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SUSTAINABLE ANODE EFFECT BASED PERFLUOROCARBON EMISSION REDUCTION

Neal R. Dando[1], Lise Sylvain[2], Janice Fleckenstein[1], Ciro Kato[3], Vince Van Son[4] and Laura Coleman[5]
[1]Alcoa Technology, 100 Technical Drive, Alcoa Center, PA 15069-0001 USA
[2]Alcoa Canada Primary Products, 1 Boulevard des Sources, Deschambault, Québec G0A 1S0 Canada
[3]Alcoa Pocos de Caldas, Rod. Pocos-Andradas, Km 10, Pocos de Caldas 37719-900 Brazil
[4]Alcoa, 2300 North Wright Rd, Alcoa, TN 37701 USA
[5]Alcoa Global Primary Products, 6641 West Broad Street, Suite G100, Richmond, VA 23230 USA

Abstract

Commercial aluminum reduction is a significant anthropogenic emission source of the perfluorocarbon (PFC) gases carbon tetrafluoride (CF_4) and hexafluoroethane (C_2F_6). Given the high global warming potentials of these two gases (6500 and 9200 respectively), concerted efforts are underway to monitor and reduce emissions of PFCs from aluminum smelters.

Alcoa has been performing plant-specific perfluorocarbon (PFC) emission testing at operating smelters for over 15 years and has the largest data base of Tier 3 coefficients in the aluminum industry. From 2005-2009, Alcoa smelters have reduced anode effect (AE) based PFC emission intensity by 0.48 T CO_{2e}/T Al produced, resulting in an absolute annual reduction of 2.3 million tonne CO_{2e} over this same time period.

These systematic, sustained PFC reductions were the result of 1) continuous attention to detail and process optimization at operating locations 2) consistent sponsorship and interest from all levels of the organization 3) comparative monthly performance reporting on anode effect performance, 4) internal workshops regarding shared AE reduction efforts and 5) production technology changes. This paper will discuss examples of these key enablers for sustaining AE-based PFC reductions of 15.9 million tonnes from Alcoa smelters over the period 1990 to 2009.

Introduction

Perfluorocarbons (PFCs) are known greenhouse gases with exceptionally long atmospheric lifetimes.[1] These trace gases are linked to global warming due to their strong infrared absorption in the upper atmosphere. The two most common PFC gases emitted to the atmosphere are carbon tetrafluoride (CF_4) and hexafluoroethane (C_2F_6). Aluminum smelting is considered to be the largest anthropogenic source of these PFC emissions worldwide.[2] PFC emissions from aluminum smelters occur during a transient process condition known as an anode effect (AE), which occurs when the alumina (Al_2O_3) level in the bath drops below ~1%, the cell voltage rises, and the bath itself begins to react.[3]

Estimates of a smelter's PFC emissions (kg PFC/tonne Al produced) can be calculated by multiplying the total number of anode effect minutes (AE minutes/cell-day) observed by a PFC slope coefficient [(kg PFC/ tonne Al)/(AE min/cell-day)]. The PFC slope coefficients for (CF_4) and (C_2F_6) can be estimated using Tier 2 default coefficients from the good practice guidelines of the Intergovernmental Panel on Climate Change (IPCC)[4] or they can be calculated from plant-specific measurements of PFC emission rates (Tier 3 coefficients).

An increasing number of smelters opt for plant-specific measurements of PFC emission factors, since these factors more accurately represent the true emission rates for that particular plant, as opposed to IPCC default Tier 2 coefficients. To facilitate this process, Alcoa has a long-established (> 15 years) program in place to ensure that PFC emissions are measured in a comprehensive manner at each Alcoa smelter on a recurring basis. As a result of this program, Alcoa has the largest Tier 3 data base in the aluminum industry. Alcoa's Tier 3 coefficients have also been used to improve the accuracy of the default Tier 2 coefficients for multiple cell technologies.

Most aluminum companies have initiated voluntary programs for actively reducing PFC emissions[4] and all modern pre-bake smelters have implemented automated methods for terminating anode effects. These methods vary by cell technology however all have the same goal of minimizing the cumulative anode effect minutes per cell-day at the operating location. Perhaps more importantly, smelter pot feeding and monitoring programs are continually optimized to minimize the frequency of anode effect events.

The smelting operations of larger, established aluminum companies typically encompass different smelting cell technologies, each typically having significantly different alumina feeding and control practices. This situation precludes a "one-size fits all" approach to anode effect reduction programs.

The purpose of this report is to discuss contributing factors that led to a systematic, sustained reduction in annual PFC-based CO_{2e} emission of 15.9 million tonnes from Alcoa smelters over the period 1990 to 2009.

Discussion

In 1995 January, Alcoa entered into a five-year, voluntary agreement with the U.S. Environmental Protection Agency (EPA) known as the Voluntary Aluminum Industrial Partnership (VAIP),. The EPA-VAIP was a cooperative effort to measure and reduce the principal PFCs, CF_4 and C_2F_6, produced in the U.S. Aluminum Industry. The original VAIP program goal was to reduce US PFC emissions from aluminum smelting by 30 to 60%, from 1990 levels, by the year 2000. The actual performance achieved over this time period (by all US partners) was a 57% reduction in PFC emissions.[5] The PFC reduction observed over this same period for Alcoa smelters worldwide was 58%, from 17.7 to 7.4 million tonne CO_{2e}, as shown in Figure 1.

Initial successes in anode effect reductions (relative to 1990 levels) were easier to achieve, owing to pre-existing practices that used anode effects themselves as a simple process control tool for de-mucking pots and validating feed control program with respect to alumina concentration. An early key enabler was education on how modern pot control strategies and measurement technologies could effectively eliminate the need for deliberate, or scheduled, anode effects as a process control tool.

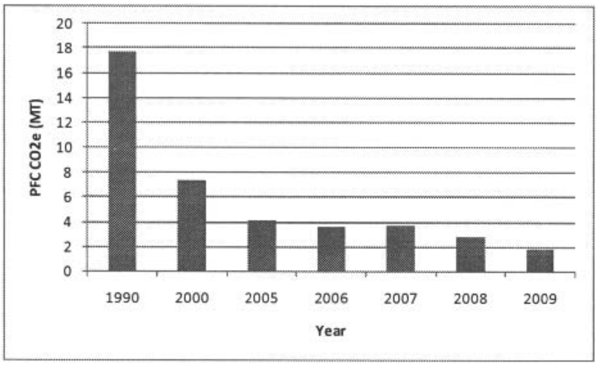

Figure 1. AE-based PFC CO_{2e} performance of Alcoa smelters, where the Y-axis in million metric tons (MT).

Over the next 5 years, from 2000 to 2005, Alcoa smelters continued to reduce anode effect-based PFC emissions by an additional 45%, from 7.4 to 4.1 million tonnes CO_{2e}, as shown in Figure 1. By 2005, however, it became apparent that additional, systematic gains in PFC reductions were going to require a renewed focus and additional attention to assure continued performance in line with Alcoa's sustainability goals.

1 Million Tonne Challenge

In 2005 Alcoa challenged its global network of aluminum smelters to reduce annual CO_{2e} emissions from anode effects by an additional one million tonnes. The One Million Tonne Challenge initiative was sponsored and monitored by top Alcoa executives

The One Million Tonne Challenge was based on the following premise: if each smelter sustainably closed 90% of the gap between 2005 annual AE minutes/cell day performance and each plant's own best monthly performance in 2004, a collective reduction of one million tonnes of CO_{2e} per year could be achieved.

A One Million Tonne Challenge Team was charged with establishing AE minute/cell-day targets for each plant as well as tracking and globally communicating individual plant and aggregate performance against targets on a monthly basis. Key performance metrics and milestones were noted:

1) Locations that established new performance benchmarks
2) Locations that met or beat their target
3) Locations that met or beat their target for 4 or more consecutive months

In addition, root causes for performance concerns as well as planned countermeasures were solicited from locations that significantly exceeded their target. At the end of each calendar year locations that were the "most improved" and that had the lowest AE minutes/cell-day were recognized to acknowledge their accomplishment.

A 0.5 million tonne reduction in AE-based CO_{2e} was observed during the first year of the One Million Tonne Challenge program, from 4.1 MT (2005) to 3.6 MT (2006), as shown in Figure 1. During the second year of the program (2007), aggregate PFC performance remained essentially static and in response a worldwide PFC reduction workshop was held at an Alcoa smelter. Representatives from all Alcoa smelters participated in three days of meetings to:

1) Share "local successes" or "best practices" regarding process or work practice optimizations to reduce anode effect minutes.
2) Share "local challenges" regarding AE minutes/cell-day reductions
3) Learn more about AE root causes, and R&D based developments for improving feed control and anode kill routines.
4) Participate in like-technology breakout sessions to identify additional tools/options for continuing to reduce AE minutes/cell-day at their locations.

Table 1 lists 19 Alcoa aluminum smelters in eight countries currently in operation. Alcoa smelting technologies encompass point-feed prebake (PFPB), side-work prebake (SWPB), vertical stud Soderberg (VSS) point feed vertical stud Soderberg (PF-VSS) and horizontal stud Soderberg (HSS). These cell technologies require significantly different local approaches to achieve and sustain reductions in AE minutes/cell-day.

Table 1. Operating Alcoa Smelters

Country	Smelter	Technology
Australia	Portland	PFPB
	Point Henry	PFPB
Brazil	Pocos de Caldas	VSS
	Sao Luis	PFPB
Canada	Baie Comeau	PFPB & VSS
	Becanour	PFPB
	Descahambault	PFPB
Iceland	Fjardaal	PFPB
Italy	Portovesme	PFPB
Norway	Lista	PF-VSS
	Mosjoen	PFPB
Spain	Aviles	PF-VSS
	La Coruna	PF-VSS
	San Ciprian	PFPB
United States	Intalco	SWPB
	Massena	PFPB & HSS
	Mount Holly	PFPB
	Warrick	PFPB
	Wenatchee	PFPB

A PFC Best Practice Team was formed to assist locations that consistently missed their monthly performance targets – or who requested assistance to enable them to push past "plateaus" in local performance. The team was composed of "core" and "invited" members wherein the invited members were typically Technical Managers from like-technology smelters, relative to the location being visited.

A PFC Best Practice Team would typically spend a week at a given smelter performing several tasks that can generally be listed as:

1) Review plant operating history and key performance indicators with plant personnel
2) Audit anode kill practices on the plant floor
3) Walk the floor during normal operation and anode change (or stub change) to observe plant practices
4) Inspect pot conditions (metal level, feeder condition, anode cover practices, etc).

At the end of the week, the Team would make a presentation to the plant operating team with a list of specific, cost-effective, prioritized recommendations or action items to enable further reductions at that location. A time-line would be agreed upon for implementation.

One of the most readily available opportunities for reducing AE frequency is to use the potroom computer system to report pots exhibiting higher than average AE's per shift (or day). AE action sheets can be used to document (and develop Pareto charts of) the root causes for atypical AE behavior and serve as the basis for implementing countermeasures to systematically reduce the number of high AE frequency pots. Point feeder issues tend to dominate the Pareto analyses developed by this approach.

At side break smelters (prebake or Soderberg), variations in crust breaking/feeding tend to cause similar variations in cell AE frequency. These variations can be often be tracked to differences in crust breaking equipment (stroke length) or breaking practice (full side vs partial side).

Additional systematic, sustained PFC reductions were enabled by several projects and practice optimizations, such as:

1) Eliminating root causes for long duration anode effects,
2) Use of predictive tools to alarm pot room operators to take preventive actions before anode effect occurrence,
3) Technology retrofits – from Soderberg side break technology to point feeder technology,
4) Revised pot start-up procedures with more uniform, higher temperature target pre-heating practices to improve pot stability during first hours of pot operation,
5) Technology-specific countermeasures for variations in alumina properties,
6) Improved standardized procedures to minimize the impact of power outages and load modulation.

The impact of the PFC Reduction Workshop and PFC Best Practice Teams was evident in 2008 performance, as shown in Figure 1, wherein a 1.3 million tonne reduction in AE-based CO_{2e} emission was achieved, with respect to a 2005 baseline (4.1 vs 2.8 MT).

An *additional* one million tonne reduction in AE-based CO_{2e} emission was achieved in 2009, with respect to a 2008 baseline (2.8 vs 1.8 MT). The net AE-based CO_{2e} emission reduction performance over the period 2005-2009 was 2.3 million metric tonne, or 56% (4.1 vs 1.8 MT).

The systematic reductions in AE-based CO_{2e}, discussed above, offer a significant contribution to the total direct CO_{2e} from Alcoa's worldwide operations, shown in Figure 2. From a 1990 baseline, direct CO_{2e} has been reduced by 43%. Approximately 80% of the CO_{2e} reduction from 1990 to 2009 is based on AE-based PFC reductions from smelting operations.

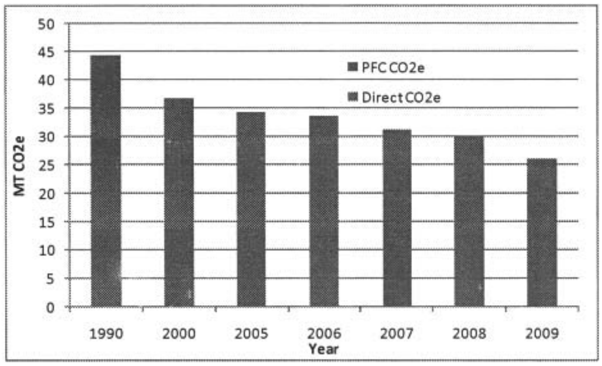

Figure 2. Total direct CO_{2e} and AE-based CO_{2e} emissions from Alcoa operations (in million tonnes).

Given significant financial constraints regarding the world economy and more specifically the aluminum industry over recent years, it is interesting to note the relative changes in aluminum production, CO_{2e} intensity and mass CO_{2e} emissions (the latter two being from AE-based PFCs). Figure 3 shows the relative performance of these metrics from 2005 through 2009, where CO_{2e} intensity is expressed at T CO_{2e}/T Al.

As indicated in the data shown in Figure 3, over the period from 2005-2009, Alcoa achieved a 56% reduction in AE-based CO_{2e}, while only a 7% reduction in aluminum production occurred over this time. The large 56% mass-based CO_{2e} reduction and the 54% CO_{2e} intensity reduction are both due to the significant, sustained AE minute/cell-day reductions achieved at Alcoa smelters over this period.

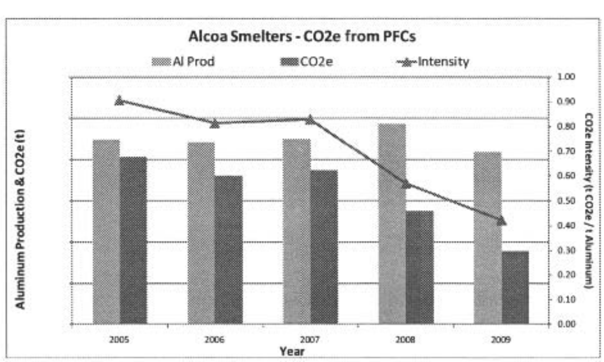

Figure 3. Aluminum production, CO_{2e} mass emission and CO_{2e} intensity.

Systematic reductions in either AE frequency, AE duration or both contribute to an overall reduction in PFC-based CO_{2e} intensity. Table 2 shows the production-weighted AE frequency and AE duration for Alcoa smelters in 2005 and 2009. Significant reductions were achieved in both metrics over this period; however the major lever contributing to an overall CO_{2e} intensity reduction was AE frequency.

As reported previously, reductions in anode effect frequency can offer a linear route to CO_{2e} reductions while a focus on fast anode effect kills (to minimize duration) can reach a point of diminishing returns, given that PFC emission rates (per second of anode effect) are highest during the initial AE onset.[6,7]

Table 2. Production Weighted AE Frequency and Duration

Year	AE Frequency Prod Weighted	Calculated AE Duration Prod Weighted
	(#/pot day)	(mins)
2005	0.51	1.58
2009	0.29	1.15
% Reduction	44%	27%

Conclusions

The sustained reduction of AE minutes/cell-day at operating aluminum smelters requires consistent sponsorship by leadership, the coordinated collaboration of Like Technology Teams, Best Practices Teams, R&D personnel and – most importantly - the continuous efforts of potroom floor personnel to identify, implement and transfer tools and enabling options for achieving and sustaining reductions in AE minute/cell-day performance.

In the early stages of anode effect reduction programs, significant reductions could be achieved by ending past practices of using anode effects as a process control tool. The magnitude of the reductions already made and sustained will make achieving additional reductions far more challenging.

Given the range and age of smelting technologies in operation, new options for continuing to push to lower AE minutes/cell-day need be explored on a plant-specific basis.

At Alcoa, the sustained, combined efforts of monthly performance tracking, periodic PFC workshops, inter-plant best practice teams and potroom floor personnel have allowed for a systematic AE-based reduction from 17.7 to 1.8 MT CO_{2e} on an annual basis. Further reductions from existing pot operations will require even more intense effort and innovation than have been expended to date.

Acknowledgements

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