Technology and Economics of Reducing PFC Emissions from Aluminium Production

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ABSTRACT: The worldwide aluminium industry has made good progress in reducing emissions of PFCs over the last decade and continues to work toward achieving further reductions. Depending on the technology type, a further lowering of emissions is both technically and economically feasible for many plants. The industry is working cooperatively with governments through domestic voluntary programs and globally through voluntary programs organized by the International Aluminium Institute. This paper reviews recent trends in PFC emissions from the global aluminium industry, presents an update of technical options to reduce PFC greenhouse gas emissions from aluminium production, and summarizes recent industry efforts to standardize measurement methods.

1 WORLDWIDE ALUMINUM PRODUTION

Primary aluminium production is truly a global industry with facilities on every continent. Total primary aluminium production in 2000 was 24.2 million tonnes. The geographical distribution of year 2000 production is shown in Figure 1. Future growth in demand for aluminium is projected

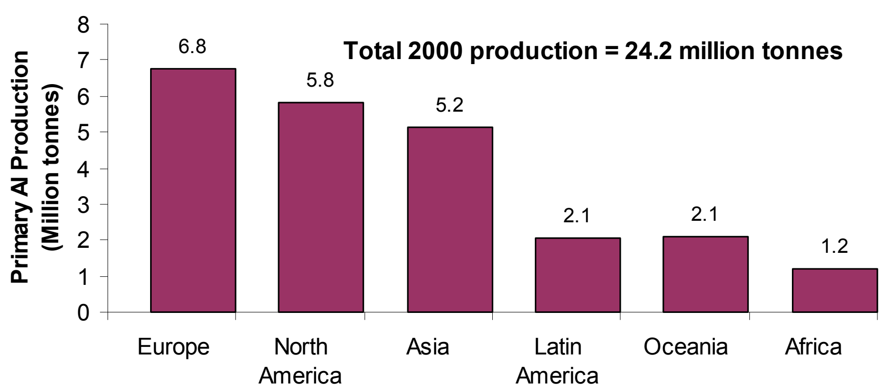

Figure 1. Worldwide Primary Aluminium Production by Geographic Region

at between 2 percent to 4.7 percent per year, depending on world economic conditions. About two-thirds of future new production is expected to come from upgrading current facilities while another third will result from installation of modern new electrolysis facilities. Over the past four decades aluminium prices have declined by about 1 percent per year, therefore, costs must be constantly reduced to maintain profitability. Locations for new smelters depend primarily on the dependable availability of electrical power. Currently about one-third of world demand is supplied from recycled products and the increase in the use of recycled material is expected to grow slightly faster in Europe and the US than for primary product.

2 ALUMINIUM TECHNOLOGY AND PFC GENERATION

An operational aluminum smelter consists of one or more potlines. Each potline may have up to several hundreds of electrochemical cells electrically connected in series, with each cell or "pot" producing hundreds or thousands of kilograms of metal each day. The voltage drop across each cell is usually quite small, approximately 3.5 to 4.5 volts, but the current passed through the cell can range from many tens of thousands of amperes to several hundred thousand amperes. Two perfluorocarbon compounds (PFCs), tetrafluoromethane, CF_4, and, hexafluoroethane, C_2F_6, are produced during the Hall-Heroult process of electrochemical reduction of alumina, Al_2O_3, to aluminium metal. The two PFC compounds are not produced continuously, but instead are emitted only occasionally when the alumina content of the molten salt bath from which aluminium is electrolysed falls below a critical level. Below this critical level the voltage rises rapidly and the fluoride-containing molten salt begins to be electrolysed producing the PFCs. The rate of production of PFCs depends primarily on the magnitude of the current being passed through the cell. There are also a number of important additional factors that are less well understood which affect the rate of emissions. These include cell voltage, how long the anode effect endures before termination, and cell molten salt chemistry (Marks et al, 2000, Zhu & Sadoway, 2000). The total amount of PFC compounds produced during anode effects can be calculated from the average PFC emission rate during the anode effects, the frequency of anode effects and the duration of the effects.

While the basic aluminum production process is a century old, various technology implementations have evolved over the years. The oldest technology is the Soderberg reduction cell, in which the anode is formed and baked at the cell. Variations include Vertical Stud Soderberg (VSS) and Horizontal Stud Soderberg (HSS), indicating the orientation of the studs to the anode. Prebake technology uses anodes that are baked in a separate process prior to use. Prebake smelters can differ significantly in the way alumina is fed into the smelting pot. Point feeding, which generally allows the most control, is found in newer smelters. Smelter technology type plays a critical role in the amount of PFCs emitted. Since anode effects occur when there is too little alumina in the smelting pot, the way in which the alumina is fed in and the frequency at which it is fed in are important factors in determining how often anode effects occur. There are many technology parameters and operations that impact anode effect frequency and duration. These include such things as: manual or automatic feed; type and quality of automatic feed system and feed strategy: variability in the physical properties of alumina feedstock; ability to maintain bath quality, quality and timeliness of measurement of reduction cell parameters; age of cell computer technology; manual or automatic anode effect termination. Good operational practices will also reduce total emissions and improve overall smelter performance.

3 PAST PROGRESS ON PFC EMISSION REDUCTION

Global efforts to reduce emissions include voluntary efforts within industry through the International Aluminium Institute, between industry and government, and through regulatory programs mandated by government. By 1999, over half the world's primary production was involved in voluntary emission reduction agreements with national governments: such as Australia, Bahrain, Brazil, Canada, France, Germany, Norway, New Zealand, the United Kingdom and the United States (Dolin et al, 2001). The framework and requirements of voluntary programs vary; however, certain characteristics are common to all. Typically, participants: set emission reduction targets, either company-specific or industry-wide. They implement a process to monitor, track and report progress toward achieving these reductions. There is usually a commitment to the sharing of information of relevant science, technology research and best practices. In the U.S., primary aluminium producers have committed themselves to PFC emissions reductions through the Voluntary Aluminium Industrial Partnership (VAIP), a voluntary program between individual primary aluminium producers and the U.S. EPA. VAIP members, who represent over 90 percent of US production capacity, reduced emissions over 40 percent from 1990 to 2000. On an international scale IAI member companies represent over 60 percent of global production. Over the 1990 to 2000 period the combined specific emissions of CF_4 and C_2F_6, as measured by carbon dioxide equivalent emissions, has been reduced by sixty percent from 4.0 to 1.6 tonnes CO_2 equivalents per tonne of primary aluminium produced. These reductions are the result of a combination of both economic and environmental factors.

4 PFC MEASUREMENTS & INVENTORIES

PFCs are measured to develop an inventory of greenhouse gas emissions. The most accurate sector inventory can be produced by the use of facility specific emission factors based on PFC measurements at individual sites. Facility inventories are used by industry for benchmarking and to set goals for process improvement to reduce emissions. Also, the inventories are useful to national governments in developing more accurate national inventories as required under the United Nations Framework Convention on Climate Change. In the future, production of accurate inventories of GHG emissions is likely to be an essential element of any proposed emissions trading programs.

The IAI has sponsored three global surveys of PFC emissions covering the time period from 1990 through 2000 and surveys will be conducted annually in future years (IAI, 1996, 2000, in prep 2002). These surveys contain anode effect data and calculations of PFC emissions based on IPCC Tier 2 methodology. Recently, PFC measurement campaigns have been carried out in the United States, Canada, Norway and Germany (Bouchard et al, 2001, Kvande et al, 2001, Marks et al, 2000). The measurements were made with at line instrumentation and included an assessment of fugitive emissions, which can account for as much as 15 percent of total emissions for some Soderberg cells. Production process data was collected including anode effect frequency, anode effect duration and the time rate of aluminium production. These data were used to calculate facility specific slope values, recommended by the IPCC Good Practice Guidance as the most accurate methodology for inventory estimation of PFC emissions from primary aluminium production. The measurements allow the ongoing calculation of PFC emissions and calculation of inventories according to the IPCC Tier 3b method. The recent measurements have illustrated that Tier 2 calculations can result in emissions errors of as much as 100% for some individual facilities. For the production of accurate inventories, the use of emissions factors based on the Tier 3b facility-specific method is highly recommended over factors from the Tier 2 technology average method. USEPA and IAI are collaborating to develop a protocol for measuring PFCs. The protocol is intended to foster consistency and improve the quality of emissions factors that result from facility-specific measurements.

5 POTENTIAL FOR FURTHER REDUCTIONS OF EMISSIONS

IAI member companies have placed a high priority on achieving a further reduction of PFC emissions. Member companies are surveyed annually for anode effect data. The IAI publishes reports to provide interested parties with a data source on PFCs from aluminium production. Workshops are held to inform member company staff on benchmarks and to share good practices for the reduction of anode effects. The IAI also collaborates with national regulatory agencies, supports the UNFCCC/IPCC process and international business groups and member companies to improve methods for PFC emission inventories. Finally, the IAI sponsors fundamental atmospheric research and atmospheric measurements to better understand how PFCs affect climate change and how historical aluminium production correlates with increases in atmospheric concentrations of PFCs. Past IAI anode effect surveys have covered the decade from 1990 through 2000 and future annual surveys are planned.

The IAI prepares tailored reports of survey results for each member company so that data cannot be identified with individual facilities other than those of the company for which the report was prepared. Figure 2 illustrates a benchmarking graph of the total annual emissions of CF_4, by facility, for the years 1990 and 2000. Each point on the cumulative plot, ranked from lowest to highest facility emissions, represents the increment in CF_4 emissions for an individual facility plotted versus the increment in primary aluminium production for that facility.

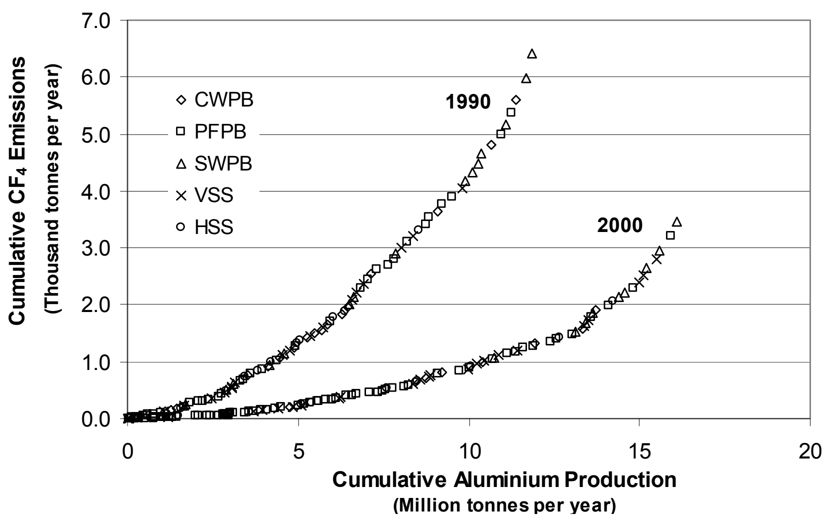

Figure 2. Comparison of Annual Emissions of CF_4 from Primary Aluminium Production Facilities for 1990 and 2000. (IAI, 2001)

Figure 2 shows an overall reduction of 2936 tonnes of CF_4 emissions to the atmosphere by IAI member companies while primary aluminium production increased over the same time period from 11.8 to 16.1 million tonnes. While excellent progress has been made over the last decade, IAI surveys show that still further improvement can be achieved. The surveys show that anode effect performance differs considerably within specific smelter technology categories. Figure 3 shows the range of survey results for the point fed prebake reduction technology operators that reported anode effect data for 2000. The specific emissions data is best fit with a lognormal distribution with a mean of 0.12 and standard deviation of 0.16. The median of the distribution is 0.078 kg CF_4/t Al. Calculations show that if those facilities that operate above the median performance could improve performance up to the median level, some 609 tonnes of CF_4 emissions could be eliminated and the average specific emissions level could be halved from 0.11 to 0.057 kg CF_4/t. Similar results are obtained from other reduction technologies.

Incorporation of good practices for anode effect reduction and technology improvements are successfully lowering the frequency and duration of anode effects. Point feeders are being installed on Soderberg cells and side work prebake cells, which result in considerable reductions in emissions. Improved computer algorithms better control the alumina levels in cells and terminate anode effects more quickly, once initiated. The startup of new production capacity also reduces world average specific emissions, since emissions performance of the newest technology is typically better than the year 2000 overall average emission level of 0.2 kg CF_4/tAl.

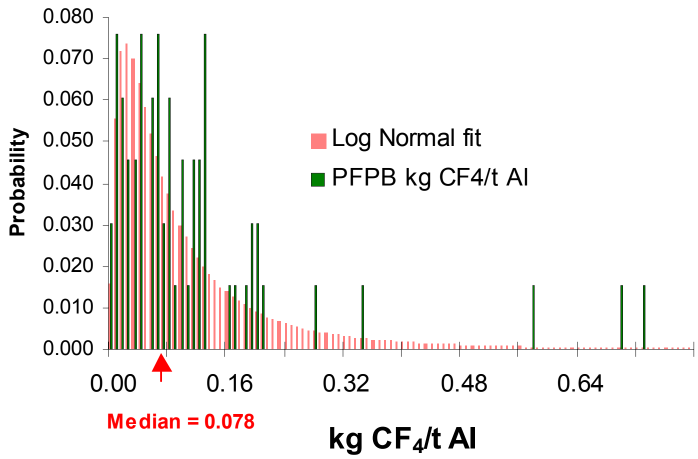

Figure 3. Specific CF_4 Emissions Performance of Point Fed Prebake Smelters

Anode materials that contain no carbon are currently under development, which are not consumed during the electrolysis process. PFC emissions would be totally eliminated, if this technology were successfully commercialized. Finally, additional research is being carried out aimed at developing alternative processes to the 100-year-old Hall-Heroult process. The current candidate processes include carbothermic reduction and a clay chlorination process, both of which would emit no PFCs. Furthermore, recycling currently provides about one-third of worldwide aluminium demand and recycling rates are projected to rise in the future. Recycling produces no PFC emissions, requires only five percent of the greenhouse gas energy required for primary aluminium production and produces only five percent of the emissions of primary production. The IAI is actively working to encourage increased recycling. It has recently formed a Global Aluminium Recycling Committee to develop a better understanding of global material flow, gather improved statistics on recycling and recycling rates.

6 ECONOMICS OF PFC REDUCTION

An aluminium smelter embodies a large capital investment. The capital cost of any of these technology options, such as a retrofit to an existing plant, is large. However, these changes also improve process efficiency and return. Changes are implemented usually for competitive reasons, not for the prime purpose of reducing PFC emissions. The decision to implement a technology retrofit will depend on a smelter's economic fundamentals and the ability of the new technology to decrease on-going costs per tonne of metal production. Technology retrofits must meet enterprises' internal return criteria. The US EPA and the IAI are collaborating to develop a methodology for estimating the financial implications of anode effects on aluminum smelting facilities. The key cost elements include increased fluoride consumption, decreased aluminum production, and increased power consumption. By allowing companies to quantify total costs of anode effects to a facility and the cost per anode effect, emission reduction investment decisions can be greatly refined. Costs vary by smelter type, by power system design (constant power versus constant current), but preliminary estimates indicate yearly costs resulting from anode effects for a hypothetical "typical" (525 pot facility) range from tens of thousands to millions of US dollars (USEPA & IAI, 2002).

7 SUMMARY AND CONCLUSIONS

The global aluminium industry has made excellent progress over the past decade in reducing PFC emissions from primary aluminium production. Specific PFC emissions, reported as carbon dioxide equivalents per tonne of aluminium produced, have been reduced by sixty percent by IAI Member companies over the period from 1990 to 2000. While production has increased by 24 percent over the past decade, total emissions to the atmosphere have been reduced. The industry's achievements illustrate the effectiveness of voluntary programs in reducing greenhouse gas emissions. The IAI member companies have placed a high priority on achieving further PFC emissions reductions. Toward this goal, an active program has been developed involving the annual surveying of members on anode effect performance, developing benchmark information to help member companies set reduction goals, holding workshops and conducting seminars on reducing anode effects and providing guidance on good practices for making PFC measurements and developing emissions inventories. USEPA and IAI have developed a draft protocol for measuring PFCs to foster consistency and improve the quality of emissions factors that result from measurement campaigns. IAI has also placed a high priority on increasing recycling rates for aluminium products to further reduce PFC emissions and also to reduce the overall energy requirements for aluminium.

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