M_d	Molar weight of air	(29 $\cdot$ 10^{-3} kg/mol)
R	Gas constant	(8.314J/molK=Nm/mol K)
$P_{0(1atm)}$	Pressure at 1 atm	(Pa = N/m^2)

The term ΔP in equation (3) represents the pressure loss through the openings in the hooding, while the term $P_{0(1atm)} \cdot g \cdot h \cdot \frac{M_d}{R} \cdot \left(\frac{1}{T_{ext}} - \frac{1}{T} \right)$ represents the chimney effect under the anode superstructure. When the chimney effect is larger than the pressure loss through the opening at height h, gas flows out of the anode superstructure. The term ΔP in equation (3) is determined by the open area in the cell superstructure (hooding efficiency) and the suction rate. When covers are removed from the electrolysis cells, the suction rate is increased to keep ΔP larger than the chimney effect. This ensures a high gas collection efficiency even when work is performed on the cell.

Equation (3) is then substituted into equation (2), which is integrated from h = 0 to h = H. This gives:

$$M = B \sqrt{\frac{2\rho}{C_d}} \cdot \frac{2}{3X} \cdot \left(\Delta P^{\frac{3}{2}} - (\Delta P - X \cdot H)^{\frac{3}{2}} \right) \quad (4)$$

where:

$$X = P_{0(1atm)} \cdot g \cdot \frac{M_d}{R} \cdot \left(\frac{1}{T_{ext}} - \frac{1}{T_{ext} - \frac{Q}{M_d \cdot C_p}} \right)$$

To use this simplified model in practice we need to know some specific data about the anode superstructure that we are investigating, such as the total opening area of the cell when all the covers are removed. Then we need to know the opening in the shielding due to the tolerance limits for construction of the cell. Further improvement in the hooding (reduction of the opening area) is achieved by using other shielding devices, such as "lips" and anode rod collars, as shown in Figure 2.

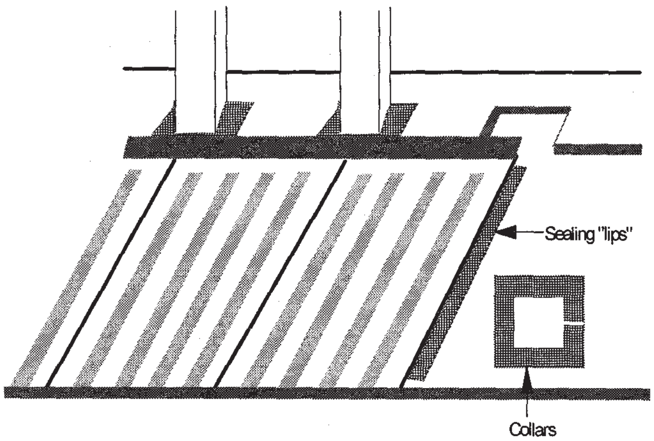

Figure 2. A sketch of extra shielding devices used on HAL230 kA cells.

For the HAL230 kA cell the following construction parameters are valid:

Total opening area:	40.8 m^2
Opening area with all covers on:	0.6 m^2
Hooding effeciency	98.5 %.
Opening area with extra shielding devices:	0.2 m^2
Hooding effeciency	99.5 %.

If we introduce the value for the minimum opening area in the model, it is possible to calculate the minimum gas suction rate needed to maintain the draft inside the superstructure and the gas collection efficiency. This means that the pressuredifference between the draft from the suction system and the pressure from the chimney effect should always be less than zero (pressuredifference ≥ 0 measured inside the superstructure means emissions to the working atmosphere).

The model is important for determination of the width of the covers, the anode dimensions and the number of covers that may be removed during cell operations like anode changing etc., with a fixed gas suction rate.

A summary of different calculations concerning gas suction rates and opening area (number of covers removed) is shown in Figure 3. The input to the model is as follows:

B	Width of the opening in the shield, for instance the width of the covers and the number of covers removed	(m)
M	Mass flow (Gas suction rate)	(kg/s)
T	Internal temperature	(°C)
T_{ext}	External temperature	(°C)
H	Distance (height) from the deck plate to the gas skirt	(m)
C_d	Dimensionless constant describing the pressure loss over the openings in the shielding, which varies between 0.6 and 1.4.	

Figure 3 represents the probability for emission to the potroom atmosphere. If the over-pressure > 0, process gases will most likely escape to the potroom atmosphere and pollute the potroom and the surrounding environment.

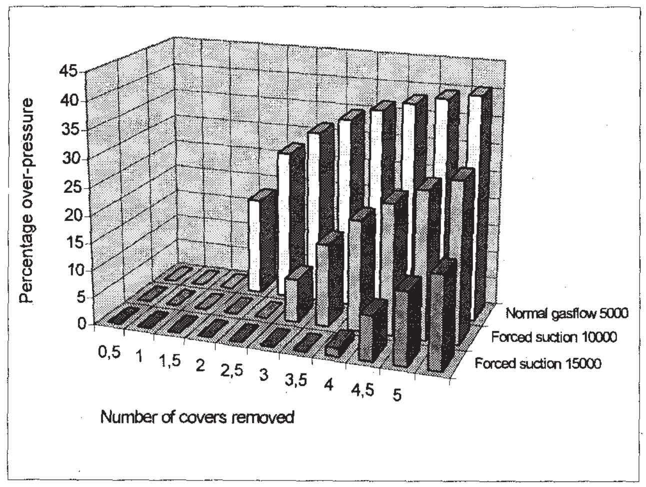

Figure 3. Model calculations of the percentage of the over-pressure inside the hooding as a function of the number of covers removed and the gas suction rate.

As long as the over-pressure is < 0, no fumes escape to the working atmosphere. Obviously it is possible to remove more covers, and thereby increase the opening in the shield and still avoid emissions, as the gas suction rate is increased. This means that all the process gas goes into the gas suction system and are transported to the dryscrubber, and no emission to the potroom atmosphere will occur.

The effect of ventilation on the gas collection efficiency

Measurements have shown that the gas collection efficiency depends on the potroom ventilation rate, or more specifically on the air flowing upwards along the side of the cell. FLUENT simulations have confirmed this. The effect is visualised with simple vectors (Figures. 4 and 5). The air flow up along the potshell is highly turbulent and thus very complex, and the simple vector model described below is used only to illustrate the principle. A horizontal vector represents the air flowing into the anode superstructure. A vertical vector represents the air flow through the gratings in the potroom floor along the cell. The resulting vector then represents the direction of the air flow.

The influence of the air flow along the cell on the flow into the cell is illustrated in Figs. 4 and 5. The examples are given for the case of two covers removed. The shaded area represents the angle of the position of the covers. The dashed line represents the resulting vector from the ventilation air and the air that is sucked into the cell. It is shown that the influence of the ventilation on the emissions through the openings in the superstructure becomes more important at low suction rates.

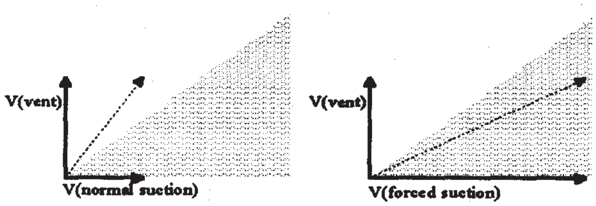

Figure 4. Ventilation rate according to the basic design of the Hydro Aluminium potrooms.

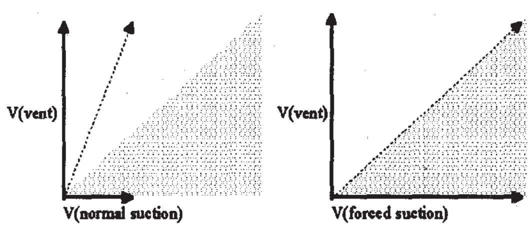

Figure 5. Double ventilation rate compared to the basic design of the Hydro Aluminium potrooms.

Experimental and discussion

Factors influencing the hooding and gas collection efficiencies

In 1992 Hydro Aluminium started to work on improving the hooding and gas collection efficiency by investigating the emission status of the existing prebake (PB) lines in Norway. These PB lines had different technologies supplied by different companies and should therefore have different hooding and gas collection efficiencies. By using Hydro Aluminium's HF monitoring system it was then possible to distinguish between the emissions into the potroom from different cell operations and from the cell construction itself. The result from such a stydy should clearly show where to attack to accomplish higher hooding and gas collection efficiencies. The work is now in continuous progress. Five different cell technologies were monitored, three side-by-side and two end-to-end PB lines. The results from potline K3/K4 are from 1995, potline Hø-A from 1993, and potlines Å1 and Å2C from 1995.

The results of the investigation are shown in Figure 6. An HF monitor developed by Hydro Aluminium, as described by Foosnæs et al. (3), was used to measure the HF emissions. The draft in the cell was measured by a manometer, and it was then possible to show how poor hooding practice gave increased background emissions (no manual work was done on the cell).

Further investigations about different working routines and the corresponding emission levels taught Hydro Aluminium a lot about cell hooding and construction. For instance, it is clear that side-by-side and end-to-end cells have different characteristics in connection with the working routines and the overall emission to the potroom.

After this investigation was performed, there has been more focus on working operations in the potroom and their contribution to the overall emission. This has resulted in improved gas collection efficiency in the Hydro Aluminum PB lines.

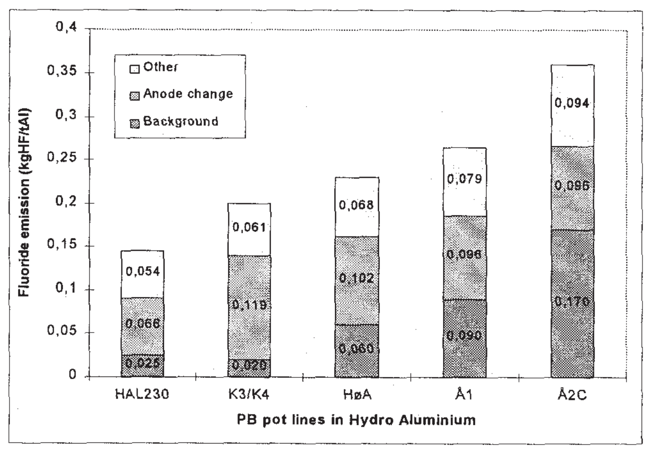

Figure 6. Monitored fluoride emissions from different Hydro Aluminium prebake potlines. The data represent the net emissions from the potroom operations as a part of the average emission through the potroom roof.

Background - Emissions when there is no activity on the cells in the potroom. It represents the hooding efficiency or emission due to the construction of the anode superstructure.

Anode change - Emission due to the anode change itself as a part of the average emission measured.

Other - Emission due to other cell operations in the potrooom as a part of the average emission measured.

Hooding efficiency measurements

In practice the hooding efficiency is determined by the gas exhaust flow rate and the design of the covers. These two parameters also determine the gas collection efficiency. The latter may be experimentally measured by determination of the draft (negative pressure) inside the cell superstructure, relative to the pressure of the working atmosphere in the potroom. This negative pressure, which is caused by the hooding itself and the gas suction rate, determines whether the fumes will be transported into the gas collection system or leak out into the potroom atmosphere.

During our measurements on the cells in Slovalco`s HAL230 kA potline in Ziar nad Hronom in Slovakia, the static pressure was measured (given in mm H_2O). A micro manometer was placed at three different positions under the covers on each side of the cell, and at three different heights for each horizontal position. The hooding efficiency was then measured as a function of the gas suction rate and the conditions of the covers and their seals with respect to gas tightness.

The following parameters were varied during these pressure measurements:

1. The anode superstructure without any extra shielding devices
2. With sealing "lips" on the covers (two on each side)
3. With square collars around the anode rods
4. With both square collars and sealing "lips"

The pressure measurements for these four cases are shown in Figure 7. It is seen that the draft clearly increases with tighter sealing. The higher the draft is, the better is the hooding efficiency. Forced suction is considerably more efficient than normal suction with respect to achieving high draft and good gas collection efficiency.

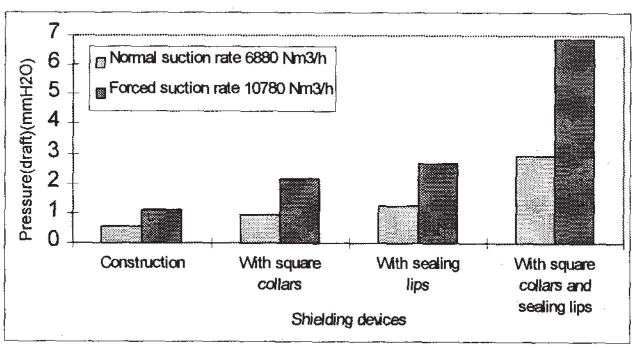

Figure 7. Draft in the hooding with extra shielding devices, measured in a HAL230 kA cell in Slovalco, with normal and forced gas suction rate.

The background emission was measured with all covers on and no manual work done on the cell. In order to determine the hooding efficiency during certain cell operations, the pressure was measured when one or more covers were removed from the cells. In this particular case a maximum of three covers were removed at the same time. Figure 8 shows how the measured pressure varied with the gas flow suction rate for two different cells in the same potline. The measurements were done with sealing lips on both cells and with and without the use of collars around the anode rods.

The absolute pressure value was found to be above 0.4 mm H_2O for cells with forced gas suction. This is very close to the calculated limit for the pressure at which the fumes will start to leak out through the shielding and into the potroom. For these cells at Slovalco, a normal gas suction rate of 7000 Nm^3/h per cell was employed, and the measured absolute pressure value was then found to be **below** 0.4 mm H_2O when three covers were removed. This means that a cell with forced suction will be tight enough to collect the fumes even with three covers removed, whereas with normal suction the fumes will flow out into the working atmosphere if more than one cover is removed.

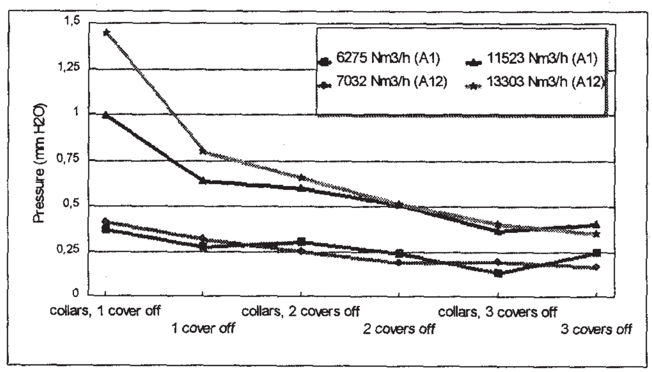

Figure 8. Average static pressure measured with one, two and three covers removed, for normal and forced gas suction rates.

This effect was demonstrated visually by placing a smoke indicator under the hooding of one cell and then varying the gas suction rate. While the smoke leaked out from the hooding with two or three covers removed at normal suction rate, it was kept inside the hooding and collected by the main gas duct system when forced suction was started.

Measurements of HF emission rates

HF emission rates from a single HAL230 kA cell were measured with the above-mentioned HF monitor. The parameters varied in this experiment were the number of covers removed (two or three), the number of anodes taken out simultaneously (one or two), and the gas suction rate (normal or forced). The practical purpose of varying the number of anodes taken out, is to study the effect of a double anode change, and thereby determine if the total open surface area of molten electrolyte has any influence here. These measurements are illustrated in Figure 9.

With a normal gas suction rate the HF emissions seem to increase with the number of covers removed and with the number of anodes taken out, but the differences are not statistically significant.
When two anodes are being changed simultaneously, this can reduce the accumulated time when the covers are removed during the day. Thereby the HF emissions can be reduced correspondingly, even with normal suction rates. One of the purposes of a double anode change is to keep the same number of operators for each anode change, while reducing the total number of anode changing operations by 50 %. Thus, the exposure of each operator to fluoride emissions will not be reduced in the same way as the total emissions. This makes forced gas suction necessary, because high fluoride exposure during anode changing will be unacceptable according to new standards for the working atmosphere.

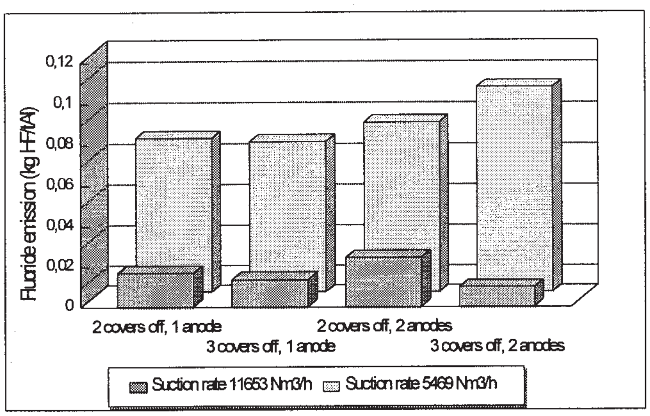

Figure 9. The effect of gas suction rate on HF emissions from a HAL230 kA cell. The number of anodes removed and the number of covers removed, are varied.

The most important effect seen in Figure 9 is certainly the influence of the forced suction rate on the HF emission. Statistical treatment of these data shows that only the gas suction rate has a significant effect on the HF emission rate. Increased suction rate up to 15000 Nm^3 gives reduced HF emissions, especially from the anode changing routine.

Measurements of the effects of air ventilation rates in the potroom

In modern potrooms the ventilation system is important to improve the internal working conditions for the operators. In most cases air is entering from the basement and up through the gratings between the cells.
When the covers are removed from the cell during an anode change, the air ventilation from the basement may draw gases and dust out of the cell and thereby cause increased fluoride emissions.

This was studied experimentally. The effect of the air ventilation rate along the side of the pot shells and up through the gratings in the potroom floor was determined by measurements using the HF monitor. Twenty-five cells were covered by the monitor, and the HF emissions during anode changing, with two covers removed (HAL230 standard procedure), were measured.

The results are shown in Figure 10. It is seen that for the lowest gas suction rate of 8780 Nm^3/h, the air ventilation rate has a significant influence on the HF emissions. A doubling of the air ventilation rate gives a corresponding increase by a factor of two in the HF emissions during anode change. On the other hand, when the gas suction rate was increased to 10500 Nm^3/h, the air ventilation rate had a much smaller effect.

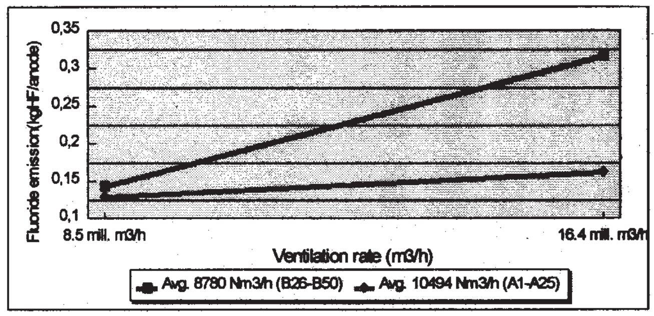

Figure 10. Effect of ventilation and gas suction rate on HF emissions.

It is the resulting velocity vector from the product of the air velocity vector into the cell and the air velocity vector up through the gratings in the potroom floor, that determines whether air will be drawn into or out of the open cell. Thus, these measurements have shown that increased gas suction rate can practically reduce and even eliminate the negative effects of the air ventilation into the potroom. Another way to attack the problem of correlation between the gas collection system and the potroom ventilation system, is to reduce the air velocity through the gratings by simply increasing the width of the gratings.

Emissions independent of hooding and gas collection efficiencies

Emissions caused by the anode changing routine consist of three different contributions:

- emissions from open bath (dependent on suction rate)
- emissions from warm butts
- emissions from the bath cleaning operation

Emissions from warm butts:
The experiment was performed on a single HAL230 kA cell at Hydro Aluminium R&D center in Årdal. One anode butt

was taken out of the cell and left for free HF evolution to the potroom. At the same time the cell was closed as soon as possible after the anode butt had been removed, and no bath cleaning was performed. The HF emission from the single anode butt was monitored for 2.5 hours. At this time the HF level in the potroom had reached the background level. The experiment was repeated five times.

Emissions from bath cleaning and warm material from the same routine:

This experiment was performed on the same cell as described in the case for the warm butts. The removed material (2 to 3 operations of the clam shell) from the bath cleaning routine was placed in the potroom for 2.5 hours, and all the HF emitted to the potroom was monitored. After this time the HF level in the potroom had reached the background level. The experiment was repeated five times.

From these two experiments it is possible to distinguish the contribution from warm butts and warm material from the bath cleaning routine from the total emission from the traditional anode changing routine, as shown in Figure 11.

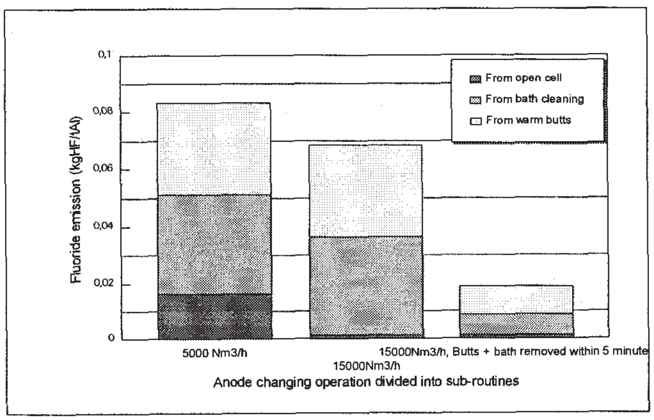

Figure 11. Emissions from the anode changing routine as a function of gas suction rate divided into sub-routines.

From Figure 11 it is evident that it is possible to reduce the fluoride emissions from open cells with open bath by approximately 50 % by use of forced gas suction at a rate of minimum 15000 Nm^3/h. The rest of the emission from the anode changing routine is mainly from warm butts and from warm material from the bath cleaning routine, plus a small portion due to the background emission level.

The future concept for the anode changing routine in Hydro Aluminium will be to reduce the time the warm materials are emitting fumes to the potroom to a minimum. If the warm butts and the warm material from the bath cleaning routine are removed from the potroom and the evolved pollution lead to the gascleaning system within five minutes, it is possible to reduce the overall emissions from the anode changing routine by approximately 75 %.

Conclusion

When the cell design is optimised with respect to hooding, gas suction and ventilation, the gas collection efficiency from the cell will be close to 100 %. It remains to evaluate other sources of emissions from the potroom. The greatest challenge here lies in obtaining an efficient transport of anode butts and molten or solid cryolite in the form of material removed from the bath by the clam shell during anode changing, as well as after bath tapping. An optimized system for handling of all powder materials in the potroom, including also alumina and aluminium fluoride, needs to be developed.

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