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JET INDUCED BOOSTED SUCTION SYSTEM FOR ROOF VENT EMISSION CONTROL: NEW DEVELOPMENTS AND OUTLOOKS

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Abstract

Reduction of fluoride emissions is necessary today as a result of production growth and/or increasingly demanding environmental regulation contexts.

Over 40% of roof vent emissions are generated by the pot during periods when pot hoods are open. These periods are therefore targeted for improvement, which is usually obtained by significantly increasing pot exhaust flow while the hoods are opened.

The Rio Tinto Alcan solution, patented since 2007 [1], the Jet Induced Boosted Suction system, trialed and now rolled-out on AP22 potlines in Tomago, has been scaled up to fit AP3X technology. This has led to implementation of an industrial demonstration on a 36-pot section in the Alma smelter, including automatic pot hood opening detection. The operational and environmental performance of the system was evaluated during the trial. At the same time, the design and proof of concept of an AP60 version has taken place in LRF, preparing for future evaluation as part of the AP60 Jonquière project.

Introduction

All industries are under increasing scrutiny to reduce the environmental footprint of their operations and processes. The aluminium industry is no different, and aluminium smelters are under ever-increasing pressure to minimize their environmental impact for both existing operations and new plants. This is particularly challenging when production is increased at the same time, which is now the case for many smelters.

Fugitive emissions from aluminium reduction line roof vents are typically between 75% and 95% of fluoride emissions from an aluminium smelter. As illustrated in Figure 1, over 40% of these roof vent emissions are generated by the pot during periods with opened hoods, mainly during anode change. This contribution can be minimized by reducing the total time that hoods are opened and/or significantly increasing pot exhaust flow during this operation, through the use of a dedicated Boosted Suction System [2, 3].

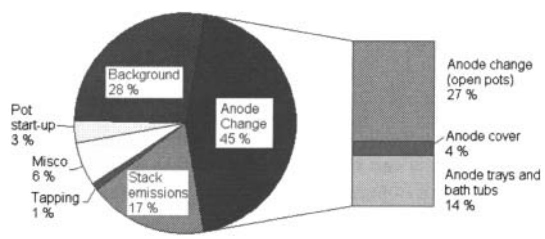

Figure 1. Estimation of the individual contributions of the main sources of fluoride emissions from one smelter.

Jet Induced Boosted Suction System (JIBS) development

Boosted Suction systems aim at significantly increasing exhaust flow when hoods/tapping doors are moved, mainly during the Anode Change and tapping shift, in an attempt to maintain a minimum negative pressure inside the pot superstructure and consequently collecting most of the emissions.

The initial developments on AP2X pots

Traditional Dual Duct Boosted Suction systems require heavy capital investments, a fact that has prevented their widespread deployment. In this context, Rio Tinto Alcan has developed a lower cost alternative to this traditional design, the Jet Induced Boosted Suction system, first for AP2X technology at the Tomago Aluminium smelter in Australia.

The Rio Tinto Alcan patented JIBS system relies on two phenomena to boost pot flow. First, the existing fixed orifice plates, which balance the flow amongst pots connected to the same dry scrubber, are replaced by removable pivoting orifice plates. When flow has to be boosted, the restriction created by the orifice plate is removed, thus mechanically increasing pot flow (typically +40 to 50%). This is the partial JIBS and it is used principally during tapping operations, as just a slight boosted flow will reduce considerably emission at roof vents, when tapping doors are open.

In order to boost flow further, in addition to the pivoting orifice that remove restriction, a jet of low pressure air is introduced at the pot outlet inside the ductwork through a purpose-built nozzle, which entrains the surrounding air and thus provides extra boosted flow, as per Figure 2. This is the full JIBS and it is used principally during operations that need to open hoods.

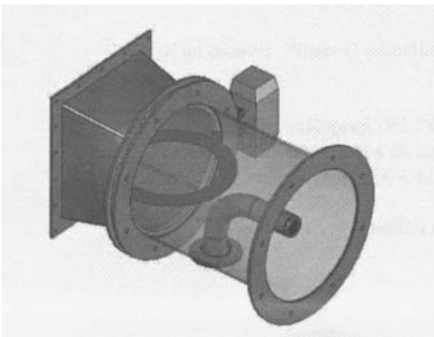

Figure 2. Principle of the JIBS system

Figure 3 represents the static pressure evolution in the pot outlet ductwork both without and with the JIBS operating. The following equations can be used to evaluate the gain in pot flow versus the nozzle operating conditions (jet mass flow and velocity).

- Between 0 (atmospheric conditions) and 1:

$$P_0 = P_1 + \frac{\rho_1 . V_1^2}{2} + k_{0-1} . \frac{\rho_1 . V_1^2}{2}$$

- Between 1 and 2:

$$\frac{m_j . V_j^2}{2} = \eta_e m_g . \frac{P_2 - P_1}{\rho_g} + k_{0-1} . \frac{\rho_1 . V_1^2}{2}$$

- Between 2 and 3:

$$P_2 + \frac{\rho_2 . V_2^2}{2} = P_3 + \frac{\rho_3 . V_3^2}{2} + k_{2-3} . \frac{\rho_3 . V_3^2}{2}$$

With...

P : static pressure

ρ : pot gas density

V : velocity

k_{x-y} : pressure drop coefficient

η_e : jet efficiency coefficient

The jet efficiency coefficient depends on the nozzle design and the overall ductwork arrangement. One objective of the R&D activities is to maximize the jet efficiency.

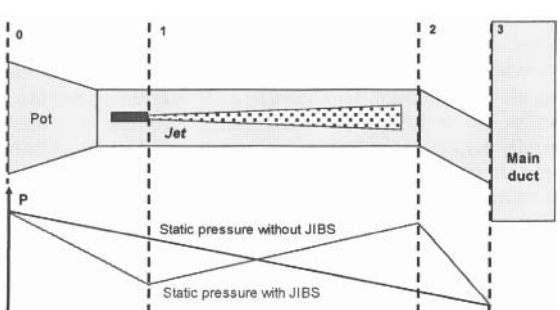

Figure 3. Static pressure evolution in the pot outlet ductwork

Following a successful demonstration phase, which showed a potential environmental benefit around 0.15 kg Ft/tAl, this system is now being generalized across the three potlines in Tomago.

<u>The latest developments on AP3X pots</u>

R&D activities aiming at scaling up the concept to fit the AP3X pot technology took place at the Saint-Jean-de-Maurienne and Aluminium Dunkerque smelters in France. At the same time, the optimum boosted suction pot flow rate required for each pot technology was defined. This critical step in ensuring a maximized value for money ratio was based both on empirical measurements and Computational Fluid Dynamics (CFD) studies. This approach is believed to be more accurate than the utilization of analytical models [4, 5]. As the target pot exhaust flow in full JIBS is not only a multiplier of the pot base flow, many parameters are used to determine the target, as pot size, pot seal and basic pot flow.

The Saint-Jean-de-Maurienne trial was a one pot proof-of-concept which confirmed technical feasibility. The nozzle design required to achieve the target pot flow rate was fine tuned on this occasion [3].

A second test phase was then organized on 6 pots in Aluminum Dunkerque from early 2009. The aim was to validate the technical solution on a small scale in industrial conditions and evaluate the environmental benefit associated with this system. Figure 4 shows the air injection nozzle outside one of the trial pots.

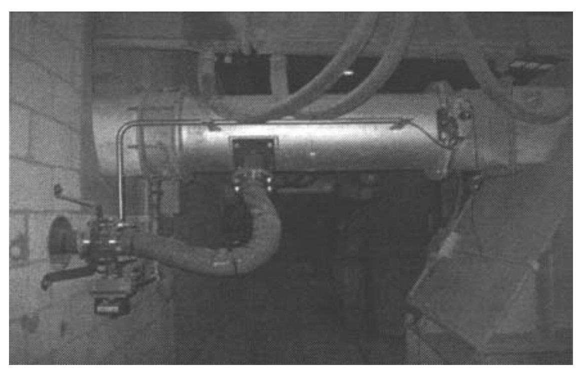

Figure 4. Air injection nozzle and rotating orifice plate at Aluminum Dunkerque

Fluoride emissions were measured in accordance with the method specified for the smelter's regulatory reporting, in turn complying with the USEPA 14 Standard. A continuous monitoring system was also installed at the same time. Tests were organized to evaluate the specific contribution to roof vent emissions from the anode change, excluding that from the spent anode and the crust cover material (open pot contribution only). Figure 5 represents the roof vent gaseous fluoride emissions (HF concentration) during these tests, with boosted suction off and on, measured using the USEPA method 14. Each value corresponds to the HF emission measured at the roof vent above 3 pots undergoing anode change. These 3 pots are located in the centre of the 6 pots trial section, which corresponds also to the monitoring section. Measurements only lasted for the duration of the anode change operation on these 3 pots, from the opening of the first pot to the closing of the third and last pot. These confirmed that a significant reduction in emissions could be achieved by boosting pot flow rate.

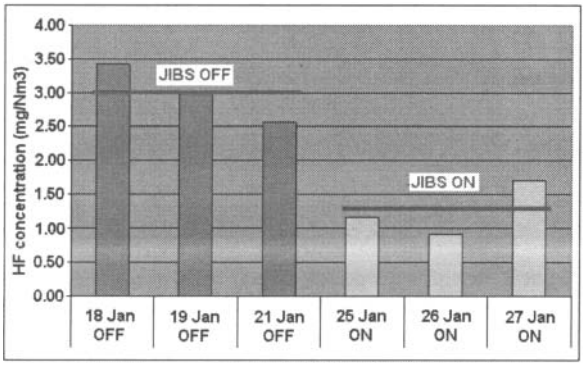

Figure 5. HF concentration at the roof vent above the 3 pots of the trial section during the anode change operation

The JIBS can be automated by means of a hood / door opening / closing detection system. In addition to being easier for potline operators, it also ensures boosted suction is always active when hoods or doors are open, therefore maximizing the system environmental benefit.

The pot hood detection algorithm triggers request to start (and then stop) boosted suction, which can also be initiated by the pot control system when it is undergoing a specific activity resulting in increased emissions. These include, for example, anode change and metal tapping. The pot control system then makes it possible to prioritize the individual boosted suction requests, should their number exceed the maximum design value. For example, pots undergoing anode change would have priority over pot tapping, due to the higher emissions expected.

The detection system measures gas temperature with two thermocouples, in the pot outlet gas duct. Opening hoods results in a rapid change in gas temperature, which quickly reverts to its original level when hoods are closed. These sudden changes in gas temperature are used to identify the times when hoods were opened and then closed, as illustrated in Figure 6. It also allows differentiating between hoods and tapping doors opening. On this basis, a hood opening detection will trigger a full boosted suction operation whereas a tapping door opening detection would result in a partial boosted suction mode (orifice plate removed).

On this basis, the trial allowed the corresponding detection algorithm to be finalized. In practice, rapid changes in pot off-gas temperature can result from many other situations such as, for example, during spent anode removal from the pot when open bath is exposed. The technical challenge is therefore to design a robust algorithm that can distinguish between temperature changes due to hood/door handling and changes associated with other pot operations. The percentage of times this tool is correct in detecting a hood opening is more than 99%.

The complete system has continued to be operational on the 6 pots in Aluminum Dunkerque since February 2009 when the trial first started. From this date, the system has been operating satisfactorily, and the equipment is still monitored to validate its overall long-term reliability.

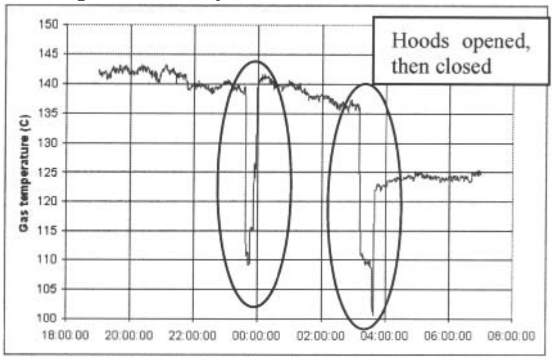

Figure 6. Gas temperature variations at the pot outlet when hoods are opened / closed

Alma smelter industrial demonstration (AP3X)

Context

After deployment of JIBS technology on AP2X pots in Tomago and development to fit on AP3X pots as described here above, Rio Tinto Alcan decided to conduct an industrial demonstration on a full section of 36 pots at the Alma smelter (1/12 of the smelter). This trial was carried out in 2011, to measure the impact of the JIBS on roof vent emissions and on the energy required, as well as the industrial operation.

Basic equipment installed and targets

The Rio Tinto Alcan Smelter Technology group has updated the JIBS package further to the trial at Dunkerque. The basic equipment composed of blowers, duct, pivoting orifice, air injecting probe and manual control box, has been installed on a 36-pot section in Alma (see Figure 7). Tightened fix orifices for the 108 non-JIBS pots on the same gas treatment center, have also been installed.

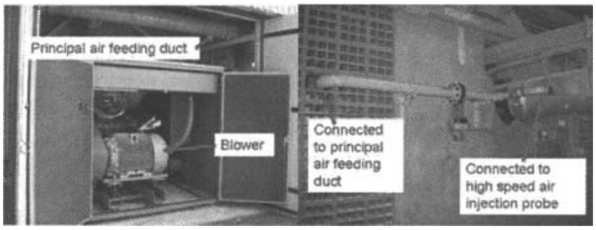

Figure 7. Blower connection to each individual pot air injection probe.

The system designed for industrial demonstration at Alma is targeted to have a basic pot exhaust flow of 2.5 Nm^3/sec, + 40 % and + 80 % in partial and full JIBS. A maximum of three pots on partial JIBS, and three pots on full JIBS, can be in operation simultaneously, without reducing the other pot flow by more than 10 %.

Alma specific JIBS installation and final setup for the demonstration

For the 2011 demonstration, the complete JIBS system (equipment and control system) has been installed so that it is completely separate from the smelter operation control equipment. Close coordination with operation was critical during installation, as all equipment has been installed on operating pots. The system has been installed on a section of 36 pots, fitted with three cassette systems to measure total fluoride emissions at the roof vents.

A very tight schedule had to be complied with, from October 2010 to December 2011, to install the equipment on operating pots, start up the JIBS system, improve the efficiency of the automatic control logic, train the potroom operators, measure impact on roof vent emissions and issue a final report, as specified in Figure 8.

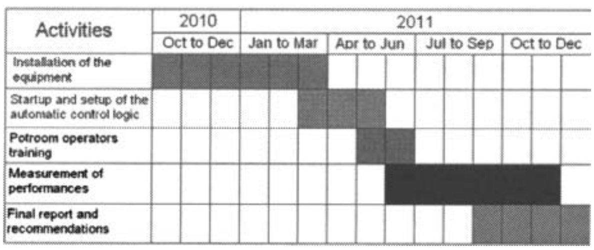

Figure 8. Schedule of the Alma JIBS project.

During startup of the JIBS system, as the cassettes that sample roof vent emissions are replaced every 15 days, the decision was made that, for measurement of the impact on roof vent emissions, the JIBS system would not operate for the first two weeks of each month and operate for the last two weeks of each month.

Fine tuning of operating parameters and pot exhaust flow achieved

Following the pre-operational verifications, a number of parameter adjustments were made to optimize the efficiency of the automatic control logic. The goal was to obtain an automatic control logic that would be close to 100 % efficiency, to detect any open/closed pots and identify whether the hoods or the doors are concerned. If open hoods are detected, the full JIBS will be activated, while the partial JIBS will be activated if the tapping doors are detected as open. The partial or full JIBS will be stopped when hoods/doors are detected as closed, and if nothing is detected, a set time is entered in the program by the system manager, to define the limit. As greatly varying pot conditions/operations are possible, it is a challenge to obtain a full degree of efficiency to detect open/closed pots. For the Alma JIBS demonstration, the final performance of the automatic control logic was to detect 99 % of pots with an open hood/door, within 45 to 60 seconds, and detect 88 % of hood/door closure (see Figure 9). When closure is not detected, a 60-minute timer ensures that the JIBS is stopped.

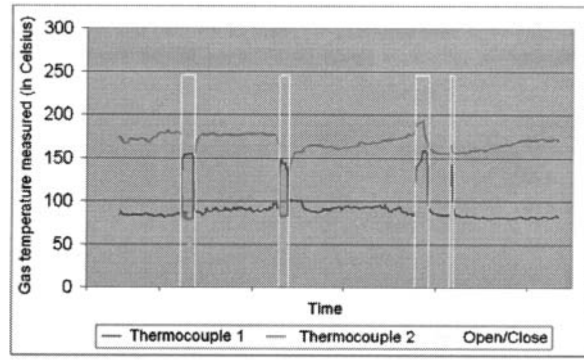

Figure 9. Detection of open/closed pots based on gas temperature, to activate/deactivate the JIBS in the 36-pot test section in Alma.

As a maximum of three pots on the partial JIBS and three pots on the full JIBS, can be in operation simultaneously, a priority management system has been set up in the management program, to respect these limits. The priority is always given to the last pot open, as it is probably the pot that will be open for the longest time. For example, if the hoods of four pots are opened, the last three pots opened will be covered by the full JIBS.

Pot exhaust flow is a critical parameter for performance of the JIBS system. The boosted flow created by the JIBS, when there is any work on pots requiring open hoods or doors, is important for improved gas collection on these pots. Pot exhaust flow measurements were taken to confirm flow reached on the partial JIBS (duct orifice pivoted) and the full JIBS (duct orifice pivoted and addition of high speed air). For the full JIBS, as the system can inject air at a maximum of 90 kPa, two different air pressures have been tested, 70 and 90 kPa. Results proved that the Alma JIBS system achieved the goal for pot exhaust flow (see Figure 10).

All number in Nm^3/sec	Objectives	Measurement results	
		Full JIBS air injected at 70 kPa	Full JIBS air injected at 90 kPa
Baseline	2.5	2.5	2.5
Full JIBS	4.5 (+80 %)	4.1 (+65 %)	4.5 (+ 80 %)

Figure 10. Pot exhaust flow measured as baseline and full JIBS.

Although achievement of these flows on JIBS pots was the first goal, it is also important that, when the partial or full JIBS is operating on pots, the flow of the remaining pots does not drop excessively, to ensure minimized gas collection reduction on those pots. This is especially true when three pots are using the full JIBS, as extra air is added to the gas collection system. Depending on pot exhaust duct orifice setup, calculations must be made to confirm whether the original open diameter on fixed orifices can maintain a good flow (<-10 %) on non-JIBS pots. For the demonstration in Alma, as each gas treatment center covers 144 pots, for the GTC where 36 pots were modified to install the

JIBS system, the remaining 108 pots had their fixed orifice modified to ensure flow would not be reduced by more than 10 % on non-JIBS pots.

Performance results – roof vent emissions and energy consumption

A first test was conducted from July 6th to August 20th 2011. Due to summer high temperatures, this first test was limited to a pressure of 70 kPa for air injection, i.e. a pot exhaust flow of 4.1 Nm^3/sec in the full JIBS. This corresponds only to a base flow + 65 %, as the goal is to inject air at 90 kPa, to reach 4.5 Nm^3/ sec in the full JIBS (base flow + 80 %). The JIBS did not operate for the first two weeks of each month, but was activated, in automatic detection mode, for the last two weeks. A HF continuous monitoring system, using laser technology, was also installed over the JIBS test section of 36 pots, to measure emissions. Tests were organized to evaluate the impact of the JIBS on the roof vent emissions, with no changes to the smelter's regular work practices (virtually the same number of anode changes, tapping and cover material addition per day, spent anodes completely cooling down in the potrooms, etc.). Figure 11 shows the roof vent gaseous fluoride emissions results (HF concentration measured by the continuous monitoring system) during these tests, with boosted suction off and on. These results confirmed that a significant reduction in emissions could be achieved by boosting pot exhaust flow rate.

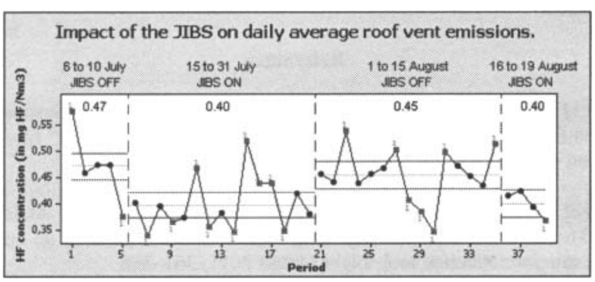

Figure 11. HF concentration at the roof vent above the 36-pot trial section.

This test result showed a significant reduction of 13 % of measured HF concentration, when the JIBS is in operation (0.46 vs 0.40 mg HF * Nm^{-3}). These results are very encouraging, as this full JIBS test maximum pot exhaust flow was below target. Reported in kilograms of gaseous fluorides per ton of aluminium produced, this would represent a significant reduction of 0.07 kg HF/t Al, or 0.10-0.11 kg Ft/t Al if taking the usual particulate fluoride into account. Examining the contribution of each different type of work, the JIBS has lowered roof vent emissions for each type (see Figure 12). It is important to point out that different results of emission reduction due to the JIBS, for various type of potroom work, are directly related to the quality of the potroom standard work practices, corresponding to number of pots open at the same time and the duration of the work.

Type of potroom work.	Single work specific emission (all in kg HF/t Al)	
	JIBS OFF	JIBS ON
Metal tapping	0.04	0.02 (-42 %)
Anode change	0.06	0.03 (-42 %)
Addition of covering material	0.04	0.03 (-12 %)
Re-addition of covering material	0.03	0.02 (-43 %)

Figure 12. Impact of the JIBS on each different type of potroom work.

During this test, energy consumption of the JIBS was also calculated, based on the average time per day the blower would be in operation (in the full JIBS). The blower would operate approximately 500 minutes per day, resulting in a consumption of 224 MWh per year or 6 kWh/t Al, on a system installed on 36 pots (1/12 of the smelter).

Current developments

The JIBS concept has been successfully demonstrated on AP2X and AP3X pot technologies. However, preliminary tests conducted at the LRF R&D Center in Saint-Jean-de-Maurienne (France) suggested that scaling-up to the AP6X pot would involve specific challenges, mainly related to this new pot size and aeraulic characteristics. A step change in JIBS performance is therefore required.

In this context, a project was set up to improve our understanding of the main drivers influencing efficiency. Both the nozzle design and the process operating conditions were investigated. Help from external consultants specialized in ejector design was sought. Dedicated Computational Fluid Dynamics (CFD) models were also built to simulate different configurations in order to orient the development. Figure 13 shows one such configuration.

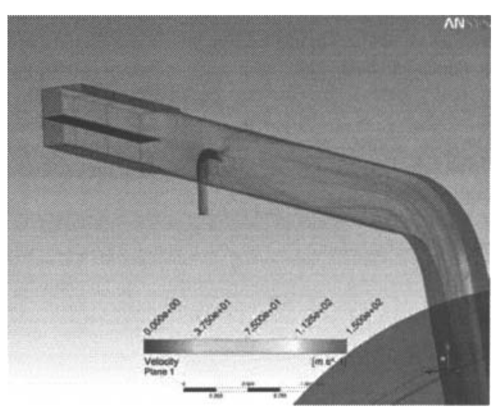

Figure 13. CFD representation of the JIBS located inside the pot outlet ductwork

The project focus was on maximizing jet efficiency, as defined by the following ratio: $\eta = \frac{entrained\ air\ mass\ flow\ rate}{entrainment\ air\ mass\ flow\ rate}$

Achieving higher ratios would result in reduced energy consumption for similar performance (boosted flow). Alternatively, the gain could be used to further increase pot flow rate for similar air consumptions.

Following this initial phase of investigation, tests for the most promising nozzle designs and process parameters were organized on one pot at the Saint-Jean-de-Maurienne smelter. Figure 14 shows the results obtained for 6 different nozzle designs (A to F) and 3 different sets of process parameters (1 to 3). The tests were conducted on two different AP3X superstructure designs, which have different aeraulic conditions.

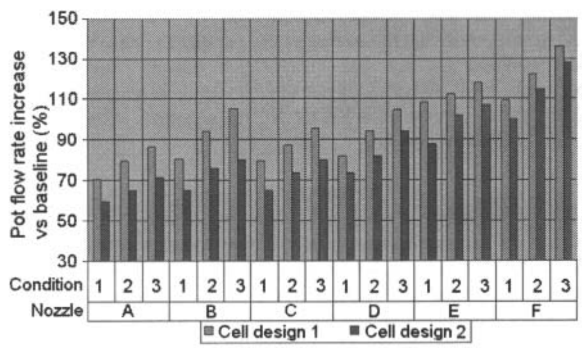

Figure 14. Pot flow rate increase versus baseline flow for different nozzle designs and process conditions

The results show that performance is very closely related to both the nozzle design and the conditions under which it is operated (pressure and temperature). Cell superstructure and outlet ductwork designs have also a significant impact. The same nozzle will induce higher boosted flows on a less resistive superstructure. But other design conditions will also affect performance, such as the distance between the nozzle and the first elbow of the ductwork.

On the basis of these tests, the most efficient combination of design and process parameters compatible with an AP6X superstructure was identified. This new design will be tested on a group of pots shortly after AP60 Technology Center start up. These new designs could also offer opportunities for energy consumption reduction.

CONCLUSION

The latest series of tests have allowed the JIBS technology to be demonstrated on AP2X and AP3X pots, confirming both its operability and its efficiency in reducing fluoride emissions.

The demonstration section in Alma is providing encouraging results with respect to emission reduction, with an estimated gain of approximately 0.10 kg Ft/t Al. The hood/door opening detection tool has shown its efficiency and can now be used to reliably trigger boosted suction. As a significant added benefit, this tool can be used as a potline management KPI to monitor compliance to standard operating practices.

Combined with the ability to accurately define the required boosted suction flow rate, this technology is a cost-efficient alternative to the traditional dual duct boosted suction system. It is now being considered as part of the AP60 pot development.

Acknowledgements

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