Light Metals 2014
Edited by: John Grandfield
TMS (The Minerals, Metals & Materials Society), 2014

THE END OF AN ERA FOR SØDERBERG TECHNOLOGY IN NORTH AND SOUTH AMERICA

Mike Barber[1] and Alton T. Tabereaux[2]
[1]Consultant, 2468 Wyndale Crescent,Ottawa,On. K1H 7A6 Canada
[2]Consultant, 1585 Wilson Lake Shores, Muscle Shoals, AL 35661, USA

Keywords: Søderberg, Smelters, history

Abstract

In the 1970s twenty three Søderberg smelters located in North and South America had a primary aluminum capacity over 3 million tpy. The largest operating Søderberg smelter, Companhia Brasileira de Aluminio with a plant capacity of 475,000 tpy built the last Søderberg potline in 2007. Today there are only five Søderberg smelters operating with a capacity of less than 1 million tpy. Compared with prebake technology, Søderberg cells have higher production costs, they are more difficult to automate and they have the greatest environmental and health challenges. Health studies from the middle of the 1970s show a clear link between Søderberg tar fume exposure and the incidence of various types of cancer lead companies to propose a program of replacement. Starting in the late 1970s a number of programs and actions were taken to reduce PAH emissions and worker exposure to fumes, but in Canada they were always seen as stop-gap actions until replacement was completed.

Introduction

In the beginning, there were Hall prebake cells. In 1888, Charles Martin Hall with the help of Alfred E. Hunt started the Pittsburgh Reduction Company with an experimental smelting plant using small prebake Hall cells on Smallman Street in Pittsburgh, Pennsylvania. In 1891 the company went into production in New Kensington, Pennsylvania. In 1895 a third site opened at Niagara Falls New York. Aluminum production started in Canada in 1901 at Shawinigan Falls using 10 kA Hall cells installed by the Pittsburgh Reduction company. Later, in 1923 production started at the Arvida plant using 23 kA Hall prebake cells. Until almost 1930 all aluminum was produced with Hall-type prebake cells.

The invention of the single self-baking “Søderberg” anode by Carl Søderberg and others in 1918 was seen as a major advancement. The first Søderberg anodes had a circular cross section, but operational difficulties with this configuration lead to the development of rectangular anodes in the early 1930s. The real starting point of the Søderberg revolution came in 1931 at the Pechiney aluminum smelter at Riouperoux in France near Grenoble. This cell had a Søderberg anode with horizontal studs, or conducting pins, operated initially at 22 kA although in his patent application Pierre Torchet claimed to have operated pots at up to 60 kA [1]. The plant also developed a hooding system for improved gas collection and working conditions. Horizontal stud Søderberg (HSS) cell was such a success that by 1937, 17 plants world-wide were using the new technology. At this point the electrical current in Søderberg cells had increased to about 30 kA.

At that time Søderberg type pots had a number of advantages over the early prebake cells;

- Cost savings linked to anode preparation. These include both reduced capital costs for the anode plant (no forming, baking and rodding facilities are required), as well as reduced operating costs.
- Because the anode plant is much simpler to build a smelter can be brought into operation quickly.
- Anode plant production flexibility; it is easy to start small, and later scale up production.
- No handling and cleaning of hot anode butts.
- No need to handle large amounts of anode crust material or to prepare anode cover material.
- Fewer disturbances of cell heat balance.

The first HSS cells were introduced to Canada in 1936 when 2 prototype HSS cells were tested at the Alcan Arvida aluminum smelter. The cells ran successfully and the following year half a potline was built, operating at 30 kA. In the same year an Alcan expert visited Europe and on his return recommended 40 kA HSS lines to be built at Arvida and Shawinigan smelters. By 1938, 2 potrooms at Arvida and 1 potroom at Shawinigan were operating with HSS cells at 40 kA. Results must have been good because in the following year the decision was taken to build a 42 kA potroom at Arvida.

In 1927 the first aluminum smelter in the U.S. operated a potline of cells with one large Søderberg type round electrode and cathodes at the Alcoa Tennessee smelter in Maryville, TN. These round cells operated at 30 kA with a 221 cm diameter vertical anode and 290 cm diameter. The operational performance of these round Søderberg cells proved to be not competitive with the improved Hall prebake cells at that time and thus they were eventually shutdown after a very brief period. No more Søderberg cells were built in the U.S. until 1939 when Alcoa built a 50 kA HSS plant.

The Second World War

The critical moment in the expansion of Søderberg technology occurred with the outbreak of WW II on September 3rd, 1939 as it created almost immediately a huge new demand for aluminum. In both Canada and the U.S. planners realized that new production facilities would have to be built as quickly as possible in order to supply the military needs for the war.

Figure 1. Breaking a hole in the side crust of a HS Søderberg cell at the Alcan Arvida smelter in 1944. Source: Rio Tinto Alcan

At this time Alcan only had 8 potlines in operation; 6 in Arvida and 2 old lines in Shawinigan with a total production of only 70,000 tonnes. They did not have enough operating experience with the new 40 kA Søderberg cells at this point, so the first phase of production increased was achieved by building 6 potlines of 42 kA prebake cells in 1940. Work on the Søderberg cells continued and by 1941, when the greatest expansion in war-time aluminum started, the technology was considered to be mature. Søderberg technology was thought to be better adapted to rapid expansion as the anode plant requirements were much simpler.

Figure 2. Siphoning aluminum metal from a HS Søderberg cell at the Alcan Arvida smelter in 1944. Source; Rio Tinto Alcan

So when the call came to increase production for the war effort, Alcan responded by building a total of 21 potrooms of Søderberg cells, (in addition to prebake potlines) at five smelters during the 1941–1943 period, as shown in Table I, that operated between 42 to 45 kA, as shown in Fig. 1 and Fig. 2. The last Søderberg pot line built at Isle Maligne operated at 50 kA, the highest achieved by Alcan at this point.

By the end of 1943 primary aluminum production from all the Søderberg potlines in Quebec (with increased amperage and the number of cells per potline) reached over 300,000 tonnes per year of which all were produced with energy from hydroelectric generating stations.

Table I. The first five Alcan Søderberg smelters in Canada.

Plant	Technology	Start	Potlines
Arvida	HSS	1937	12
Shawinigan	HSS	1941	4
La Tuque	HSS	1942	2
Beauharnois	HSS	1942	2
Isle Maligne	HSS	1943	1

A similar story played out in the U.S. as the U.S. Federal government embarked on a program in the 1940s that expanded aluminum production capacity two-fold over the next four years to meet demands of the military. The government-owned Defense Plant Corporation spent over $180 million on nine aluminum reduction plants between 1941 and 1945, some of which were operated by Alcoa and the others operated by industry newcomers. Unlike the Canadian expansion, the expansion in the U.S. during the war years was split roughly evenly between Søderberg and prebake aluminum smelters. The primary aluminum annual production at the 5 new Søderberg smelters shown in Table II was around 200,000 tonnes per year.

Table II. The first five Søderberg smelters in United States.

Company	Plant Location	Start	Technology	Potlines
Alcoa	Alcoa, TN	1939	HSS	3
Alcoa	Alcoa, TN	1946	VSS	3
Reynolds	Longview, WA	1941	HSS	3
Reynolds	Listerhill, AL	1942	HSS	3
Kaiser	Tacoma, WA	1947	HSS	2

Unfortunately, the boom did not even last until the end of the war. By early 1944 it was evident that aluminum production had exceeded demand as ingots started to pile up in the smelters. Arvida alone had a stockpile of 60,000 tonnes. By April 1944 Alcan had started to shut potlines in Arvida, but still the ingots accumulated. At the end of 1944 Alcan had closed 15 potlines, including both prebake and Søderberg, in Arvida, 3 potlines in Shawinigan and the entire plants at Beauharnois and La Tuque were closed (La Tuque permanently). And still the cut-backs continued;

before the end of 1945 Shawinigan was completely shut down, including the original Hall prebake cells; 5 additional potlines in Arvida were shutdown. Alcan's annual production was at that time similar to what it had been at the start of the war.

The Golden Years – 1950 to 1970

The gloom didn't last too long though as by 1946 signs of economic recovery were growing and Alcan, slowly at first, but then with increasing haste started activating their closed capacity. Amazingly, by early 1949 all the shuttered capacity had been restarted and still the demand for aluminum increased. Plans were made for further expansion and for operating cells at a much higher current.

Pechiney, Reynolds and Elektrokemisk had started working on VSS (vertical stud Søderberg) cells in the late 1940s, attempting to reach 100 kA. In 1949 Alcan built and tested a VSS cell at Arvida operating at 42 kA. The test cell worked well and an audacious plan was made to scale up the current in cells by a factor of more than 2, aiming for 100 kA. This design was used in 1952 at Isle Maligne. But due to unexpected magnetic problems the cell design had to be modified and thus it was this modified cell design which was used for the new smelter at Kitimat BC in 1954. Unfortunately, the modifications were not a complete success as potline 405 was closed in 1976 and potlines 1 & 2 in Kitimat probably at that time had the highest specific energy consumption of any pot in the world.

The operating problems in Kitimat were so severe that it was decided to change technologies for the second stage of construction. Alcan representatives visited the Pechiney aluminum smelter at Saint Jean-de-Maurienne, France and saw the operation of their 100 kA VSS pots. The operation was so much better than potlines 1 & 2 that the decision was taken to use the Pechiney VSS cell technology for the rest of the Kitimat potlines. Thus, Kitimat potlines 3, 4, and 5 were started in 1955-56, using that design, but with the amperage at 105 kA. The current was increased to 125 kA in the late 1960s following a program to widen the anodes from 80 to 100 inches, (203 to 254 cm). There followed a lull in construction activities due mostly to unfavourable economic conditions. The last potlines (7 & 8) were built from 1964 to 1967 using essentially the same cell design that had been used in lines 3-5. The first building, 8B, was started with smaller anodes, but the next two buildings, 8A & 7B, were started with wider Søderberg anodes. These were to be the last new Søderberg potlines to be built in Canada.

At the same time British Aluminium was building a VSS aluminum smelter at Baie Comeau Quebec. The first potline started operation at the end of 1957 with a capacity of nearly 50,000 tonnes per year. It used the same 100 kA pot that BACO started at Lochaber, Scotland.

From 1941 until the early 1960s Alcan built no new prebake cells. It wasn't until 2000 that Alcan's prebake primary aluminum production exceeded its Søderberg production!

Table III. Søderberg smelters that started operating in United States in the 1950s.

Company	Plant Location	Start	Technology	Potlines
Kaiser	Chalmette, LA	1951	HSS	8
Reynolds	Corpus Christi, TX	1952	HSS	2
Reynolds	Arkadelphia, AR	1953	HSS	1
Reynolds	Longview, WA	1957	HSS	(3)*
Reynolds	Listerhill, AL	1958	HSS	(3)*
Martin Marietta	Columbia Falls, MT	1955	VSS	2
Martin Marietta	Dales, WA	1958	VSS	2
Alcoa	Point Comfort, TX	1959	VSS	7
Reynolds	Massena, NY	1959	HSS	3

*Expansion of existing potlines.

The situation was the same in the United States as the aluminum industry's cycle of rapid wartime build-up in the U.S. was repeated during the Korean War in the1950s. The United States government encouraged existing U.S. companies to construct additional reduction plant facilities due to a deficit in aluminum availability for military purposes. The majority of the aluminum plants were built using the Søderberg cell technology as at that time it was considered to offer lower operating costs and a higher metal purity than the alternative choice, prebake cell technology. The atmospheric emissions from Søderberg cells were not a concern at that time. Additionally, Søderberg cells were less costly than prebake cells which require baking furnaces and rodding facilities.

From 1951 to 1959, 1.16 million tonnes of primary aluminum capacity was added from six new Søderberg smelters in the United States; Reynolds Corpus Christi, Reynolds Arkadelphia and Reynolds Massena; Martin Marietta Dales; Anaconda Columbia Falls and Alcoa Point Comfort. Potlines were added at two existing smelters; Reynolds Longview and Reynolds Listerhill as shown in Table III. The largest HS Søderberg cell every developed was the 150 kA cells utilized at Reynolds Arkadelphia, AR and Corpus Christi, TX with anodes that were 10 meters in length as shown in Fig. 3.

Figure 3. A 150 kA side-by-side HS Søderberg cell at the Reynolds Arkadelphia smelter in the 1980s.

Table IV. Søderberg smelters that started operating in United States in the 1960s.

Company	Plant Location	Start	Technology	Potlines
Anaconda	Columbia Falls, MT	1965	VSS	1
Kaiser	Chalmette, LA	1967	HSS	(1)*
Anaconda	Columbia Falls, MT	1968	VSS	2
Kaiser	Tacoma	1968	HSS	(1)*
Martin Marietta	Goldendale	1971	VSS	3

*Expansion of existing potlines.

Further expansion of primary aluminum smelters continued in the 1960s although at a slower pace as shown in Table IV. Two new Søderberg smelters were added by Anaconda at Columbia Falls, MT and Martin Marietta at Goldendale, WA; additional Søderberg potlines were added at Kaiser Chalmette and Tacoma smelters.

The primary aluminum industry had also taken root in South America. A small smelter had started operations in Ouro Preto MG, Brazil in 1945, using HS Søderberg technology supplied by Elektrokemisk. Initially owned by Elquisa, it closed in July 1946 due to financial problems. Bought by Alcan in 1950, the plant restarted production in August 1951 with a capacity of 1,800 tpa. In 1956 production was expanded to 6,000 tpa, and in 1958, a second potline (Reducao II) was started using an HS Søderberg pot design from Arvida. A new VS Søderberg plant was started in June 1955 by CBA (Companhia Brasileira de Aluminio) located at Aluminio, near Sao Paulo with a capacity of 10,000 tonnes per year using Søderberg technology from Montecatini.

Table V. Søderberg smelters in South America.

Company	Plant Location	Start	Technology	Potlines
Alcan	Ouro Preto, Brazil	1958, 1978	HSS	2
CBA	Aluminio, Sao Paulo, Brazil	1961-2007	VSS	9
Alcan	Aratu, Sramenha, Brazil	1968	VSS	2
Aluminio Vera Cruz	Veracruz, Mexico	1963	VSS	2
Alcoa	Paranam, Surnam	1965	VSS	1
Alcan	Aratu, Saramenha, Brazil	1970, 1982	VSS	1
Alcoa	Pocos de Caldas, Brazil	1970	VSS	3

By 1960 the region was ready for rapid expansion; VS Søderberg plants were built at Vera Cruz, Mexico (Alcoa technology) in 1963; Alcoa smelter at Paranam, Surinam in 1965; as well as expansion of the CBA VS Søderberg plant in Aluminio, Brazil. These plants were followed soon after by the construction of a new Alcoa VS Søderberg plant at Poco de Caldas, Brazil in 1970; a HS Søderberg at Aratu, Brazil in 1970; and further expansions of potlines by CBA in 1970 and in 1977; and a third potline at Ouro Preto in 1978.

By the 1970s the twenty three Søderberg smelters located in North and South America shown in Fig. 4 had a primary aluminum capacity over 3 million tpy.

The Decline

Although Søderberg plants would continue to be built in the Americas after 1980 (Aratu VS Søderberg in 1982, and a continued expansion program by CBA stretching from 1982 until 2007), the glory years of Søderberg cell technology were over.

A number of factors contributed to the decline:

- Energy costs: Most of the Søderberg plants had been built when energy costs were low. As a result, extra money was not invested to implement large busbar cross-sections as high voltage drops were offset by lower capital costs. In addition, almost all Søderberg potrooms had an end-to-end cell arrangement, which increased busbar lengths, and thus voltage drops. In addition, Søderberg pots are generally not as energy efficient as prebake pots, so their energy cost per ton of aluminum is higher.

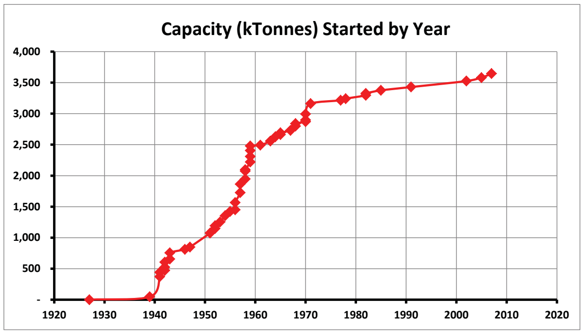

Figure 4. The expansion of primary aluminum production from Søderberg smelters, 1940 to 2010.

- Amperage levels: Once amperage levels started to exceed 120 to 150 kA, MHD effects became too strong to be compensated for in an end-to-end pot cell arrangement and consequently as the Søderberg anodes became larger, their operation became more and more difficult.
- Health: In1975, the Canadian Federal Health Protection Branch signalled the presence of an unusual number of bladder cancer cases in the Chicoutimi area, including Arvida [2]. In 1979 Gibbs et. al., published a report linking Søderberg potroom workers to an increased risk of lung cancer [3]. In both cases, tar fumes from the Søderberg anodes were identified as being the probably toxic agent. The tar fumes were found to contain polycyclic aromatic hydrocarbons (PAH). Some of its components such as benzo[a]pyrene (BaP) were identified as being mutagenic and highly carcinogenic. The sources of PAH is the coal tar pitch binder of the anode. The PAH problem is unique to the Søderberg operation as they are emitted to the working atmosphere during anode baking and spike replacement. By comparison the PAH components of coal tar pitch in prebake anodes are destroyed when heated 1150-1200°C in anode baking furnaces.
- Environment: In the 1990's the aluminum industry also became aware of the harmful effect of the perfluorocarbons (PFC) greenhouse gases that develop during anode effects. Originally Søderberg smelters operated with a high anode effect frequency, typically 1 to 2 AE/pot-day, due to its large side-break and alumina feeding operations at ~2 hour intervals. Consequently, some Søderberg potlines have being retrofitted with point feeder technology to reduce anode effects.
- Manpower" Søderberg potlines typically use twice as many man-hours per tonne of metal as prebake plants. In addition, due to lack of space and the nature of the work, it has proved very challenging and expensive to mechanize or automate work.

The cumulative shutdown of Søderberg capacity in North and South America from 1940 to 2013 shown in Fig. 5 indicates that there have been four crisis periods.

Period 1: In 1974, the OPEC Middle East oil embargo initiated a worldwide energy crisis. Between October 1973 and January 1974 world oil prices quadrupled and affecting the price of electrical generation. This was followed a couple of years later by an increase in natural gas prices. As a result, aluminum capacity was closed in the U.S., Japan and in Western Europe and new capacity added since the late 1970s has been only in regions with low cost energy.

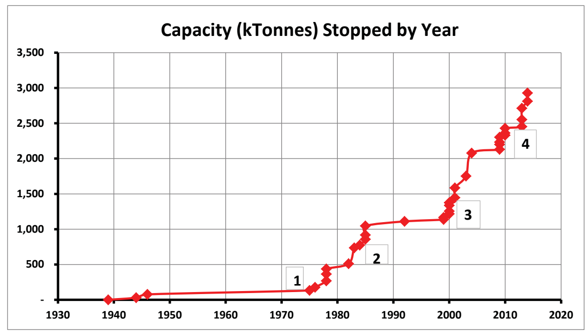

Figure 5. The decline in primary aluminum production from Søderberg smelters in North and South America, 1940 to 2013.

Period 2: Corresponds to a major increase in power costs by the Tennessee Power Authority (TVA) as it affected smelters in the US Southeast with the closure of 18 potlines.

Period 3: Includes a number of factors. Skyrocketing electrical power prices resulted due to the California electricity US Western energy crisis of 2000 and 2001 as California had a shortage of electricity. Only two of the original 10 aluminum smelters in the Northwest are operating. In addition, old capacity in Quebec was shut down as new replacement smelters were built, A and in Surinam, the Alcoa Paranam plant was closed due to low rainfall affecting hydro-electric power generation

Period 4: Corresponds to the 2008-2009 global recession began with a marked global economic decline that began in August 2007 as a liquidity crisis and took a particularly sharp downward turn in September 2008. It resulted in the plummet in the price of primarily aluminum from US $3,000/mt (July 2008) to $1,340/mt (March 2009). This was followed by record high metal inventories. LME aluminum inventories more than tripled from 1.2 million tonnes pre-crisis to more than 4.5 million tonnes by the middle of 2009 Aluminum, and stockpiles in warehouse climb to record levels above 5 million tonnes in 2011-2013 and consequently depressed aluminum prices. The LME 3 month price was US$1880 in September 2013.

During this period, Aluminum companies did their best to improve the environmental impact, working conditions, and economic performance of their smelters. Dry scrubbers were introduced to capture and recycle fluoride emissions, and lithium was introduced as an additive to the electrolyte to reduce fluoride emissions. Much work was done improving the capture efficiency of the exhaust systems. Changes were made in Søderberg paste formulation and anode operating practices to lower tar fume emissions and reduce their toxicity. Workers were better protected as well. The use of high performance respiratory protection became mandatory. Where possible, workers were inside closed cabins provided with air conditioning and high-efficiency filtering. To the extent possible, tasks were automated. Yet despite very significant improvements, Søderberg plants continued to fall further behind the performance of the new generation of prebake plants.

The Future

Of the 108 Søderberg potlines that have operated in the Americas, only 22 are still in operation and there have already been announcements concerning the closing of 12 of them. Of these remaining 12 Søderberg potlines, 11 are located in Brazil with 9 of them being operated by CBA. So, is there a Søderberg future?

Adolf Syrdal (Elkem Aluminium Lista) stated that, "Modernisation of a Søderberg smelter is often far more economic than retrofitting. Technology is available that will meet the environmental requirements and improve the productivity. It is therefore possible for even small upgraded Søderberg lines to sustain their operation and obtain a competitive position compared with the prebake alternatives"[4].

Major aluminum companies are developing improved Søderberg technology in order to reduce worker exposure to PAH compounds in the work place as well as the emission of fluorides into the atmosphere. For example, in the late 1970s, the Sumitomo aluminum company marketed and sold their Søderberg pot technology which consisted of "dry" anode paste with a lower pitch content and introduction of pot crust bar breakers for automating alumina additions and larger anodes to reduce energy consumption. These improvements lowered the PAH emissions and made feeding the pot easier. More recently, successful and valuable improvements have been reported in Søderberg pot design and operation in some countries, mainly in Norway, Spain and Russia. Improvements to Søderberg cell technology were made at the Elkem Lista smelter in Norway in the 1990s and were implemented recently at the Alcoa La Coruna and Aviles smelters in Spain to improve current efficiency and reduce energy consumption. However, the major focus of the technology is to improve the environmental performance by: (a) better alumina feeding control technology using point feeders to reduce the frequency of anode effects and the greenhouse gas emissions and (b) introducing a closed anode top to nearly eliminate the PAH emissions.

Rusal has developed different methods for hooding and sealing Søderberg pots, implemented point feeders and a colloidal anode with pitch content close to that of a prebaked anode in Søderberg potlines at the Kraznoyarsk aluminum smelter in Russia. However Søderberg smelters are facing challenging environmental requirements as the industry expects even more stringent emission requirements in the years to come.

The modern potlines that CBA operates are amongst the most energy efficient Søderberg ever built. Several of them operate at 14 kwh/kg Al and it is believed that it is possible to achieve even lower specific energy consumption values. If environmental and working atmosphere issues are addressed and resolved to the satisfaction of regulatory officials, and if economic conditions improve with higher metal prices, then Søderberg cells will certainly continue to operate for years to come - the last survivors of a once highly successful technology.

Acknowledgements

The book, "Global Mission – The Story of Alcan" was consulted extensively when writing the section on Alcan history [5]. In addition, we would like to thank Claude Gilbert and others at the Arvida Research and Development Centre for their help in providing details of Alcan's operating history.

References

1. P. Torchet, United States Patent 2,073,356, "Electrode Suspension" March 9,1937.
2. D.T. Wigle, "Bladder Cancer: Possible New High Risk Occupation", Lancet 1977 Vol. 2: pp.83-84.
3. G.W. Gibbs and I. Horowitz, "Lung Cancer Mortality in Aluminum Reduction Plant Workers", Journal of Occupational Medicine May 1979.
4. A.K. Syrdal, "The Søderberg Cell Technology – Future Challenges and Possibilities", Light Metals 2002, pp.319-325.
5. D. Campel,"Global Mission – The Story of Alcan", (ISBN:2-9801656-1-1), Ontario Press, 1985.