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RECENT IMPROVEMENT IN PASTE PLANT DESIGN
INDUSTRIAL APPLICATION AND RESULTS

C. VANVOREN
Aluminium Péchiney
Laboratoire de Recherches des Fabrications
B.P. 114 73300 Saint Jean de Maurienne - France

Up-to-date paste plant design and construction are based on :

Adjusting the flowsheet as closely as possible to the properties of the material, as determined by appropriate research.

The use of closed-loop control devices.

A system of overall process management.

INTRODUCTION

The manufacture of prebaked anodes for use in the Hall-Heroult electrolytic process of production of aluminium is the subject of ongoing research aimed at optimising anode performance in the reduction cell. This demands :

Maximum apparent density, to extend the anode cycle.

Minimum resistivity, for lower energy consumption.

Minimum reactivity in terms of side-reactions such as oxidation, to minimise rate of consumption of anode carbon.

Chemical composition matched to the grade of metal to be obtained.

While raw materials selection and mastery of the baking process are of crucial importance, particularly to the production of a chemically-pure carbon of suitable texture, the fact remains that the majority of the requisite physical characteristics of the final product are determined at the "green" stage.

This being so, a considerable part of the research and development carried on by Aluminium Pechiney has consistently been concerned with the parameters governing the green anode production process, with a view to incorporating results in existing and new paste plant design.

In 1980, advantage was taken of the complete revamping of the green anode production facilities at the Sabart smelter (at Tarascon-sur-Ariège in France) to define the prototype of a new-generation paste plant affording a significant improvement in prebaked anode quality.

From this prototype, which was the subject of a paper presented to the AIME 1983 Meeting (1), have been derived the basic principles underlying the design and construction of a modern paste plant. These can conveniently be grouped under two main headings, viz :

* processes and process equipment to be determined and selected from in-depth knowledge of the material to be processed

* operation of the plant to be maintained constantly at the optimum by means of a combination of specific and overall controls.

The commercial application of these principles can be illustrated and the results assessed by discussing what has recently been accomplished in this area by Aluminium Pechiney.

MATCHING THE FLOWSHEET TO THE MATERIAL BEING PROCESSED

The green anode production process can be subdivided into four principal stages, as illustrated by Fig. 1.

Each of these stages can employ more than one route to the same end, e.g. continuous or batch mixing, forming by pressing or vibrocompacting, etc,

A choice therefore has to be made between the various technological options. Those chosen by Aluminium Pechiney are guided by considerations of final product quality and are based on its knowledge of the material being processed.

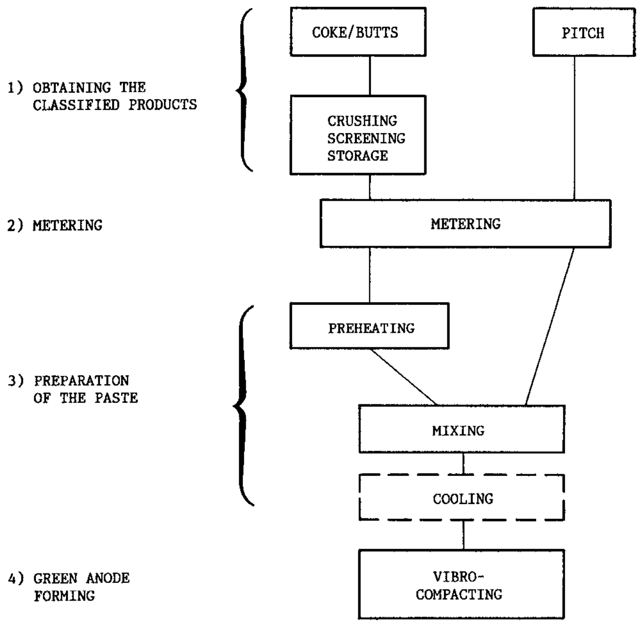

Figure 1 - Green anode production flowsheet

This may be illustrated by considering in detail the design of the classified materials preparation flowsheet. This stage of the process has to yield dry products to a specification capable of ensuring optimum final anode quality, which in turn depends on optimisation of :

- the particle size distribution curve and
- the nature of the materials so prepared.

These are matters to be investigated in the laboratory with a view to determining the preferred industrial option.

Aggregate size distribution

The effect of size distribution on prebaked anode properties was investigated, using bench-scale experimental electrodes 90 mm in diameter made from a carbon paste mixed at ca. 170°C, pressed at 450 bars in a mould held at 150°C and finally baked at ca. 1 100°C at a rate of temperature build-up of 25°C per hour.

Three size fractions were used, viz :

grains	> 300 µm
sand	300 - 30 µm
ultrafines	< 30 µm

As reported elsewhere (2), the choice of these fractions was based on insertion capacity cut-off points and types of porosity.

Again, limiting the number of fractions made it possible to employ a methodology based on three degree of freedom in designing the scheme of experiments.

A number of mixes of compositions (cf. Fig. 2) distributed around the aggregate size distribution usual in commercial operation were first made up. Next, sets of experimental electrodes were prepared from each mix and used to determine pitch-saturation levels since, for comparisons to be valid, binder contents obviously had to be optimised in each case.

Pitch contents over the ranges within 10 % of the optima were then explored to obtain the requisite experimental design data.

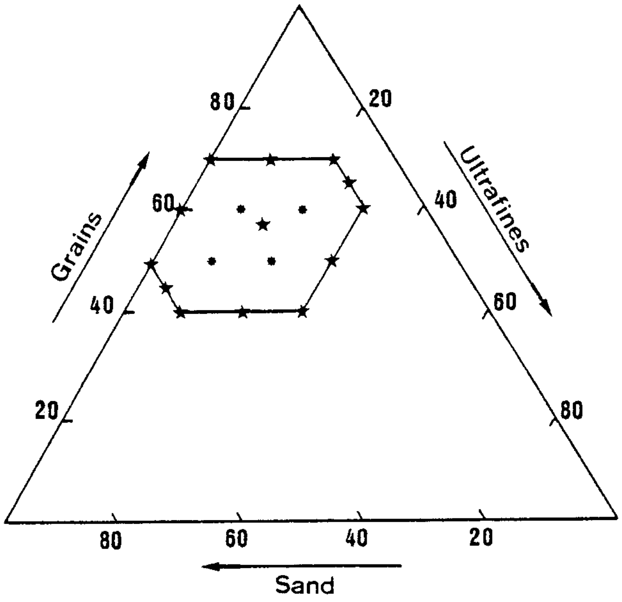

Figure 2 - Aggregate size distributions

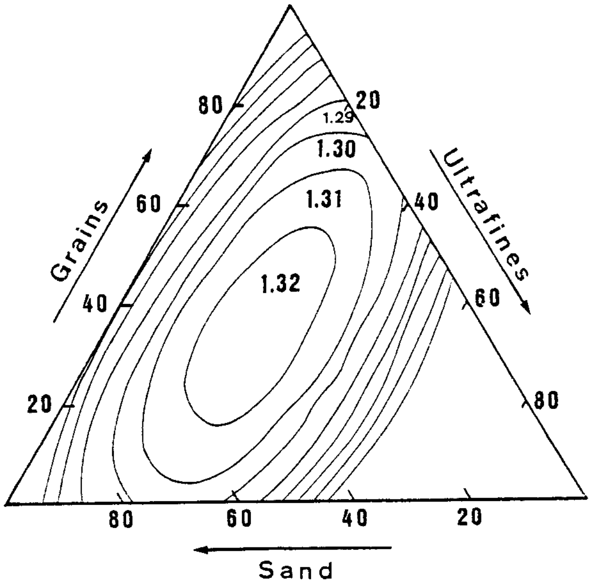

Figure 3 - Green dry density iso-response curves

Findings from the results obtained, presented in the form of iso-response curves (cf. Fig. 3) for each pitch content investigated, were that :

. depending on pitch content, optimum baked apparent density was obtained with a composition comprising 44 - 45 % grains, 34 - 35 % sand and 20 - 22 % ultrafines ;

. resistivity decreased as sand and/or pitch content increased.

Based on these findings, the size distribution of the anode paste has gradually been modified in the direction of increased content of ultrafines, while still conserving the structural characteristics required to withstand the industrial baking process.

Nature of classified materials

A considerable proportion of the dry matter entering into the composition of prebaked anodes consists of recycled anode butts. For a long time, the practice had been to blend the butts with petroleum coke at the input to the paste plant. More recently, however, it emerged (3) that butts should preferably be recycled only in the coarsest of the dry fractions.

The main concern in this investigation was therefore to examine the question of the fraction in which butts should be recycled for optimum results in terms of :

. thermal stability of fluoride content in the anode baking process

. the characteristics of the baked anode.

Fluoride stability

Experimental findings were that fluoride emission on baking was less by some 15 % when butts were recycled in the "grains" fraction.

Anode characteristics

The effects of recycling on baked anode characteristics were determined in the laboratory, using bench-scale experimental electrodes prepared as described earlier but substituting butts for coke in each of the three size fractions in turn.

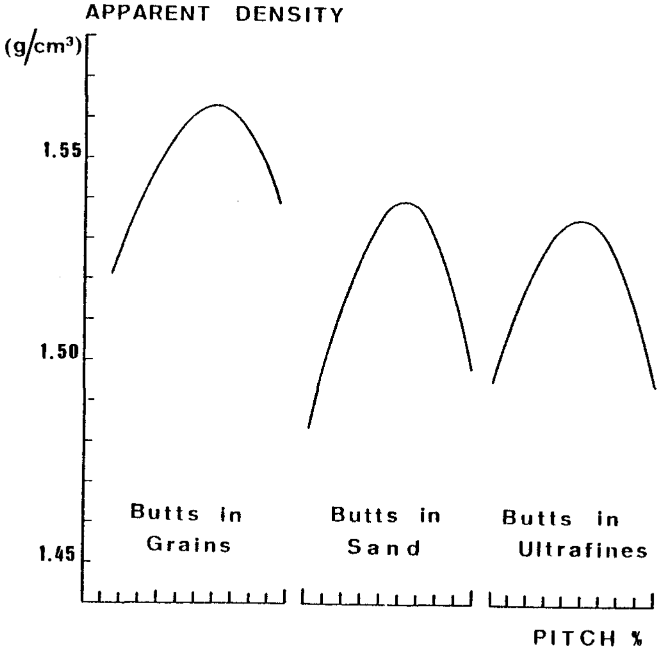

Figure 4 - Effects of recycling butts in various size fractions

Fig. 4 illustrates the effects on baked apparent density, where the case for recycling in the "grain" fraction is clear-cut, with an improvement of 0.02 g/cm^3 as compared to recycling in sand, and close to 0.03 g/cm^3 over recycling as ultrafines.

Findings were, therefore, that selective recycling of anode butts in the coarsest size fraction yielded :

. an overall improvement in baked anode characteristics, with particular reference to apparent density

. a significant reduction in fluoride emission at the baking stage.

Applications in industrial practice

In the light of these results, the main features of the process flowsheet operated in the Aluminium Pechiney paste plants are now as listed below :

* Anode butts are selectively recycled in the coarsest size fraction.

* Aggregate size distribution is controlled to an accuracy of within 1 % for the "fine" fraction (see below) and to within 2 % for the other fractions. This is achieved by using a combination of four size fractions, designated "very coarse", "coarse", "medium" and "fine", respectively, which are blended, together with green scrap, to obtain the particle size profile already referred to. The specifications

for the four size fractions are :

Very coarse	15 - 0.2 mm (100 % baked anode butts)
Coarse	6 - 1.5 mm
Medium	1.5 - 0.2 mm
Fine	< 0.2 mm

* The proportion and distribution of the fine fraction in the mix are accurately controlled by means of :

- a static air classifier, used to remove material of size below 200 µm from the medium fraction,
- a dynamic classifier installed on the ball-mill line to regulate the proportion of ultrafines in the fine fraction.

* Proportioning systems (weightometers) are employed to regulate rates of addition of each size fraction, affording an accuracy of ± 0.5 % of target values.

Taken together, these various features ensure the aggregate size distribution calculated to yield optimum anode quality.

PROCESS CONTROL SYSTEMS

Once the definitions of the process flowsheet and equipment had been optimised from in-depth knowledge of the input material, the next step was to optimise actual process operation. This is now based on a two-tier hierarchy, comprising :

Optimisation of each stage of the process via systems of regulation specific to each item of equipment and designed to minimise deviations form target operating parameters.

Optimisation of overall process operation via a plant management system designed to keep each of the specific target parameters constantly updated.

For both of these levels, procedures and algorithms have been developed by Aluminium Pechiney which enable process operation to be optimised in terms both of economics and of final product quality.

Example of a specific system : Regulation of mixer power input

The quality of the anodes manufactured from a paste of composition as defined earlier is closely linked to the efficacity of mixing. In the case of a single-shaft continuous mixer, the effectiveness of mixing is related to the energy absorbed per unit quantity of paste, thus :

$$E = P / Q$$

where :

E denotes specific energy (kWh per metric ton)
P the average power input (kW)
Q average paste throughput (tph).

Therefore, any improvement in mixing requires a higher, constant, power input. Now, constancy of the power input to a single-shaft mixer can be achieved by means of control flaps on the outlet side, the opening of which is adjusted either manually or automatically in accordance with computed power input averaged over a short time interval.

However, the specific energy value attainable by this means is limited by the attendant increase in the risk of "choking" the mixer.

The problem to be addressed, therefore, was how to design a system of regulation able to performe adequately in terms both of specific energy absorbed and of ensuring against choking.

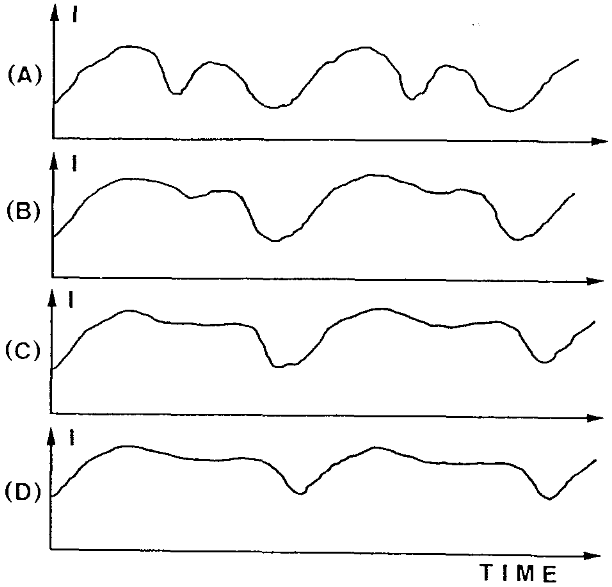

Figure 5 - Variations in motor current with time as paste level in mixer increases (from A to D)

Fig. 5 shows plots of motor current v. time (amperage being directly proportional to power in the case of a d.c. supply).

The top curve was observed to be pseudosinusoidal, of period corresponding to the reciprocating motion of the mixer shaft and amplitude varying with the position of the shaft at any given point of the cycle. Then the shapes of the curves gradually change in response to the quantity of paste in the mixer. Maximum current values are relatively unaffected by the extent to which the mixer is filled, whereas the minimum values increase with filling level.

This interpretation of the pattern of power input led to the development of a system of control of the mixing process based on monitoring instantaneous minimum values of amperage. This can be done by signal analysis or by fitting sensors to the mixer to detect the position of the shaft at which amperage is to be measured. For each cycle, the pair of minimum values of amperage is processed by a computer, compared with the target value of power input and flap opening adjusted accordingly. In the event of detection of a tendency for the mixer to choke, the algorithm is gradually modified to revert to the standard operating configuration.

This control system enables the specific energy input to the paste to be optimised continuously, thereby avoiding any likelihood of clogging. Its introduction on the plant has yielded an increase of 0.04 g/cm^3 in baked anode densities for equivalent raw materials.

Total process control system

The operation of main items of process equipment having been optimised by means of autonomous control and instrumentation systems (sequential, regulation or algorithm type), the goals of improved product quality and higher productivity called for the development of a total plant management system. This affords :

- Management of control and instrumentation functions. This encompasses all process supervision tasks, from real-time monitoring (animated mimic diagrams on colour screens, alarm management) right through to complete procedures for optimising instantaneous operating parameters, e.g. anode pitch content (4) .
- Management of product quality. The system correlates quality indicators, raw materials characteristics and process operating parameters for the purpose of medium-term management of product quality.
- Management of operating tasks. This is a system designed to assist with the planning and execution of plant operating tasks.
- Management of personnel administration tasks.
- Management of servicing/maintenance of operating appliances and equipment. This involves the monitoring and analysis of rates of failure and utilisation factors and their correlation with process operating characteristics.

The plant management system interacts and communicates with :

- plan control and instrumentation facilities involved in process operation (programmable automatic controllers, regulators and "dedicated" microprocessors),
- the process operators,
- the other process units included in the smelter complex.

The general architecture of the system is illustrated by Fig. 6.

Thanks to this overall management system continuously monitoring every item of process data, the paste plant can be run by a single operator. He is assisted by an ergonomically-designed control room equipped with all the computer peripherals needed for supervision of the plant. Permanent optimisation of the parameters governing the process ensures that the products obtained are of optimum and consistent quality and that the effects of any variations in raw materials quality are minimised.

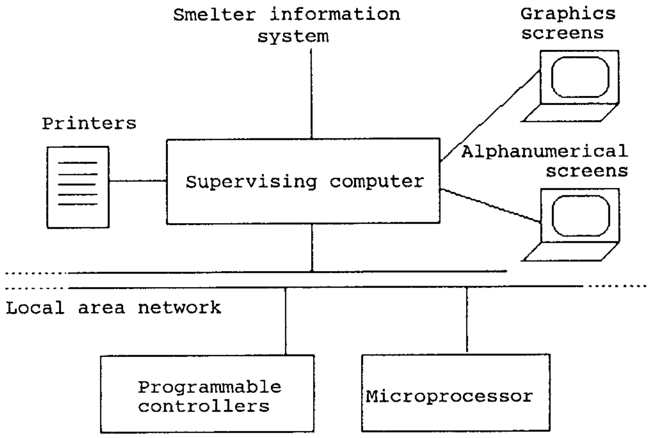

Figure 6 - General architecture of plant management system.

PERFORMANCE DATA

Product quality

Needless to say, the basic objective relates to the quality of final product. Performance is this respect can be assessed via the characteristics of a recent batch of anodes used on the 280 kA prototype reduction cells at LRF (Laboratoire de Recherches des Fabrications).

Number of anodes in lot	720	
Number of anodes sampled	120	
Characteristics	Mean	Standard deviation
Geometrical density (g/cm^3)	1.60	0.01
Permeability (nPerm)	0.6	0.3
Resistivity (µΩcm)	5130	110
Flexural strength (N/mm^2)	11.6	1.9
Crushing strength (N/mm^2)	47.7	6.6
Real density (g/cm^3)	2.090	0.008
Ash (%)	0.55	0.13

The raw materials employed were a petroleum coke of European origin (apparent density to mercury 1.75 g/cm^3) and a coaltar pitch, also of European origin (SERS fixed carbon 54 %).

Productivity

To take the case of a smelter of the same type as Becancour (with a 143 000 metric tons per annum carbon plant), the whole of the "green" section is under the control of two process operators :

- a senior paste plant operator responsible for operation of the plant and for product quality control,
- an assistant operator responsible for all the tasks of inspection and supervision of plant and machinery, from the raw materials feeding stage right through to green anode storage.

The productivity of the green section can be assessed from two figures, viz :

- 0.08 manhour per production tonne of aluminium,

or

- 0.13 manhour per production tonne of good green anode, these figures including operators, shift supervision, time off and training.

Emission to atmosphere

Pitch fume control by the coke-based dry route limits emission levels to :

< 1 mg BSO/m^3 (at STP)

or

< 0.3 µg BaP/m^3

i.e. to well below the limits specified by the most exacting internationaly-recognised standards.

CONCLUSION

Aluminium Pechiney's objective of optimising its primary aluminium production facilities in terms of product quality and cost-effectiveness applies directly to the manufacture of prebaked anodes.

This is a goal towards which systematic research and development is devoted. Theoretical modelling and practical experimentation are employed to arrive at optimum approaches subsequently built into commercial operations.

This policy has been illustrated by the examples discussed in connection with the green anode production process. Finally, Aluminium Pechiney can claim to have built up very considerable expertise as regards the raw materials and the baking process able to guarantee a high-quality anode.

Examples of the commercial application of Aluminium Pechiney know-how to the production of prebaked anodes are to be found in the plants designed and built in recent years, namely :

Tomago Aluminium (NSW, Australia)	143 000 tpa carbon plant	on stream 1983
ABI (Quebec, Canada)	"	on stream 1986
Nalco Aluminium (Orissa, India)	"	on stream 1986
St Jean de Maurienne (France)	73 000 tpa carbon plant	on stream 1987

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