Latest Developments in Aluminium Reduction

Paul H. Muller
Roland E. Oehler

SINCE the end of the Second World War the total global production of virgin aluminium has increased very rapidly. In the year 1945 it amounted to approximately 0·85 million tons a year, whereas for 1960 about 5 million tons may be estimated. The production of aluminium has grown during this time to be one of the most important industries. Although the aluminium works have often been subject to a certain criticism on account of the inflexibility of the extraction process—since in the main the fused salt electrolysis has not altered until this day—developments in the matter of cell design and operating methods have made considerable progress. With regard to further awaited expansion of aluminium production plants, there exists a lively interest to expedite developments to improve cell and building layout and to ensure a more economic operation in order to reduce the previous relatively high investment and operating costs.

Experience tells us that two types of electrolytic cells have proved their merits, namely :

(*a*) Cells with prebaked anodes
(*b*) Cells with self-baking anodes

Survey of the two types of cells employed

The classic reduction cell, as was built at the end of the previous century by Hall-Heroult, belongs to the first named of the above types. While at that time a current intensity of 4,000 amps. was applied, such cells today are operated with a current intensity of more than 120,000 amps. In Fig. 1 a modern group of cells with prebaked polyanodes of 80,000 amps. is represented. It may be said today that the reduction of such high intensity reduction cells with discontinuously working prebaked large size anode blocks is excellent and in the opinion of the authors will in the future play an important role.

In comparison with the other types of electrolytic cells, in consequence of the short path of the current in the anodes, a smaller anode voltage drop can be reckoned with. The general consensus of opinion regarding the inferior Faraday efficiency on account of greater heat dissipation may be encountered by the utilisation of a good heat-isolating alumina.

The best cell series with prebaked anodes function with an average current consumption of about 14·0 kWh/kg (specific current density of the bus bars 0·25 amps./mm^2) with a Faraday efficiency of 88–90%.

The electrolytic cells with continuously working prebaked single anodes (Fig. 2), as carried on by a German aluminium company, were developed with reference to the Soederberg cells with side stubs (Fig. 3). The anode consists of calcined blocks of carbon cemented together. The current passes through contact stubs rammed in and placed at the side.

The results of this operation according to the published figures are approximately the same as with other types of cells. One advantage is the fact that no anode residue occurs as in the discontinuous prebaked cells[1,2].

To the second group of cells belong the types with self-baking anodes. The construction of this class of cells has been pursued intensively since the cessation of hostilities (1945). The great advantage of this type is that no press or calcining equipment is necessary for the anodes. Furthermore, the mechanisation of the auxiliary contrivances can be accomplished in a more simple manner, more especially with the Soederberg cells with vertical spikes, thus only necessitating a low number of man hours.

As disadvantages of this type of cells we mention :

—The question of fumes (waste gases) is much more important than with prebaked cells, especially in case of large plants located in highly developed agricultural areas.

—The lesser specific current density of the anode lies at about 0·7 amp./cm^2 compared with 0·80–1·00 amp./cm^2 of the prebaked anode, demanding larger cells and greater floor space and thereby higher investment costs for the same level of productivity of aluminium.

—The quality of anode material has a direct influence on the working rate of the cell. The control of the quality in the anode is with the discontinuously working type easier to carry out than with the self-baking anodes. Irregularities in the anode demand by the latter several weeks for

Dr Paul H Muller, Ph.D., Manager, Operations and Technical Services and Mr. Roland E. Oehler, Mechanical Engineer, Assistant Manager, Reduction Section, Aluminium-Industrie-Aktien-Gesellschaft, Zurich, Switzerland.

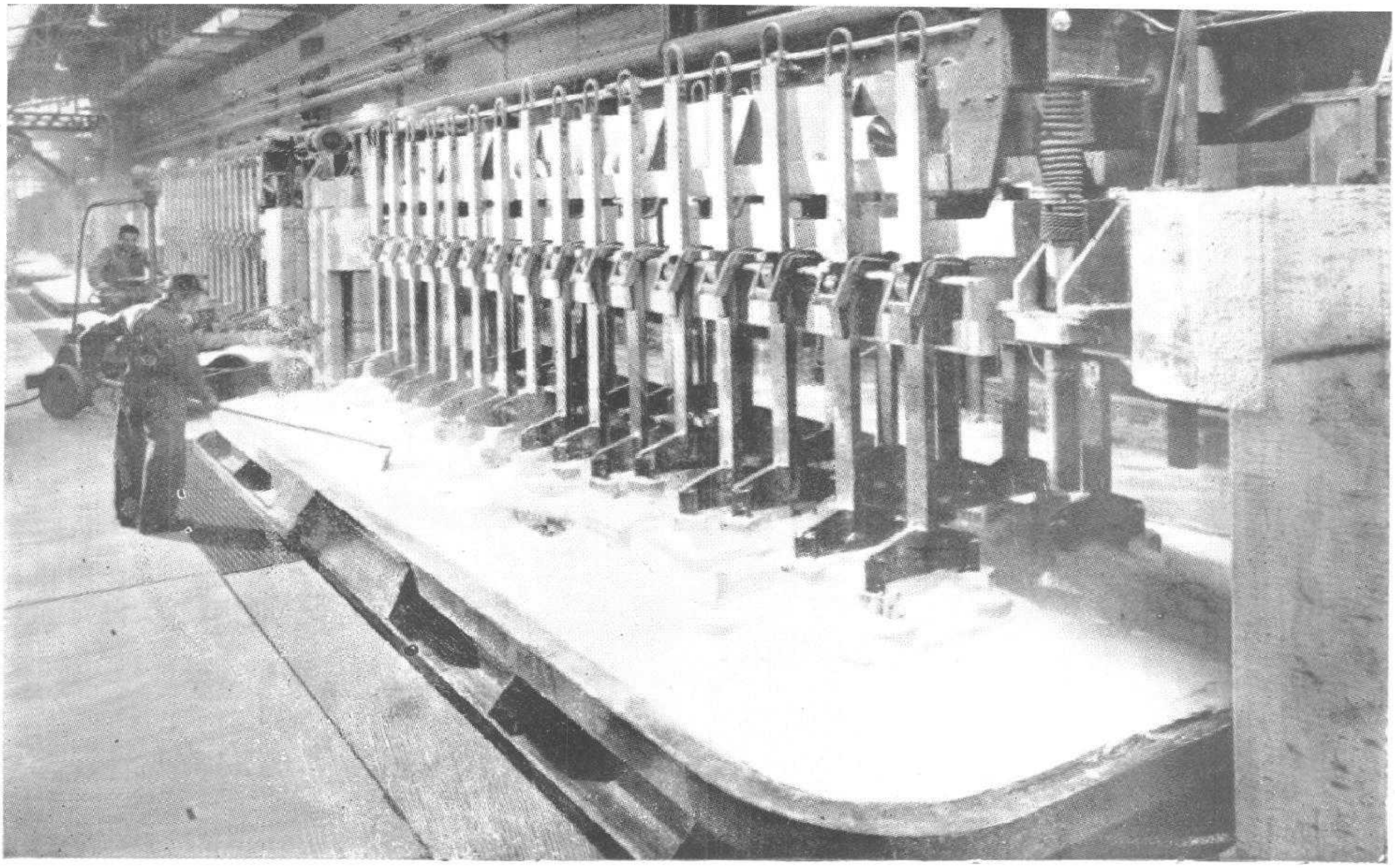

Fig. 1.
A group of 80,000 amps. cells with discontinuous prebaked anodes.

correction, whereas with the discontinuously working prebaked type qualitatively bad or damaged anodes may be replaced within the shortest time.

The types which are preferred today for high tension cells are the Soederberg units with vertical spikes and gas collecting skirt (Fig. 4). Today experimental series of such cells are in existence with 150,000 amps., but experience has shown that the question of material for cell lining as well as the control of the high magnetic field[3] cannot be developed so far to operate units of this size from an economic point of view. As shown below, the writers are of the opinion that such cells are operated to the best advantage in the region of 80–100,000 amps. As a result of the higher anode voltage drop the current consumption is somewhat higher than in the polyanodic prebaked cells. With a modern 80,000 amps. Soederberg cell with vertical spikes production figures have been reached of 14·5–15·0 kWh/kg (specific current density 0·25 amp./mm^2) and Faraday efficiency of 88–90%.

The Soederberg cells with side stubs (Fig. 3) as they were originally built are less commodiously adapted for modern huge plants, but on the other hand a further evolution in similar continuously working prebaked cells as already indicated, and in the so-called paste block cell, is described in the following paragraph.

A third type of cell with continuously self-baking anodes has been developed by a Swiss firm, a paste block cell, which in principle is similarly constructed as the continuously working cell with prebaked anodes, but works with uncalcined blocks. In Fig. 5 the principle of the construction of this cell is represented. From experimental operating results it would seem that this type of cell would reward further study under the headings of return and construction in comparison with other cells[1].

In the following section problems and recent discoveries will be discussed and an attempt will be made to outline further possible developments.

Why cells may be too large

Theoretical considerations and practical experience with Soederberg cells with vertical spikes have shown that with the present state of technical efficiency the tendency to build larger and larger cells attains an optimum in the range of 80-100,000 amps. This is

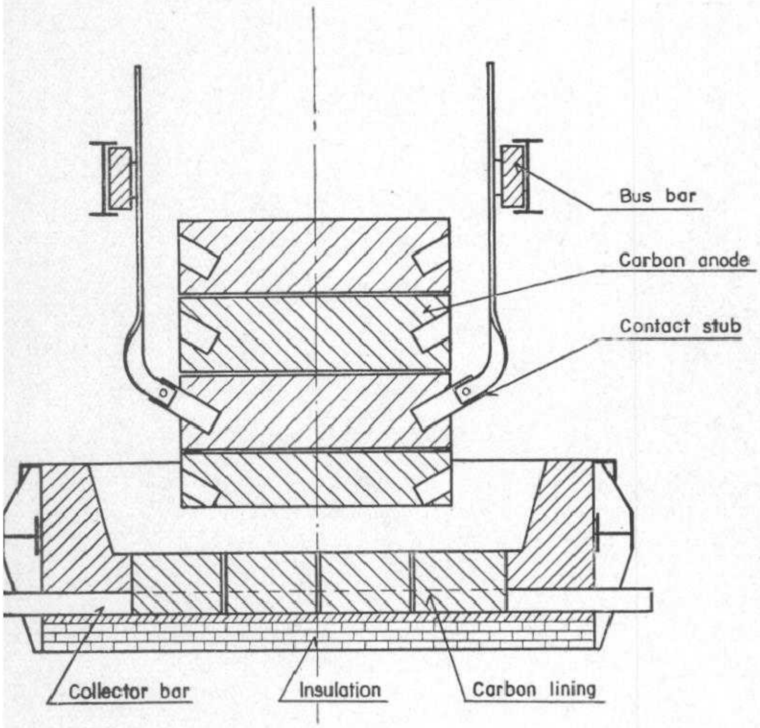

Fig. 2.
Cell with continuous prebaked anodes.

based upon the fact that in building plants with a yearly production of more than 20,000 tons, specific investment costs per ton of aluminium are not proportional with the increased current intensity, but rather reach a minimum and then ascend once more. In Fig. 6, the lower curve denotes investment costs of the cells and auxiliary equipment, while the upper curve represents the sum of the costs of the cells, auxiliary equipment and cell house. It has been shown that the cell susceptibility to repair is greater with an amperage exceeding 100,000 than others with a mean amperage. With the present day state with cathode lining technique an optimum of current intensity is reached at about 90,000 amps. (Fig. 7).

With regard to labour costs a diminution of man-hours can be observed which becomes less with a greater amperage. Moreover, it must be taken into consideration that the influence of the exceedingly powerful magnetic fields as well as the quality of the anode paste on the operation of cells with a greater current intensity is of a correspondingly greater magnitude. It is also a determining factor in the economy of the cell, as the operational results become less favourable and the cell itself becomes extremely susceptible to break-downs.

How to arrange the cells

The views regarding arrangement of cells present a certain diversity. Certain producers of aluminium prefer cells built parallel to the axis of the house because in this way completely mechanised operation is guaranteed. Allowance must be made for losses due to electrical resistance between the cells and for the fact that this disposition of cells requires a greater floor space than is apparent with cells arranged transversely to the house axis.

The parallel cell disposition permits the way of construction advocated by the writers, with a basement for the removal from below of the cathodes requiring repair (Fig. 10). This layout is once more described in detail in the section below entitled "Facts on the repair of cells".

With transversely placed cells the removal of the cathode from below is, on account of construction difficulties, only possible under certain conditions, and demands substantially higher building investment. The removal of the cathodes which are to be repaired from above by means of a crane naturally requires solidly built cranes and heavy duty building house construction. It has been proved that cells arranged transversely with a clearance of 2·2–2·5 m between the cathode shell show quite good results. The current loss as a result of short bus bars is less than with cells disposed parallel to the cell house. Again it has been

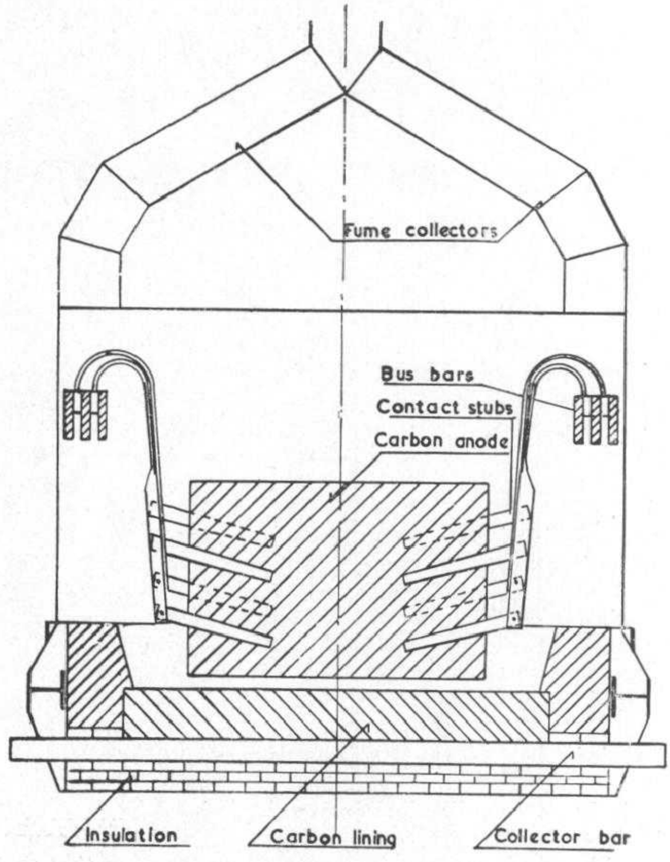

Fig. 3.
Soederberg cell with side stubs.

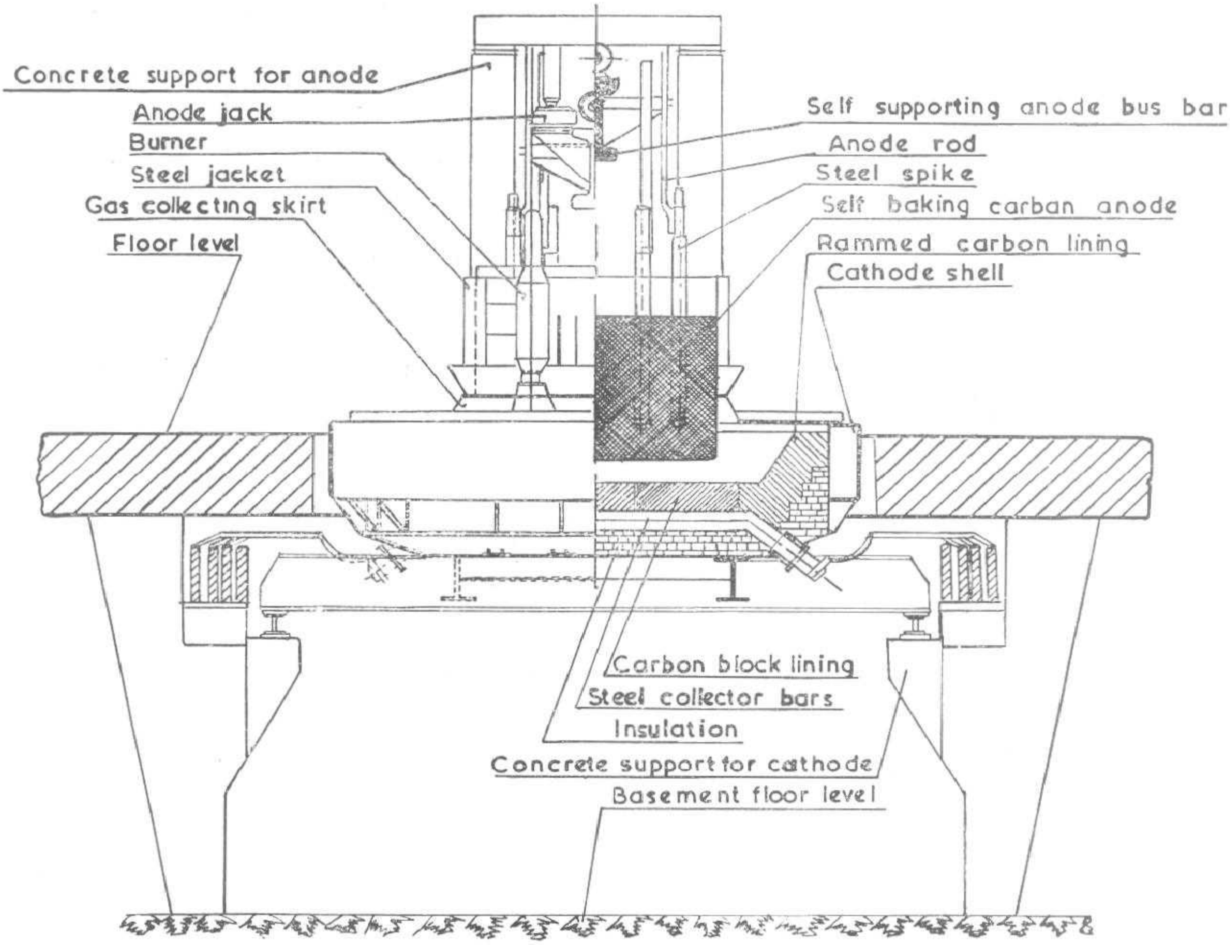

Fig. 4.
Sectioned schematic of 90,000 amps. Soederberg cells with vertical spikes.

observed that the Faraday efficiency of the transversely placed cells is somewhat higher than that of those placed parallel to the axis, probably as a result of a more favourable distribution of the magnetic fields and thereby a less apparent influence on the cell operation. The servicing mechanism can however not be carried out in such an intensive manner as with the cells placed parallel to the axis, but the writers believe that with a skilful distribution of the working processes carried out by vehicles operating on the ground and special cranes a production rate can be attained which stands on the same level as that reached by cells placed in the parallel manner.

Priniple of the shell and lining of cathodes

A thermal equilibrium in a cathode is of fundamental importance for the life of a cathode lining. On account of this fact cathode shells have been built so that the isotherms in the lining, which normally are more or less parallel with the outer casing, ensure a more favourable operational result. With reference to this theory the cathode shell with sloping sides shown in Fig. 4 has been developed. Lengthy experience, especially with Soederberg cells, has shown that this type of cathode is less susceptible to abrupt differences of temperature as a result of interruptions in operation and that moreover a higher Faraday efficiency may be reckoned with[5].

Various investigations and letters patent have been concerned with the reduction of voltage losses in the cathode by arranging the constructive grouping of the collector bars in such a way that the current flows essentially in a vertical direction from the anode to the cathode. The Swiss Aluminium-Industrie-Aktien-Gesellschaft has found a satisfactory solution in the application of specially shaped collector bars as shown in Fig. 4. In this design the magnetic circulation in the liquid metal is reduced considerably, resulting in a more stable operation and slightly higher Faraday efficiency. With this grouping the voltage drop in the cathode with an average current density of about

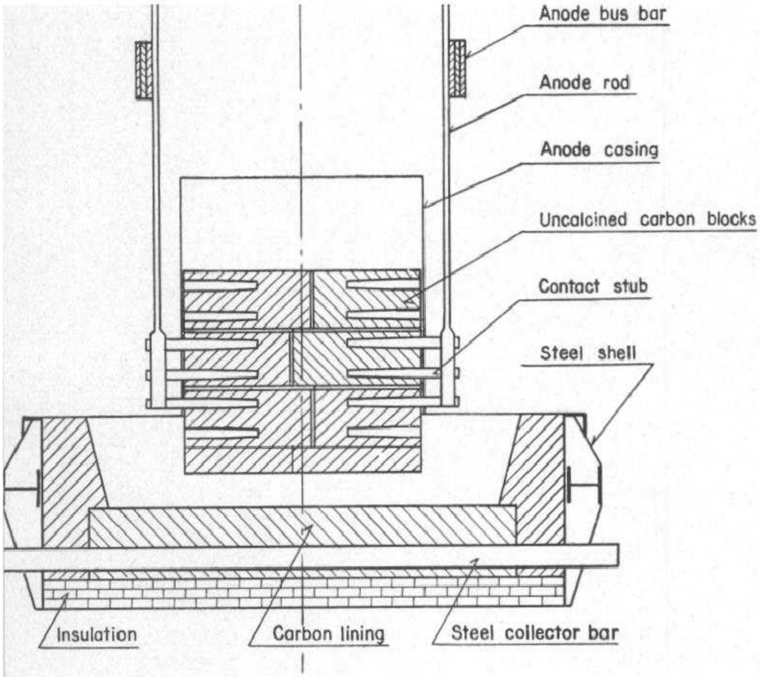

Fig. 5.
Sectioned schematic of cell with self-baking blockanode.

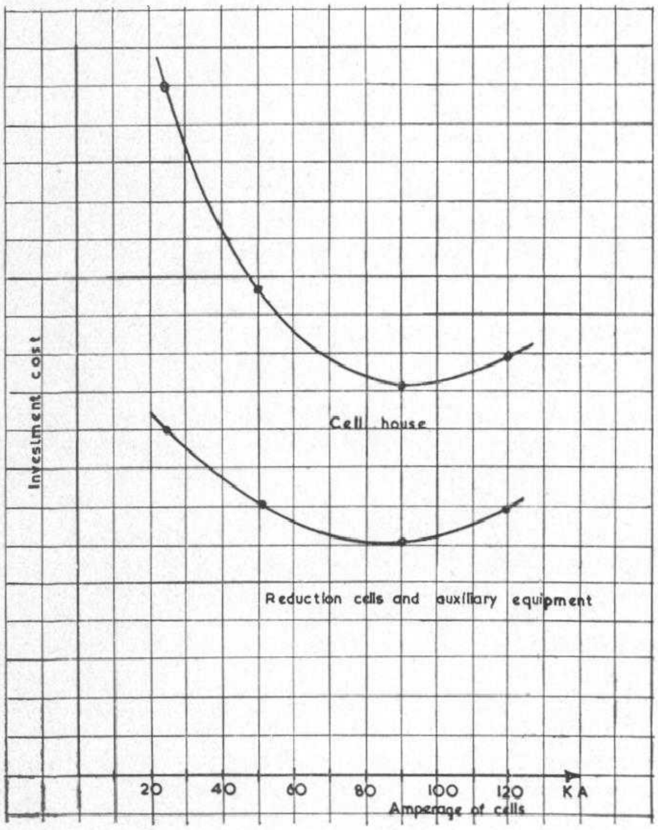

Fig. 6.
Investment cost in relation to cell size.
(Soederberg vertical spikes).

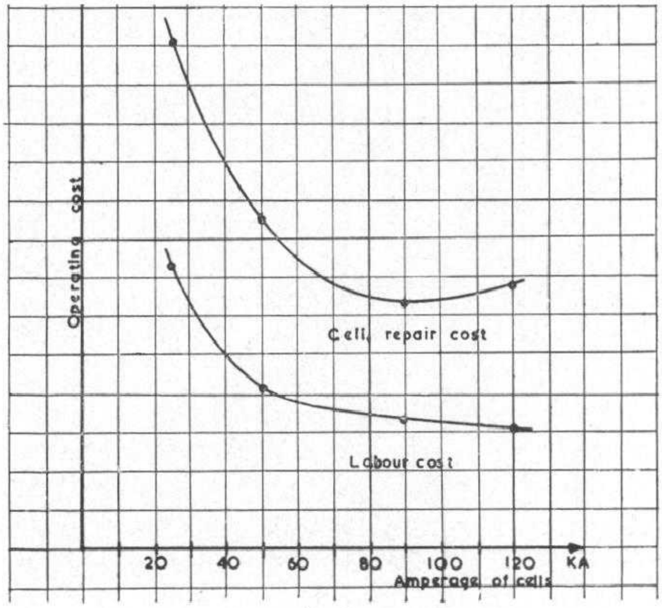

Fig. 7.
Operating cost in relation to cell size.

0·2 amp./mm^2 is somewhat reduced as a result of the short path of the current in collector bars. The writers are of the opinion that the path followed by them in construction of cathodes can still be improved and that in this direction noteworthy advantages as compared with the conventional construction may be cited.

It is the opinion of the authors that cathode shells fixed on both sides and solidly attached to the foundation, as is the case with various producers of aluminium, are not beneficial in the long run. A cathode must possess a certain malleability in order to be able to meet these forces appearing with a limited elasticity in the lining.

The life expectation of a cathode lining for cells with an amperage of 80–100,000 amps. is on the average 3 years. As already mentioned the life expectation of larger cells is shorter. The use of rammed monolithic carbon bottoms and sidewalls as has been the US practice up to now becomes impracticable with cells of the indicated or larger size. Prebaked block carbon lining which is more expensive but guarantees a longer cell life is already common practice in many aluminium production centres. For a long time attempts have been undertaken to improve the material ultilised in the lining to reduce the costs caused by a relining. Endeavours in this direction have been undertaken for several years with oxide-bonded or nitride-bonded silicium carbide sides.

A further development which is being pursued especially by the English aluminium industry consists in lining the cathode floors with permanent coductive materials, mainly Zirconium and Titanium borides and

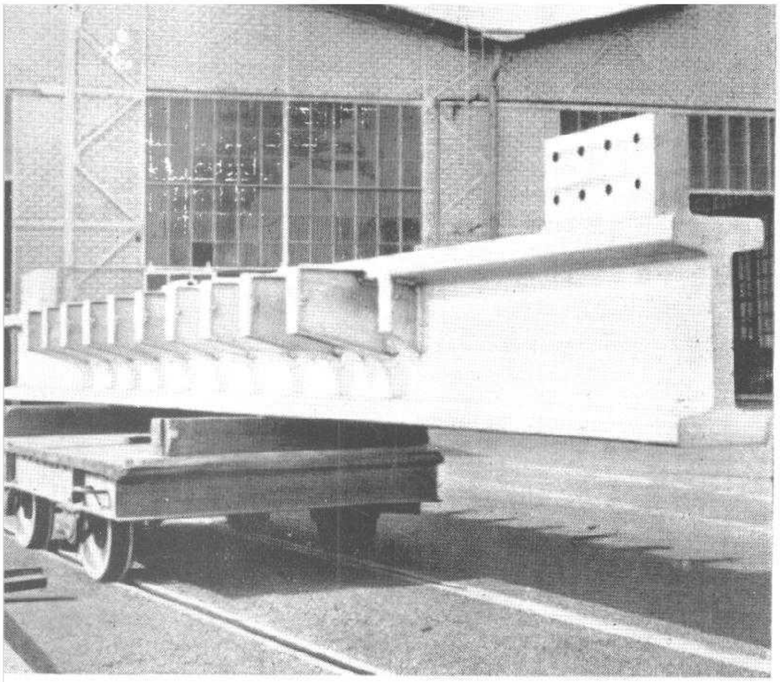

Fig. 8.
Self-supporting anode conductor for 80,000 amps. Soederberg cell with vertical spikes.

carbides. The authors see in this development a great improvement in the lining of cathodes and a raising of the life expectation. It is surely impossible at this time to produce the substances mentioned at an economic price and therefore as yet they do not possess any great industrial application[6].

Anodes

The disadvantages of the Soederberg type cells prompted the engineers to develop larger polyanodic prebaked type cells. The trend was directed toward increasing the anode block size up to $1{,}000 \times 500$ mm and thus minimising the amount of handling and decreasing the current densities to 0·8–1·0 amp./cm^2 resulting in an improvement of the Faraday efficiency to the figures as normally obtained with large Soederberg cells. The use of mechanical means for change and adjustment of anodes which were to some extent neglected in comparison with the Soederberg cells resulted in considerably lower anode operating costs.

Many possibilities are now open to adapt classic poly-anodic prebaked type cells as modern production units which compare favourably with large Soederberg cells.

On the other hand improvements of the design and the operation of the Soederberg anode with vertical spikes are being pursued by all producers. The schedule of exchanging the contact spikes has been subject to extensive studies, all with the aim of reducing the anodic voltage drop. For large cells with four rows of spikes a pulling cycle with four intervals of 5–6 days each appears to be the optimum. Although such a pulling schedule may require a somewhat higher handling time than 2 or 3 interval cycles experience has proved that the anodic voltage drop is definitely better.

With highly mechanised anode handling equipment, such as from crane cabin controlled spike puller and spike clamps, the specific man hours are reduced to such a low figure that it is decidedly economical to introduce a more complicated spike pulling schedule.

With the improved knowledge of the MIG welding of aluminium to steel, the aluminium rods, where they are used, are nowadays mostly welded onto the steel spikes. The voltage drop of the electrical connection aluminium rod-steel spike has thus been reduced to practically zero.

Measurements of magnetic fields have shown that the influence of steel parts in the anode, especially in the normally built-in lengthwise steel carriers, exert a certain influence on the strength of such fields in the liquid metal. By substitution of the steel carriers in the anode by materials which have no influence upon the magnetic field, this effect may be reduced, thus leading to a more advantageous cell operation as regards the movement of the metal. In Fig. 8 is represented a DC cast machined and welded, self-supporting anode conductor of aluminium for an 80,000 amps. Soederberg cell with vertical spikes. The aluminium rods of the vertical spikes are pressed against the welded cast aluminium extension arm by means of clamping devices as can be seen in Fig. 4.[7,8]

Bus bars

In general, bus bars for electrolytic cells are manufactured of aluminium and are mainly cast on vertical or horizontal DC machines. All contacts with exception of the contact of anode conductors and spike rods are welded today to eliminate the relatively high losses met with press contacts. The current distribution for cells placed transversely to the building axis and those placed parallel is different in principle. Whilst with the former a distribution of the current on both front sides in relationship of 1 : 1 is deemed as appropriate, one has with the latter come to the solution of a distribution of current in the relationship of approximately 2/3 to 1/3. The latter current distribution has proved itself until today as regards quantity of bus material and uniformity of the magnetic fields produced by the bus bars for parallel located cells. Observations on cells with a greater current intensity have shown that a 1 : 1 current distribution on both front sides of parallel located cells is detrimental and the operation of the cell is adversely influenced. The powerful forces in the current carrying molten aluminium bath created by irregular distribution of the magnetic fields may cause violent agitation and build up static differences of the liquid cathode surface.

In recent times the tendency has been to reduce substantially the mean specific current density of the bus bar. It is well known that an optimal specific current density may be calculated by consideration of various factors, such as power cost, cost of the bus bars, aluminium scrap value and capital cost. It is therefore advantageous for instance with a relatively high power cost to choose a specific current density below 0·2 amp./mm^2. It may be emphasised in this connection that comparing the cell voltage and the consumption of power between different plants, a picture corresponding to the actual situation is only then deduced when the operating data are corrected to the same mean specific current density. It is therefore recommended upon giving details of operational data to quote at all times the mean specific current density of the bus bars.

A good figure of comparison for the same types and same disposition of cells is attained when a so-called efficiency rate calculated from the voltage drop in the bus bars and the weight of the bus bars is applied. This rate elucidates the suitability of their arrangement and from this may be inferred which grouping permits the attainment of the least current loss consistent with the lowest consumption of material.

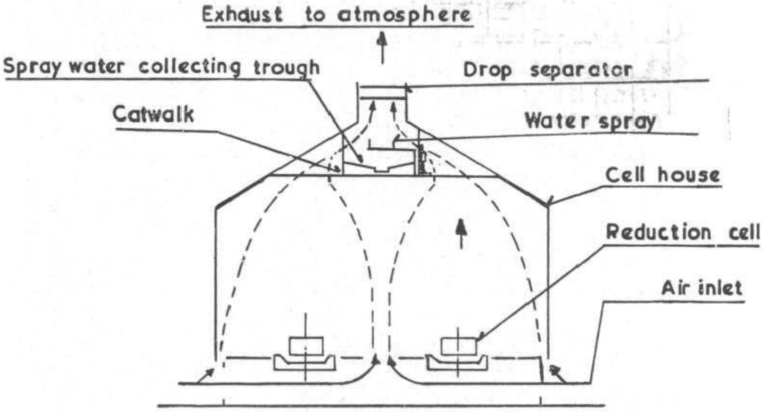

Fig. 9.
Fume scrubbing installion.

Fume treatment

Experiences from various works which are located in agriculturally highly developed districts have shown that extensive purification installations are essential for the absorption of the dangerous fluorine fumes. This emanation of fluorine is less with prebaked cells. Roof spraying equipment which cleans the fumes on the top of the roof in a spray curtain has been successfully introduced. With the self-baking cells a separate withdrawal of the cell waste gases by suction and later cleaning in water scrubbing plants and eventually electrostatic filters is necessary. We refer in this connection to the publications cited,[9, 10, 11] in which the development and the present state of absorption equipment are described in detail (see also Fig. 9).

Facts on the repair of cells

As already mentioned, the authors hold the opinion that the repair of cathode shell lining should not take place in the cell house. The replacement of the spent cathode by a new one and the renewed operation can be realised in a relatively short time. Thereby the loss of production can be limited to less than one day, whereas repairs carried out in situ mean a loss of production of two weeks or more. Moreover, the repair in the cell house causes undesirable disturbances with the transport of material and repair works, interrupting the normal procedure of the works. Furthermore, it has been proved that repairs in specially equipped workshops with an experienced repair team are carried out more quickly than in the cell houses.

There are in principle two possibilities to remove the cathodes from the works :

— By dismounting the anodes and raising the cathodes through the cell opening by means of a crane and transport through the cell house to the exit, where the cathode is further transported by another means.

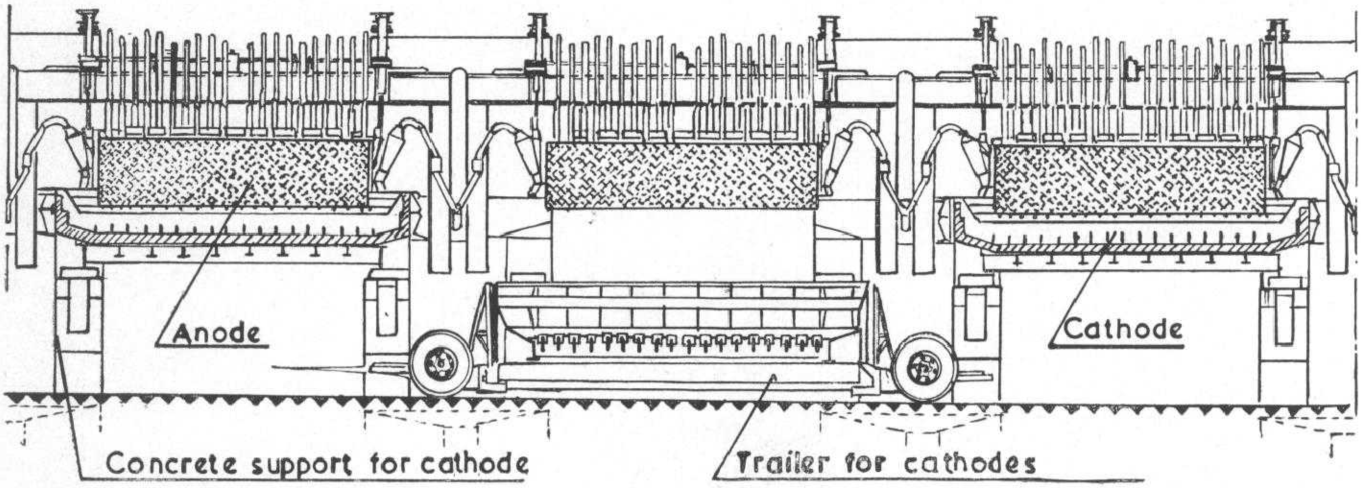

Fig 10.
Sectioned view of Soederberg cells with one cathode lowered on trailer.

—By dismounting the cathode into the basement and removal by a trailer especially constructed for this operation[12].

This latter solution has been realised in the electrolytic works of MOSAL in Mosjoen, Norway, and has proved itself to be extremely effective. It is illustrated in Fig. 10. The authors are of the opinion that the higher investments, as a result of the building with raised working surface in comparison with the first solution, are justified. Through this arrangement further advantages are made possible in the matter of construction and cell operation ; for instance, the basement structure permits a better ventilation of the cell house by the insertion of grids in the floor surface, and also, as a result of cooling, the losses due to electrical resistance in the bus bars are smaller. The thermal uplift of the atmosphere of the building, which is produced by the heat emanated from the cells, is sufficient to maintain a satisfactory circulation of air. It can be estimated that with cell houses lacking a roof spraying equipment, a change of air ensues 30–40 times per hour[13]. If a roof spraying equipment with a droplet separator is installed, the air change has proved by experience to be somewhat less but completely sufficient to provide a pleasant working atmosphere. A cell house with a raised working floor offers in addition a protection against damages which could be occasioned by possible inundations.

Outline of economic factors

Whilst only a few years ago, in order to erect a large electrolytic plant, an operational cost of about US $ 1,000 per ton of aluminium produced was regarded as acceptable, opportunities are offered today to reduce this figure considerably. As may be deduced from the above, the cost of erection of Soederberg electrolytic cells with vertical spikes and of the cell house itself is higher as a result of the more complicated construction and the greater need of floor space. Moreover, in districts which are primarily of an agricultural nature, expensive fume treatment equipment for the cell gases is necessary for the Soederberg cells. On the other hand, for the manufacture of electrode paste a relatively simple plant is required. The cost of the building of cells with prebaked anode blocks and of the corresponding cell houses is somewhat less on account of the more simple construction and lesser floor space. Against this, besides an electrode paste factory, presses and calcining furnaces for the production of the blocks as well as a rodding plant are necessary.

The authors believe that both the prebaked and the Soederberg cells can be considered for new modern plants. In every case it must be ascertained which type is more suitable with reference to the production and investment costs.

References

1 Peters H., "Degree of development of aluminium electrolysis". Lecture held on the occasion of a meeting of the Light Metal Commission of the GDMB on May 13th, 1958 in Toging, Germany.

2 German patent DBP 946, 924, English patent 786, 379.

3 Bockmann O. C. and J. Wluegel, "Electromagnetic forces in large aluminium furnaces"—*Electrochem. Soc.* Vol. 105, p. 417–420 (1958).

4 Swiss patent 344, 219, Indian patent 59,615. Swiss patent application 70, 166, Indian patent application 70, 958.

5 Swiss patent application 58, 844, Indian patent application 67, 485.

6 Swiss patents 299, 434/330, 206/301, 030/343, 651, Indian patent 47, 215/English patent 802, 905/—/English patent 826, 635.

7 Swiss patent application 53, 249, Indian patent 66, 144.

8 Oehler, Roland, "High intensity aluminium electrolytic cells with self-supporting anode centre beam"—*Aluminium Suisse* No. 1, 1960, p. 3–7.

9 Swiss patent application 70, 165, Indian patent application 70, 733.

10 Muller, Paul H., "The fluorine problem in the aluminium industry, Part I"—*Zeitschrift fur Erzbergbau und Metallhuttenwesen*, Vol. XII. (1959), No. 8, p. 400–405.

11 Muller, Paul H., Schmitt H., Bischofberger G., "The fluorine problem in the aluminium industry, Part II"—*Zeitschrift fur Erzbergbau und Metallhuttenwesen*, Vol. XIII (1960), No. 9. p. 419–424.

12 Swiss patent 341, 003, Indian patent 59, 973.

13 Swiss patent 341, 987, Indian patent 59, 774.