Historical Development of Aluminium Production Technologies in Germany

Horst Peters
Business owner
Aluminium Technology Consultants, Bonn, Germany
Corresponding author: horst.d.peters@web.de
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Abstract

Ørsted in 1824 and Wöhler in 1827 are credited with the discovery of aluminium, which they obtained from aluminium chloride, the former in reaction with potassium amalgam, and the latter with pure potassium: $AlCl_3 + 3K \rightarrow Al + 3KCl$. Initially, both likely obtained an aluminium alloy with some potassium. In 1827, Wöhler obtained aluminium powder, but continued his research, and in 1845 he was able to produce small pieces of the metal and described some of its physical properties. For this, he is credited with the first isolation of the metal in its pure form.

The aluminium discovery initiated an aluminium hype and people from all over the world came to Göttingen, including the Frenchman Henri Sainte-Claire Deville and Frank Jewett from USA. Jewett motivated his student Charles M. Hall to develop a process for industrial production of aluminium. In Wöhler's Institute worked Alfred Wilm. He developed the age hardening of aluminium alloys and made aluminium a versatile material suitable to build planes.

Bunsen obtained in 1854 aluminium in an electrolytic process with the power source of the "Bunsen Element". Industrial production of aluminium by electrolysis was not possible until after Siemens found in 1866 the electrodynamic process for continuous generation of electricity. But Bunsen had already focussed on competitive alumina production. Two of his Heidelberg students were successful. Georg Otto Guilini and Karl Josef Bayer were able to digest bauxite in liquid potassium at a very cost competitive basis. Bayer later used sodium hydroxide (caustic soda) for alumina production, and this is known as the Bayer process. Bielfeldt in 1966 invented the tube digestion process for high pressure, high temperature digestion of monohydratic bauxites. The Bayer process in combination with the Hall-Héroult process enabled the industrial production of aluminium in a competitive way - till now.

In 1936, Roth developed in Hannover a water-cooled mould to cast extrusion billets and rolling slabs. A further development was Hot Top Moulds.

In more recent times, Germany contributed to the development of Hall-Héroult cell technologies with continuous prebaked anodes. A special retrofit package for smelters with short payback periods was developed with items like debottlenecking of busbar systems, ELAS's Pot Control System and various alumina transport and distribution systems.

Keywords: Wöhler process, Bunsen electrolytic process, Bayer process, Tube digestion, Aluminium reduction technology.

1. Historical Developments

Ørsted in 1824 and Wöhler in 1827 are credited with the discovery of aluminium, which they obtained from aluminium chloride, the former in a reaction with potassium amalgam, and the latter with pure potassium:

$$AlCl_3 + 3K \rightarrow Al + 3KCl.$$

1.1 Wöhler

Wöhler was born on 31st of July 1800 in Frankfurt. He studied medicine in Heidelberg from 1820 to 1823 and additionally chemistry from 1821.

Figure 1. Friedrich Wöhler.

In the years 1823 and 1824, Wöhler worked with Berzelius in Stockholm, at that time the highest competence in chemistry. On his way back to Germany, Wöhler stopped from 27th to 30th September 1824 in Copenhagen to meet Ørsted.

Ørsted worked from 31st May 1824 to 31st May 1825 on the discovery of aluminium from aluminium chloride. In many trials Ørsted was not able to obtain pure aluminium, but most likely an aluminium alloy with the elements used in the experiment, mercury and potassium; the metallic shiny lump of material he obtained looked like tin. In 1820, Ørsted discovered magnetism. He focussed his research further on this item and the related electricity.

Ørsted informed Wöhler about his research to obtain aluminium and recommended him to "follow up this matter" [1].

In 1827, Wöhler repeated in Berlin the Ørsted trials with the same result [2]. Wöhler became in 1836 professor of chemistry in Göttingen and in 1845 he repeated his tests replacing potassium amalgam with pure potassium, and with this so-called "Wöhler process" he was able to obtain a small quantity of liquid aluminium. These pieces of aluminium made it possible to define the chemical and physical characteristics of aluminium. For this, Wöhler is credited with the first isolation of aluminium in pure form. When Wöhler published his results in 1845 in "Annalen der Chemie und Pharmazie", an international aluminium hype began [3].

On 6th of February 1854, the Frenchman Henri Sainte-Claire Deville reported at the Academy of Sciences about his success to obtain aluminium. By replacing potassium by sodium, he was able to make a few kg of aluminium in good quality. Because Deville did not mention that he applied the Wöhler process, a priority dispute started.

The dispute was settled by honouring Wöhler with the French State medal by Napoleon III and he was called "père d'aluminium". Wöhler recognised that Deville achieved bigger quantities of pure aluminium and gave the discovery public attention. Both became later friends and performed, in 1857, in Göttingen tests with boron, silicon and titanium [4].

From 1874 to 1875 Frank Jewett from USA studied in Wöhler's laboratory. Jewett motivated his student Charles Martin Hall at Oberlin College, Ohio, USA, to develop a process for industrial production of aluminium, which became the Hall-Héroult process.

The idea of Ørsted and Wöhler to obtain aluminium from aluminium chloride, was revived by Alcoa who developed the process of $AlCl_3$ electrolysis, and in its final stage built and operated a demonstration plant in Palestine, Texas between 1976 and 1982 [5]. The daily production was 13 t. Due to corrosion problems and other reasons, the plant was closed in 1985.

Hydro Aluminium and SINTEF have reactivated the aluminium chloride process again with the prospect of 30 % lower power consumption than the Hall-Héroult process and no CO_2 emission but oxygen instead, since CO_2 is recycled within the process, called HalZero [6].

1.2 Wilm

Alfred Wilm (1869-1937) worked in the Wöhler Institute. In 1906, he discovered the age hardening of aluminium. This knowledge made aluminium a versatile material for a variety of applications. Junkers could build with this Duraluminium in 1913 the Ju 13 as the first all-aluminium plane [7].

Figure 2. Ju 13 all-aluminium plane.

1.3 Bunsen

Robert Wilhelm Bunsen (1811-1899) studied chemistry in Göttingen. In 1850, he developed the “Bunsen Element”, a zinc-carbon battery. With the “Bunsen Element” Bunsen started in 1850 in Breslau tests to obtain aluminium and magnesium with an electrolytic process [8].

In 1852, Bunsen became Professor in Heidelberg and in 1857 he was successful in obtaining aluminium by his electrolytic process from an aluminium-sodium-chloride ($NaA1Cl_4$) melt with his Bunsen Element as power source. Industrial production of aluminium by electrolysis was not possible until after Siemens found the electrodynamic process for continuous generation of electricity in 1866.

1.4 Bayer

Bunsen had already focused on competitive alumina production and motivated his students to work on a solution. Two of Bunsen's Heidelberg students were nearly at the same time successful, Georg Otto Giulini and Karl Josef Bayer, using liquid sodium hydroxide.

Soon after publishing the Wöhler patents in 1887 and 1891, a priority dispute started between Wöhler and Giulini. The settlement was as follows:

- Bayer's patents were recognized.
- Giulini could operate his alumina plant near Ljubljana, Slovenia, without paying license fee. In 1894 Bayer built the alumina plant in Gardonne, France, with the Bayer process for Société Electrometalurgique Francaise de Froges.
- The Bayer process is patented worldwide and License Agreements are signed with Alcoa, Pechiney, Alusuisse, and British Aluminium. [9, 10].

The Bayer process in combination with the Hall-Héroult process enabled the industrial production of aluminium in a competitive way – till now.

2. Alumina Technologies

2.1 Tube Digestion Process

This section is a summary of the author's full paper in ICSOBA 2017 [11].

In 1956, VAW started the development of the tube-digestion process at its Nabwerk plant under the direction of Dr. Klaus Bielfeldt. The process, which had taken ten years to develop, was used commercially for the first time for a 20 000 t/a capacity upgrade in 1966. Tube digestion was also used at the Lippewerk plant in order to be able to economically process difficult-to-digest monohydratic bauxites from Greece.

The Aluminium oxid Stade (AOS) plant (Figure 3), a 600 000 t/a oxide plant with a completely new design based on the VAW tube-digestion process, started operation in 1973.

Figure 3. AOS alumina plant in Stade.

Essentially, three bauxite digestion processes have been used in the aluminium industry since World War II:

1) Autoclave digestion using a dual-stream process,
2) Autoclave digestion using a single-stream process,
3) Tube digestion using a single-stream process.

The bauxite available determines the choice of digestion process:

- Autoclave digestion is preferred for easily digestible trihydrate bauxites ($Al(OH)_3$), such as hydrargillite (gibbsite), which occur predominantly in the tropics.

- The tube-digestion process is preferred for difficult-to-digest monohydratic bauxites (AlOOH), such as boehmite from the Mediterranean region or diaspore, which is the main mineral in Russian and Chinese bauxites.

The dual-stream process referred to under 1) is characterized by a large number of heat exchangers, in which the digestion liquor is first heated up using vapour from the pressure-reducing units in lines that operate in parallel, and together with the bauxite suspension then heated by process steam to digestion temperatures of up to 240 °C in several large-volume autoclaves. This digestion process was developed for readily soluble trihydrate bauxites but can also be used for boehmite bauxite.

The single-stream autoclave process referred to under 2) is characterized by a large number of autoclaves arranged in series, whereby the number of autoclaves increases with increasing digestion temperature and increasing residence time.

Digestion temperatures in these plants reach up to 250 °C. Liquors of higher alkali concentration are usually used to increase the production capacity and yield, and the plants are connected to an energy-intensive-stream-supply station. A single-stream autoclave process is preferred for use with trihydrate bauxites.

The tube-digestion process referred to under 3) displays characteristics of both autoclave systems. However, it leads to considerably lower energy consumption and operates continuously. Tube digestion was developed for use with monohydratic bauxites but can also be used with trihydrates. The digestion temperature is 280 °C at an operating pressure of approx. 110 bar. The maximum digestion temperature depends on the type of bauxite used. A temperature of 280 °C is used for monohydrates.

The incrustration that takes place with time is considered by means of an intermediate increase in the salt inlet temperature from about 300 °C to about 400 °C. The heat exchanger is cleaned hydromechanically to remove titanate-containing crusts at higher temperatures and by acid treatment to remove silicate-containing crusts at lower temperatures. The time between clearing operations depends on the composition of the bauxite used. For the bauxites used by VAW, an intermediate acid treatment was carried out after about 200 operating hours and an acid treatment with hydromechanical cleaning of the salt heat exchanger and cleaning of the pressure-reducing unit after about 4 000 hours' operation.

Reciprocating diaphragm pumps are used to feed the bauxite suspension into a tube digestion plant. Likewise, for adding lime. The flow velocity in the digestion tubes is chosen so that there is no sedimentation of red mud even if the bauxite is coarsely ground; it is about 2 to 3 m/s.
There are no limitations on the bauxite composition because of the high digestion temperatures in the tube reactor. They have been used to process bauxites from Australia, Africa, South and Central America, Europe and Asia.

The benefits of the tube-digestion process compared with the use of autoclaves to process monohydratic bauxite are:

Low energy requirement

- The high turbulence during digestion favourably affects heat transfer and material transfer. This results in a lower liquor requirement and a reduced heat requirement for the process.
- The use of salt or oil as the heat transfer medium achieves a high degree of primary-energy utilization and thus low energy consumption.

- Under comparable conditions, the total energy requirement for tube digestion is 40 % lower than it is when autoclaves are used.

Low investment

- Digestion yields are already sufficiently high at low lye concentration, for example at the precipitation concentration, and thus evaporation plants are not needed to produce strong liquor.
- The high digestion temperature allows large quantities of condensate to be produced by flash evaporation, which depending on the type of bauxite and quantity of red mud can suffice to meet the process' washing-water requirement completely. One can thus dispense with evaporation units to produce washing water.
- The use of salt as the heat-transfer medium means the tube-digestion process does not require any high-pressure stream. Thus, savings associated with evaporation compensate for the considerable investment needed for the digestion system.

High plant availability

- The availability of the plants is about 90 %. Together with operating data for upstream and downstream activities, plant utilization is designed to be 85 %.
- At Aluminium Oxid Stade, utilization is practically 92 %.

Removal of organics

- Another important benefit of tube digestion is the inline removal of the troublesome organic constituents of the bauxite [12].

2.2 Alumina Plants Using the VAW Tube-Digestion Process

The autoclave technology frequently used for bauxite digestion has economic and technical limitations. One cannot increase the size of the reaction area in autoclaves arbitrarily. Furthermore, the availability of readily digestible trihydrate bauxites is declining. With an increasing fraction of monohydrates, the digestion temperature has to be increased to 250 to 300 °C in order to achieve economic efficiency. It is here that autoclaves have their limitations and tube digestion is an option. VAW worked on this from 1956 onwards and developed the technology to the production stage.

Citation from [11]:

"In the late 1980s, VAW decided to close Tube Digestion Unit No. 6 in Lünen for economic reasons. The plant was sold to China Great Wall Corp. in Zhengzhou, Henan, where it was erected again. After start-up, there were problems with the service life of the pump membranes, but these could be solved. The plant is operating successfully with China's very hard monohydratic bauxites. According to the project manager, Professor Li Yuan, there are now more than 20 tube digesters based on the VAW process operating in China.

The Chinese engineering company NFC has built two alumina plants based on the VAW tube-digestion process, each with an annual capacity of 600 000 t, in Tan Rai and Thanh Nien in the Central Highlands in Vietnam. The first unit started operation in 2014, and the second is commissioned in 2017. An expansion to 7 M t/a is under way.

In 2002 VAW awarded a licence to Rio Tinto Alcan and provided expertise to build a tube digester for the Yarwun alumina plant in Gladstone in Central Queensland, Australia. The plant went into operation in 2005 with an annual output of 1.8 M t; the capacity was expanded to 3.4 M t/a in 2012.

In 2009, Ma'aden Aluminium of Saudi Arabia decided to use VAW tube digestion for the difficult-to-digest monohydrates from the Az Zabirah deposits. The alumina plant was completed in 2014.

Also in 2014, Emirates Global Aluminium decided to build an alumina plant based on VAW tube digestion alongside the 1.4 million t/a aluminium smelter in Abu Dhabi. The plant has been in operation since 2019. The capacity is 2 M t/a."

2.3 Aluminium Hydroxide Calcination

The hydrate from the Bayer process is calcined to alumina circulated fluidised bed (CFB). This task was originally performed by rotary kilns. Meanwhile all new capacities are installed as fluidised bed calciners.

In 1961, VAW started at its Lippewerk, Lünen, a pilot plant for alumina calcination with a capacity of 24 t/d in cooperation with Lurgi. The first industrial alumina calciner with a capacity of 500 t/d was put in operation in 1968 in Lünen. Fluidised bed calciners are now built by Metso Outotec (formerly Lurgi) [13].

Meanwhile, more than 70 units have been sold. Nearly 50 % of word's production of smelter grade alumina is calcined in these units.

Unit production of calciners has meanwhile upgraded to 3 500 t/d, with an energy consumption of 2 790 kJ/kg aluminium compared to 25 000 kJ/kg Al in rotary kilns. A new development is the replacement of gas by electricity is heating element. [14]

2.4 Filtration Technology

In order to improve the alumina production, VAW started a development program with Kraus Maffei for drum filters in the red area and vacuum disc filters for the white area.

Both filter systems are efficient and reliable. They have been installed in many alumina plants around the world. The filter systems are now marketed by Andritz. Meanwhile more than 130 vacuum drum filters and more than 60 vacuum disc filters from Andritz KMPT are operating in alumina plants worldwide.

3. Reduction Technologies

3.1 VAW Smelter Developments

VAW started in 1918 with 12 kA pots. Amperage and efficiency of the pots have been continuously improved over time (Table 4).

The capacity of VAW's first primary aluminium smelter in Lauta (Figure 4) was originally planned to be 18 000 tonnes per year. However, by the end of the war in 1918, only two of the six potlines had been equipped and commissioned. The potlines had open cells with prebaked anodes and this allowed a maximum amperage of 12 kA. The potline voltage was initially 525 V and later 450 V. The cell bottoms were prebaked as a single piece.

An aluminium smelter was also built in Erftwerk in 1916 with cells shown in Figure 5.

In the 1920s there were some 15 kA cells in operation with a cast-iron base plate and an average cell voltage of 6.8 V. With a current efficiency of only about 83 %, the specific consumption of electrical energy was about 24.4 kWh/kg of aluminium extracted.

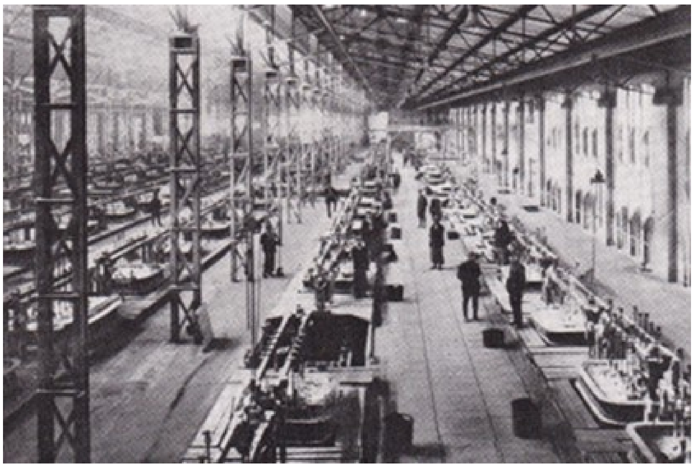

Figure 4. Lautawerk primary aluminium smelter.

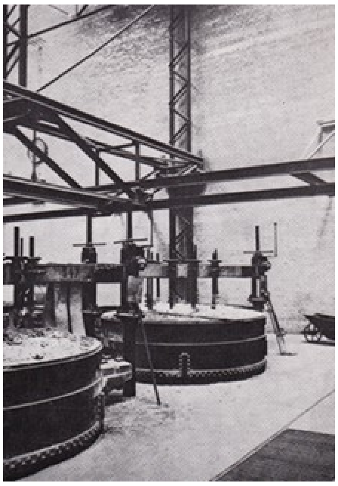

Figure 5. Erftwerk reduction cell (year of manufacture 1916/1917).

Table 1. Typical operating data of VAW reduction cells.

Cell type*	Amperage kA	Start	Cell voltage V	Energy consumption kWh/kg Al	Current efficiency %
SW 12	12	1918	6.0	21.0	85
SW 30	30	1928	5.4	18.5	86
SW 100	100	1955	4.6	16.0	87
CA 120	120	1982	4.50	13.5	92
CA 165	165	1979	4.45	14.2	92
CA 180	180	1980	4.26	13.5	94
CA 240	240	1982	4.1	12.8	95
CA 300	300	1993	4.1	12.8	95

*Cell type: SW = Side worked, CA = entre worked, with standard prebake anodes (called A anodes at VAW).

These figures demonstrate the extremely unsatisfactory state of the process and production at that time. They were improved markedly when the cell type was changed to one in which cast-iron current collector bars were rammed into the carbon bottom. The average cell voltage fell to 6.0 V, the current efficiency rose to 85 % and a specific energy consumption of 21.0 kWh/kg Al was achieved.

VAW’s annual production of aluminium surpassed the 100 000 t mark for the first time in 1938. Every potline was operating with 30 kA. Prebaked carbon blocks into which iron current collector bars were rammed, were used to make the cathodes. Prebaked anodes, partially as packets of anodes, were also used. Mercury-vapour rectifiers were used exclusively for current rectification.

3.2 Continuous Prebaked Anodes

When the rebuilding of the Erftwerk plant began in 1951, two new developments were tested there in large-scale operation. The pots, which were designed for 65 kA, were equipped for the first time with the continuous prebaked large anodes newly developed by VAW [15]. For this, anodes each weighing about one tonne were made in Erftwerk's paste plant. This pot concept contrasted sharply with the Söderberg anodes, which were clearly dominant at the time for pots of this size. The benefit of this solution was seen to be simpler and cheaper pot design, more favourable anode consumption and higher purity of the metal produced. These benefits were partly offset by a higher power consumption caused by the increased resistance due to the power supply being from the side and the cemented layer of the continuous large anode. Prebaked carbon blocks into which flat bars for the power supply were embedded, were used as the cathodes.

The second improvement involved the rectifiers used. Just like the development of the mercury-vapour rectifiers, mechanical rectifiers were used for the first time in an aluminium electrolysis plant. As a result of the favourable characteristic of the efficiency it was possible to work at a potline voltage of 450 V. The first potline, with an annual capacity of 12 000 tonnes, went into operation at the end of 1953. Following start-up difficulties for a brief period, it was already possible in 1954 to decide on doubling this capacity using the same technical equipment.

The first major new step forward was not taken until 1960 when it was decided to build the Rheinwerk plant (Figure 6) [16]. A potline with a voltage of 850 V and initially an amperage of 100 kA was installed at this plant and had an annual capacity of 40 000 tonnes. A somewhat enlarged Erftwerk pot fitted with continuous anodes with an individual weight of 1.5 tonnes was chosen as the pot type. In addition, the pots also had a novel gas collection system in the centre of the pot to remove the flue gases and recover fluorides. It was possible to reduce the man-hours required considerably. Manufacturing of the large anodes in the new paste plant was improved significantly.

Figure 6. Rheinwerk.

The power supply to the smelter in western Germany was based on lignite. Air-cooled silicon rectifiers were used for power conversion for the first time at the Rheinwerk plant. Half of the new potroom was commissioned in October 1962, with the whole plant becoming fully operational in March 1963.

In the meantime, production in all of the plants had been increased by increasing the amperage still further. The replacement of outdated rectifiers by air- or water-cooled silicon prerequisites for these measures. Increasing the cross-sectional area of the busbars in the pots resulted in further savings in energy consumption. Work was carried out constantly to improve the cathodes and anodes of the pots, and automatic control of the potlines was tackled.

With the changeover to large anodes, VAW also had to change the moulding technique used. Anodes weighing one or two tonnes when shaped could no longer be produced using presses in the usual manner. VAW developed a vibratory compacting technology at its Erftwerk plant that allowed flexibility in weight and shape as well as higher densities. The vibratory compacting technology was licensed to KHD (today Outotec), where it formed the centrepiece for the company's green anode plants. Over 100 green anode plants in the world are equipped with KHD's VAW-type vibratory compactors.

The continuous anodes used avoided the need to recycle the anode butts and thereby resulted in very pure metal. Disadvantages that manifested themselves, though, were the high energy consumption due to the voltage drop in the cemented joint and the complex handling of the pot when outside temperatures fluctuated. Another weakness was labour-intensive side break feeding and stud removal operations.

The unimpaired operation of the pot resulting from the absence of anode changes and the resultant thermal shocks could not compensate for these disadvantages, so Comalco Australia discontinued trial operation with the continuous prebake anode after two years. In Australia, more recently, there has been a fresh look at this technology [17].

3.3 Refining Process

In 1937, VAW additionally installed its only smelter for refining aluminium. A second electrolysis treatment and special electrolyte of a very clearly defined specific weight are used to obtain a high-purity metal containing at least 99.99 % of aluminium from aluminium with a high copper content. This three-layer electrolysis process is still in operation today. The annual capacity was initially set at 300 tonnes and was increased to 1 500 tonnes in 1943. Following some start-up difficulties, the process has operated perfectly throughout the intervening years.

3.4 Alumina Transport and Distribution Systems

For modern pots with point breaking and feeding, continuous alumina supply is crucial. Automated alumina distribution systems from the main alumina storage silo to alumina bins on the pots have been developed.

Claudius Peters has developed a low velocity Aerated Distribution System (ADS) (Figure 7) with Anti-Segregation System [18], and FLUIDCON, which combines the advantages of air slide and pneumatic pipe conveying [19]. These can also be used for retrofitting the alumina distribution system in an existing potline [20]

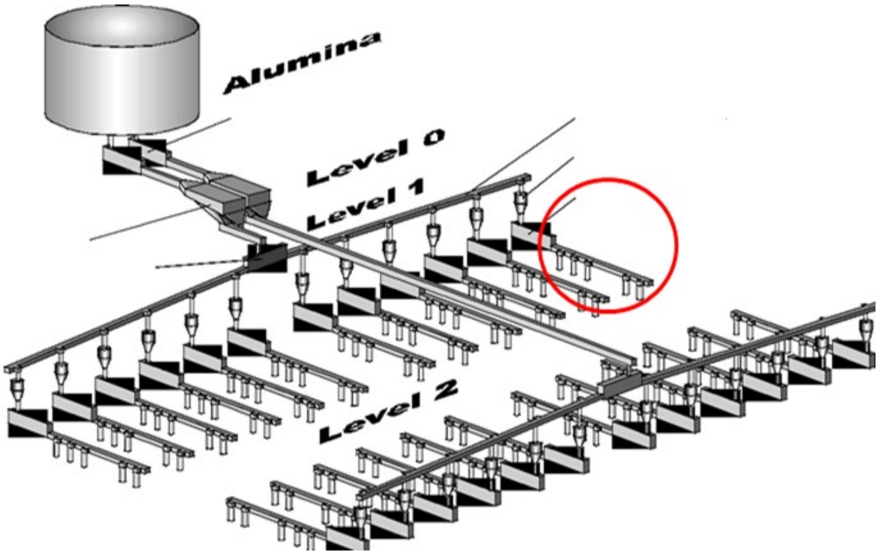

Figure 7. Example of Aerated Distribution System of Alumina.

To improve the handling efficiency, a dense phase alumina transport system, Direct Pot Feeding, was developed and introduced by Möller [21].

3.5 Retrofit of Smelters

VAW ATG developed a special retrofit package with payback periods of less than 3 years. Basis was a debottlenecking of the busbar system by simulation tools. In most cases, production could be increased by 30 %. For better operational control ATG developed the ELAS Pot Control System [22]. The ELAS pot control system used to be widely used in China and Russia.

These tools were used in modernisation of the Mostar Smelter, where side break was upgraded to point feeding, and ELAS pot control system and Möller alumina distribution system were installed with excellent results [23]. Other smelters, which have been modernised with these tools, are Kurri Kurri and Alcoa Portland in Australia, Alouette in Canada, Alusaf in South Africa, Hamburg Aluminium Werke (HAW) and Rheinwerk in Germany.

3.6 Casting

In 1936, Roth developed in Hannover a water-cooled mould for aluminium. A further development was the hot top mould for extrusion billets.

These inventions improved the casting of extrusion billets and rolling slabs dramatically.

In 1980, VAW patented the Vacural-Die-Casting Process [24]. With this process die casting characteristics were improved substantially. Die casting could be used for high duty applications like suspension systems of cars replacing cast iron. This Vacural process is now used by Tesla for the 150 kg front and back parts of the new design. Some Chinese producers cast the bottom of E-Cars and the front and end parts by this technology. It is a game changer in car manufacturing.

3.7 Activities Abroad

3.7.1 Mori and Bolzano, Italy

Together with the Italian company Montecatini, VAW established Societa Italia dell'Alluminio in 1928 in Milan. The company built an alumina plant at Porto Maghera near Venice and two smelters and hydroelectric plants at Mori and Bolzano. As first step, 12 kA cells like the ones at Lautawerk were installed. The second potline comprised 30 kA cells. 100 kA cells were installed in Potline 3 in Bolzano. The capacity in Mori was 24 000 t/a and that in Bolzano 64 000 t/a.

Alba, Bahrain: In 1970, Paul Brauner's Breton Investment Inc. GB reached an agreement with Montecatini to transfer electrolysis technology for a 90 000 t/a smelter in Bahrain. The technology was based on the 100 kA reduction cells of Potline 3 in Bolzano and was installed as P 115.

Puerto Madryn, Argentina: At the end of the 1960s, Montecatini reached an agreement with Argentinian investors to build a primary aluminium smelter in Puerto Madryn. The electrolysis process was based on the cell technology from Bolzano increased to 155 kA.

3.7.2 Mattigwerk, Austria

As demand for aluminium continued to increase ever more rapidly, a further smelter was planned at Mattigwerk in 1938. The first phase was already operating in 1941, which was followed in 1943 by a doubling of capacity. Altogether, five potlines with 30 kA pots and each with a voltage of 800 V were installed at the plant. The pots were equipped with Söderberg anodes. Electricity was supplied by Innwerk A.G. from the new barrages on the river Inn. Rectification was by means of mercury-vapour rectifiers. The total capacity of the plant in 1944 was 55 000 t/a.

3.7.3 Drauwerk, Slovenia

In 1942, work began on the building of an aluminium complex complete with hydroelectric plant at what is today Kidričevo on the river Drava. This plant now operates under the name Talum. The plans of the Lippewerk plant were used. It was intended to build a 150 000 t/a alumina plant and a 70 000 t/a smelter with standard 30 kA cells. VAW recalled its employees at the end of 1944. The plants that were under construction were completed and put into operation after the war. The dismantled pots from the Erftwerk plant were installed.

3.7.4 Nordwerk AG, Norway

On the orders of the German aviation ministry, VAW began to build the Tyin hydroelectric plant and the Årdal aluminium smelter in Norway in 1942. The building plans from the Lippewerk plant were used here, too; 30 kA cells were installed. The building works were not completed by the end of the war. The two smelters, Årdal and Sunndalsøra, started production about 1950. Erftwerk pots were also installed later.

3.7.5 Danjiang Kou Aluminium, China

The potroom at the Töging aluminium smelter was shut down in 1993. There was interest in the aluminium industry to purchase the really new electrolysis units. Potline 1 with 90 cells and an amperage of 120 kA was sold to Danjiang Aluminium Industry Co. Ltd. of China. The plant was dismantled by a Chinese team and installed at its new location near to Wuhan in China. According to Wood Mackenzie report, the VAW-technology lines were closed in 2013.

The decision to choose the 120 kA cells from Töging was based on the fact that it was possible to convert prebake technology with these cells and the superstructures fitted exactly onto existing Söderberg pots.

After permission to operate Söderberg electrolysis plants in China was rescinded, numerous Söderberg electrolysis units were modernised to prebake anodes in accordance with the Töging design.

3.7.6 Sayansk, Russia

In 1989 an agreement was signed between VAW and the Soviet Ministry for Non-ferrous Metallurgy for the development and erection of modern reduction cells with an amperage of 300 kA [25].

The cell design was planned using VAW's latest development tools, such as:

- Busbar design
- Calculation of magnetic fields
- Magneto-hydrodynamic analyses of the stability
- Thermal and voltage balances.

The test section was started up in March 1993 and was successfully operated until, as a result of the privatisation of Russian industry, the new owner showed no further interest in continuing the test operation.

With the consolidation in the Russian aluminium industry that took place from 2000 onwards, work on high current density cells was revived and the 300 kA technology was further developed using the VAW tools available at VAMI, the Russian Aluminium and Magnesium Research Institute in St. Petersburg. In 2002, the decision was made to build a new potline with 300 kA cells located in Sayansk. This increased the capacity of the smelter by 350 000 t/a to 900 000 t/a.

3.7.7 Norðurál Iceland

Norðurál Grundartangi smelter is shown in Figure 8 [26]. The smelter is part of Century Aluminum, now.

Following the closure of Potline 2 at Töging in 1993, the plant was purchased by the American businessman Ken Peterson of Columbia Ventures Corporation (CVC). The 180 kA cells formed the basis for the Norðurál primary aluminium smelter in Iceland. The busbars were modified for amperage of up to 240 kA prior to installation; a potroom of these cells (CA240) is shown in Figure 9 [27].

The first stage of the expansion with 60 000 t/a began in 1998. Subsequent expansions brought the capacity up to 180 000 t/a. The smelter is currently undergoing an expansion programme, which will increase its capacity to 350 000 t/a. The amperage is being increased gradually to 240 kA. Some 317 000 tonnes of aluminium is produced per year now.

Figure 8. Norðurál smelter, Iceland.

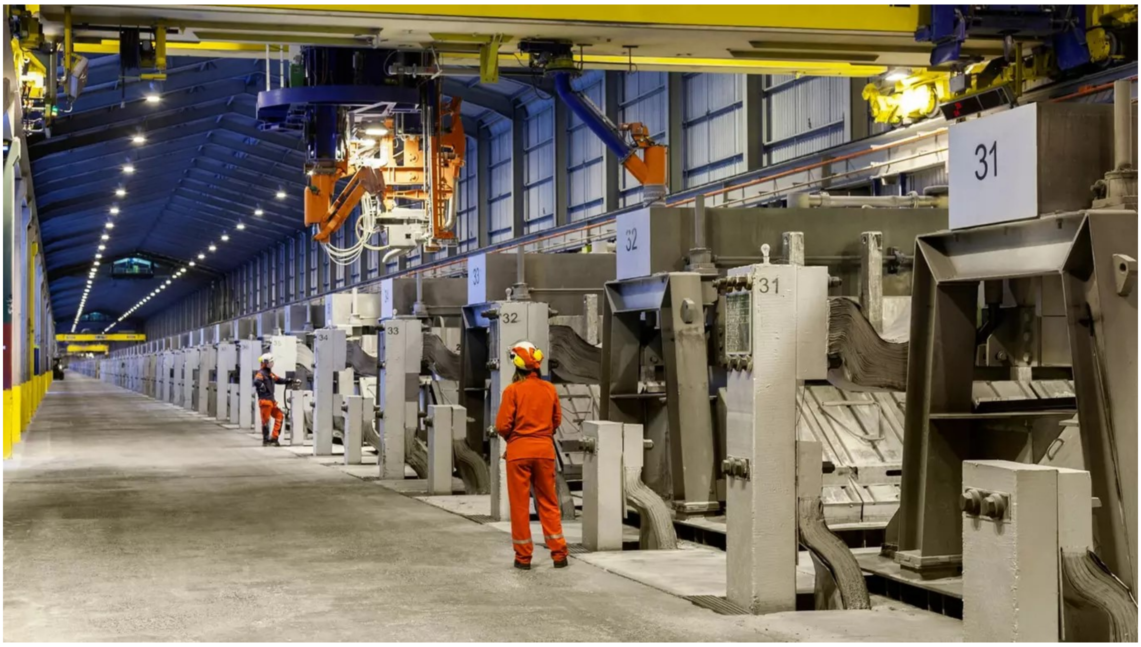

Figure 9. A potroom with VAW's CA 240 cells in Norðurál smelter, Iceland [27].

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