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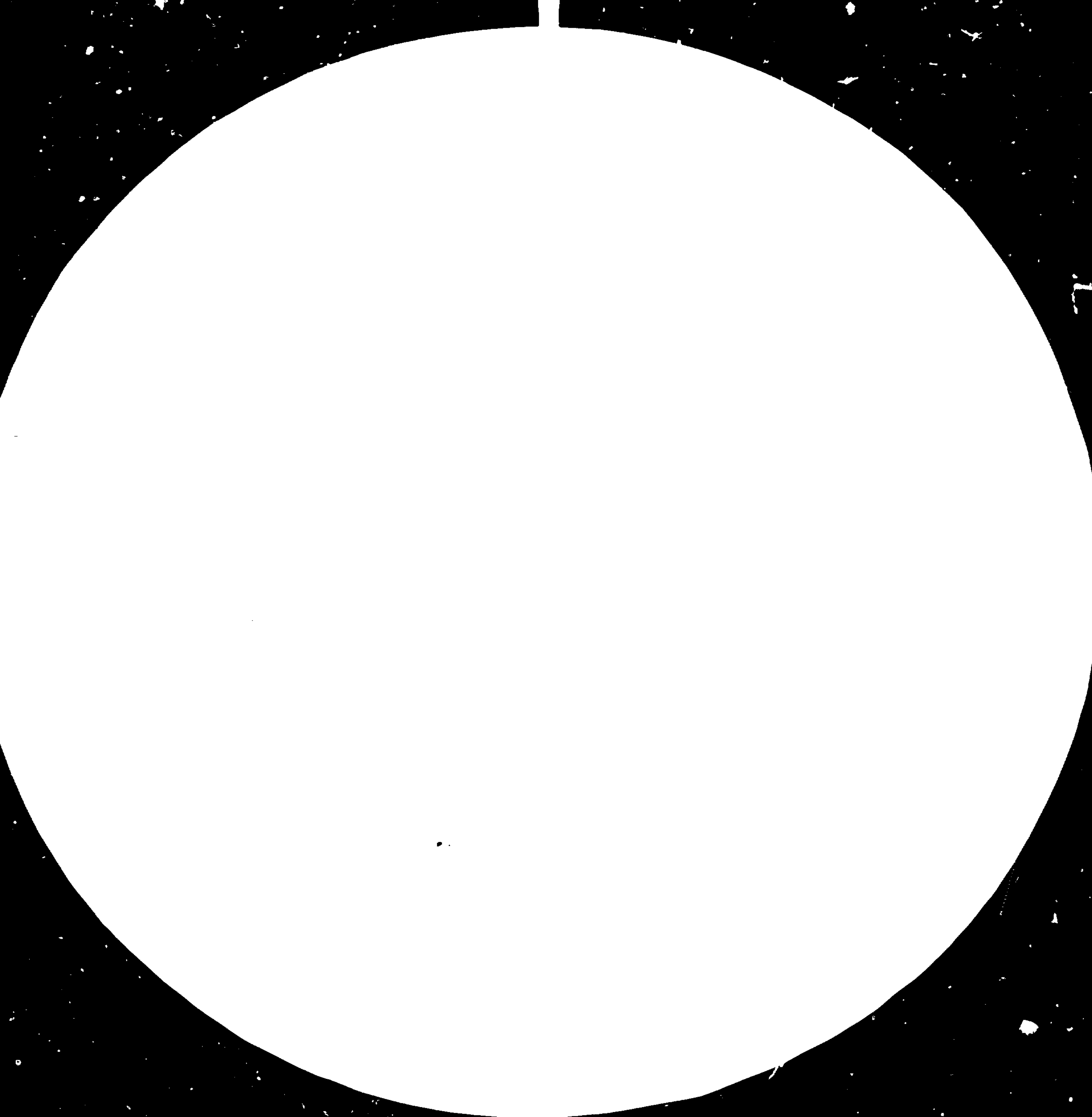

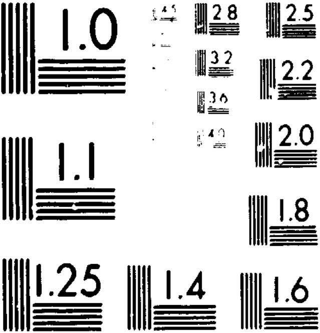
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GROUP TRAINING IN PRODUCTION OF ALUMINA
VOLUME 7

EVALUATION OF BAUXITE INVESTIGATIONS FOR THE SELECTION OF ALUMINA PROCESSING TECHNOLOGY. BRIEF OUTLINE OF FEASIBILITY STUDIES.

ALUTERV-FKI

BUDAPEST, JULY 1979

VOLUME 7

EVALUATION OF BAUXITE INVESTIGATIONS FOR THE SELECTION OF ALUMINA PROCESSING TECHNOLOGY BRIEF OUTLINE OF FEASIBILITY STUDIES

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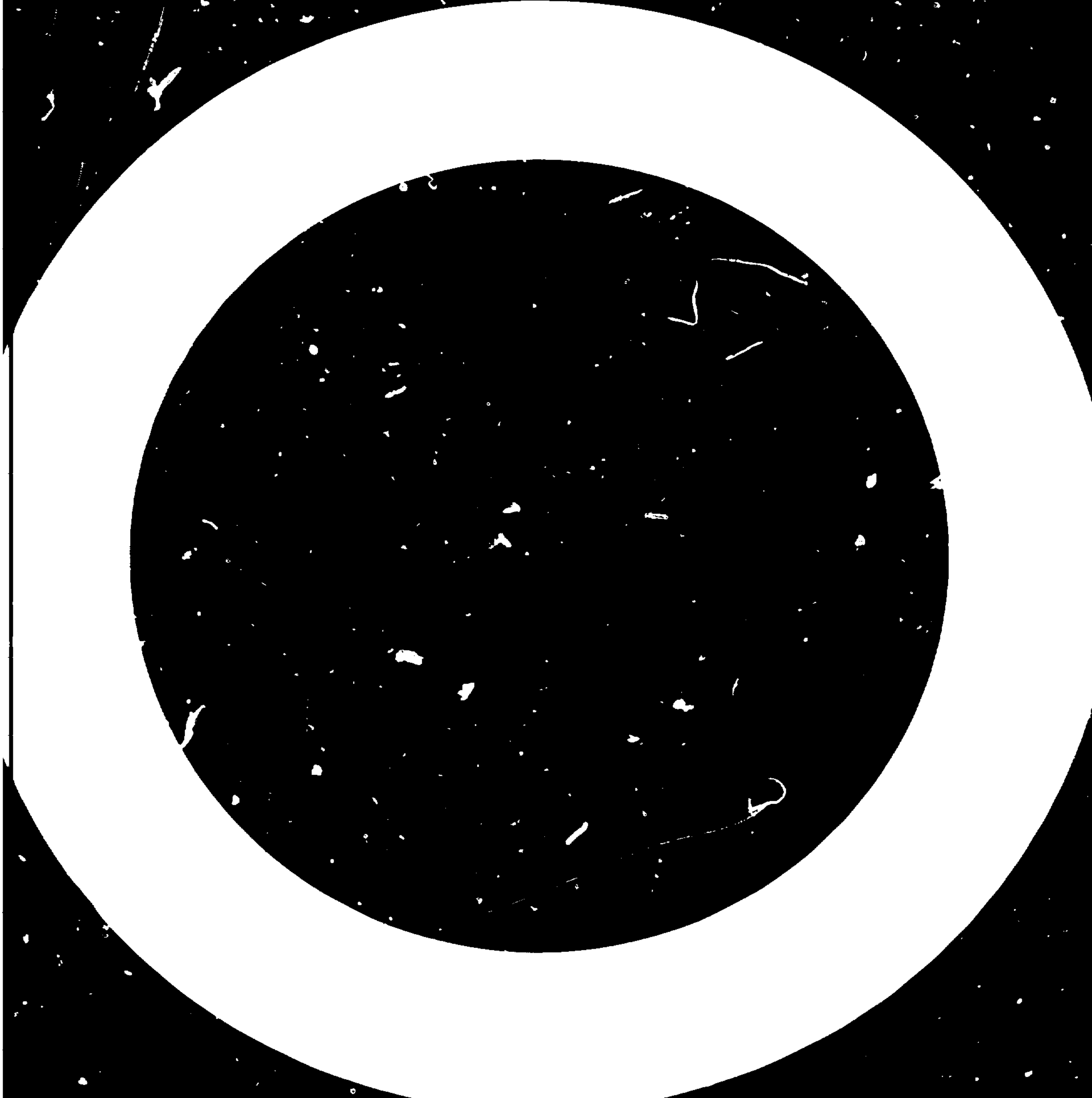


FIGURES

TABLE

1. GENERAL ASPECTS FOR MAKING A FEASIBILITY STUDY OF AN ALUMINA PLANT

Feasibility studies are prepared to investigate the technical and economical possibilities of setting up an industrial plant to produce alumina and/or related products and to outline those conditions that have to be fulfilled for the implementation of the plant in question. /"Feasibility" means only that mode of implementation when the established industrial plant operates in a profitable way./

Feasibility studies are usually prepared before technical offers are given, conceptual process and engineering designs /CPEDs/ and detailed designs are worked out.

The task of a feasibility study can be detailed as follows:

a/ Elaboration of the optimum process technology based on the most up-to-date technical level and adopted for the given bauxite type.

b/ Preparation of a capital cost estimate for the whole project, usually broken down to construction, machinery, transportation, etc. costs and/or to local and hard currency cost elements.

c/ Examination of the proposed plant site/s/ and the environment from geophysical and environmental aspects, including the mode of the transportation of the raw and auxiliary materials and of the product and the possibilities of waste /red mud/ disposal.

d/ Preparation of general layout/s/, showing - if necessary - the possibilities of plant expansions.

e/ Investigation of the economical and financial feasibility of the proposed project including examination of the conditions of optimal implementation.

f/ Elaboration of a market analysis for the marketing of the alumina and/or related products.

Feasibility studies contain mostly descriptive material supplemented with the necessary tables, figures and photographs. They usually appear in a hardbound, booklike form.

Sometimes certain parts of the study's content may be compiled separately in a volume of appendices in order to make the main volume easier to handle, however, this is not necessary in every case.

2. EVALUATION OF THE RAW MATERIAL - BAUXITE

As a first approach the alumina technologist evaluates the geological reports compiled as described in Volume 1. He will look first of all for the total amount of the available /economically recoverable/ bauxite reserves, because this figure sets the limit for the maximum capacity of the projected alumina plant. As a rule of thumb the maximum yearly production capacity of the alumina project may be one hundredth of the recoverable bauxite reserves. /This provides for a 40 to 50 year lifetime of the project, as usually 2 to 2.5 tonnes of bauxite are required for 1 tonne of alumina produced./ There are a few exceptions to this rule of thumb.e.g. if the alumina content of the bauxite is very low /35 to 40 per cent in some West Australian ores/ and, therefore, the required bauxite amount exceeds 3 tonnes per tonne of alumina, the maximum yearly production capacity shall not exceed 0.7 to 0.8 per cent of the recoverable bauxite reserves. On the other hand if there is a possibility to supplement the project's bauxite supply from another, not too distant bauxite deposit during the second half of its life-time, the yearly production capacity may be set higher.

The second question the technologist will raise concerns the mineralogical type of the bauxite. As already explained in the previous volumes, the available alumina content of the ore may be present in the form of gibbsite, boehmite and/or diaspore. Boehmite can be digested only under much more severe conditions /higher temperature and pressure, usually higher caustic concentration/ than gibbsite and diaspore requires even higher temperature, pressure, concentration and the addition of some 2 to 5 per cent of burnt lime for its digestion. Therefore, it is of a great technological and economical interest, which of these minerals will determine the digestion technology. A number of comparative economic calculations have shown that about 7 to 10 per cent of the available alumina may be sacrified for the sake of a simpler digestion technology /i.e. if at least 90 to 93 per cent of the available alumina content is present in the form of gibbsite, a low pressure and low temperature digestion can be chosen; if at least 90 to 93 per cent of the available alumina content is present in the form of gibbsite plus boehmite, the diaspore content may be left in the digestion residue; "available alumina" means here the total alumina content of the gibbsite, boehmite and diaspore phases/. If the amount of the less digestible mineral falls in the range of about 10 to 20 per cent of the available alumina content, some combined digestion technology /two-step digestion; sweetening process - see Volume 2/ might be chosen. The chances of the sweetening process will be greatly enhanced if the bauxite reserve contains an easily separable part of more or less purely gibbsitic ore. Above 20 per cent of the less digestible mineral the bauxite should be digested under the condition determined by that mineral i.e. an ore with a 75:25 gibbsite:boehmite ratio requires "boehmitic" digestion, an ore with the same boehmite:diaspore ratic a "diasporic" one.

In this way the knowledge about the mineralogical type of the bauxite will help to estimate the capital and operating /first of all steam/ costs of the digestion and the type and probable costs of the required steam/power plant.

The third question the technologist will have to examine in detail is the chemical and mineralogical composition of the bauxite, first of all its alumina and silica content. On the basis of these figures he may estimate the specific bauxite and caustic soda consumption of the proposed plant. As the production of one tonne of alumina requires the digestion of about 1050 kg Al_2O_3 /50 kg being the estimated total of various technological losses per tonne of product/, this figure has to be divided by the digestible Al_2O_3 content of the ore to get the most probable specific dry bauxite consumption. /"Digestible Al_2O_3 content" means Al_2O_3 in gibbsite in gibbsitic bauxites; Al_2O_3 in gibbsite plus boehmite in boehmitic bauxites; Al_2O_3 in gibbsite plus boehmite plus diaspore in diasporic bauxites./ Knowing the percentage of the adhesive moisture specific wet bauxite consumption /tonnes of wet bauxite processed to get one tonne of alumina/ can easily be calculated.

$$\text{Dry bauxite t/t} = \frac{105}{\text{digestible } Al_2O_3\ \%}$$

$$\text{Wet bauxite t/t} = \frac{\text{dry bauxite t/t}}{100 - \text{adh.moisture }\%} \cdot 100$$

Having an estimate for the specific dry bauxite consumption and knowing the percentage of reactive silica in it, the probable caustic soda losses can be estimated in the following way: first these two figures are multiplied to get the total amount of reactive silica introduced into the plant with the bauxite. 1 kg reactive silica causes roughly 1 kg of NaOH loss /0.91 kg/kg during the chemical reaction leading to the formation of desilication product, the rest through secondary effects such as the increase of the amount of red mud/. Some 15 to 20 kg per tonne of alumina are added for other, non-silica-related caustic losses to the above product and this gives a rough estimate of the probable caustic soda consumption of the projected plant. Caustic soda kg/t = 10 x dry bauxite t/t x SiO_2 % + /15 to 20/.

It has to be taken into consideration that under "gibbsitic" digestion conditions /low temperature, pressure and caustic concentration, relatively short digestion time/ only the silica content of the clay minerals will react with the caustic liquor whereas under the more severe conditions of the "diasporic" digestion other silica-bearing minerals /first of all quartz/ may be digested, too. That means that in the case of gibbsitic ores the term "reactive silica" covers only the SiO_2 content of the clay minerals but in the case of diasporic bauxites it extends on the total SiO_2 content. Boehmitic bauxites usually stand between these two extremes, for safety's sake we usually calculate with the worse /i.e. diasporic/ condition during the preliminary calculations.

It has to be mentioned that the digestion of quartz reduces the available Al_2O_3 content of the bauxite as it takes about 0.85 kg Al_2O_3 per kg of quartz into the desilication product. This has to be taken into consideration when estimating the bauxite consumption. /This problem does not arise in connection with kaolinite since the latter has an $Al_2O_3:SiO_2$ ratio of 0.85./

3. TECHNOLOGICAL EVALUATION OF REPRESENTATIVE BAUXITE SAMPLES

SELECTION OF REPRESENTATIVE SAMPLES

Representative samples have to be selected to ensure that they represent all important characteristics of the given bauxite reserves. They are compiled from a number of individual samples, which have to be selected considering the following aspects.

a/ Every block of the bauxite reserve has to be represented by at least one sample, the amount of which should be proportional to the total amount of ore in the given block. If a block contains two or more distinguishable ore types and/or qualities, all of them should be separately represented with sample quantities corresponding to their amounts. Large blocks should be represented by more samples, say one for every million tonne of ore.

b/ The chemical and mineralogical composition of the individual samples should approximate as close as possible the average of the block represented.

c/ Should the chemical and/or mineralogical composition of the individual samples significantly deviate from those of the blocks, care has to be taken that at least the composition of their weighted average falls as close to that of the whole reserve as possible.

The form and amount of the representetive samples are determined by the tests which are to be carried out on them. All necessary laboratory tests /chemical and mineralogical analyses, digestion and settling tests, etc./ can be carried out on a sample of about 50 kg. The above test do not require lumpy ore, even samples from empire drill holes can be used for their purpose. On the other hand if grinding and/or beneficiation tests are to be carried out, too, lumpy samples are required. The latter may originate from core drillings /dia 50 mm minimum/ or from test pits and cuttings. Since the chemical composition of lumpy samples is less defined, a possible solution is to use a fine sample for analysis and digestion and settling tests and another, lumpy one for beneficiation and/or grinding tests. The latter may be compiled from the material of 5 to 10 test pits or cuttings.

The amount of bauxite required for pilot plant tests is of the order of magnitude of 100 tonnes. Since up-to-date laboratory tests usually furnish enough and reliable data for designing the process, pilot plant tests are seldom required.

Should the beneficiation tests be successful, the problem of selecting a representative sample will be more complicated. In this case all individual samples are required in a lumpy form because they have to be beneficiated /individually or as a composite sample/ according to the beneficiation technology determined by the /preliminary/ beneficiation test results.

PREPARATION OF THE REPRESENTATIVE SAMPLES

First step of the preparation of the representative samples is the chemical and mineralogical analysis of the individual samples selected according to the points of view described in the previous chapter. For this purpose all individual samples have to be sampled according to the standard procedure /quartering, etc./. Since the number of the individual samples may be around 100, the required amount of analytical work is usually quite significant even if the chemical analysis covers only the five main components /Al_2O_3, SiO_2, Fe_2O_3, TiO_2, L.O.I./ and the mineralogical one only the most important minerals /gibbsite, boehmite, diaspore, kaolinite, quartz, hematite, goethite/.

On the basis of the analysis results it can be decided, which samples should be included into the composite ones. It is very important to consult the geologist and the mining expert before making this decision. E.g. if a sample proves to be of sub-cut-off quality /low alumina and/or high silica content/, it can be left out of the composite samples only if the above experts decide that the ore body represented by it can be left out of the mining program without extremely high additional mining costs.

In some cases it can be advisable to prepare two or three composite samples of different grades by applying different cut-offs. By applying a stricter cut-off /higher minimum percentage for alumina and/or a lower one for silica/ the quality of the ore to be processed improves but the reserves diminish. A "looser" cut-off means decreasing ore quality /i.e. higher processing costs/ but larger reserves. The various cut-offs can however, be not applied in a mechanical way but only after consulting the geologist and the mining engineer again. They will decide, which of the sub-cut-off samples have to be included in the various composite samples and which of the above-cut-off ones have to be left out of them because of the technical and/or economic limitations of the mining procedure.

After deciding the principles of compiling the composite samples /how many different composite samples have to be prepared and which individual samples have to be included in which of them/ the required weight of each component has to be calculated starting from the assumption that the total weight of each composite should be about 50 kg. Since this weight is usually in the range of 0.5 to 1 kg per sample, a larger part /say, half/ of each individual sample has to be crushed in order to reduce sampling errors. Then the calculated amount of each sample is weighed out to form the composite samples. These samples have to be thoroughly mixed, usually in a rotating drum, for 1 or 2 hours. After applying the standard quartering practice a part of each composite is bottled and sealed /usually 2 to 4 bottles of 5 kg each per composite sample/ while the rest of each composite is used for chemical and mineralogical analysis and technological tests except for crushing and/or grinding tests. For the latter purpose other composites have to be prepared from the uncrushed parts of the individual samples. In this case homogenity and exact chemical composition of the composites is of a lesser interest, however, one has to take care that the proportion of lumps and fines, and that of the harder and softer materials should be close to that of the run-of-the-mine ore.

Laboratory testing and subsequent economic calculations will show the grade of which composite sample should be chosen when designing the plant. This will be a compromise between plant capacity and life-time on one hand and operating costs /bauxite, caustic soda and energy consumption/ on the other. The sample corresponding to this "optimum grade" is called "representative sample" and the sealed bottles containing it are treated accordingly.

The procedure is slightly different if preliminary tests show that the ore can be profitably upgraded by some beneficiation process /washing and/or sieving, etc./. In this case first of all it has to be decided if all the ore or only a part of it should be beneficiated, since the quality of the better part of the ore can be usually only slightly improved /but a part of it gets lost during the beneficiation process/ whereas in the case of the lower grades a significant quality increase more than compensates for the lost quantity. The geologist and the mining engineer has to be consulted again before this decision is made because they know if the different qualities can be separated prior to the beneficiation at acceptable costs. After this decision the individual samples representing the ore bodies to be beneficiated should undergo the same beneficiation procedure /all of them if the decision calls for the beneficiation of all the bauxite/, and the composite samples /or rather one composite sample in this case/ should be compiled of them and of the untreated ones, if any, in proportion to the ore bodies represented by them. When calculating the weights one has to consider the different beneficiation losses characteristic of the various ore qualities.

CHEMICAL, MINERALOGICAL AND MORPHOLOGICAL INVESTIGATION OF THE REPRESENTATIVE SAMPLES

The composite sample/s/ prepared according to the previous chapter first of all undergo a chemical and mineralogical investigation. The chemical analysis extends over and above the five main components mentioned above to the following/usually minor/ constituents:

FeO, CaO, MgO, ZnO, MnO, P_2O_5, V_2O_5, Cr_2O_3, Ga_2O_3, F, SO_3, CO_2, organic carbon.

In some rare cases some other components such as sulphidic or pyritic S or ZrO_2, etc. are determined too.

The description of the analytical procedures can be found in Volumes 3 and 8. This volume deals with the conclusions which can be drawn from the analysis results.

The amount and mineralogical form of the above components will help to determine the necessary technological tests to be carried out.

The predominant form of the alumina minerals determines the temperature and concentration range to be applied during the digestion tests. Gibbsitic bauxites are usually digested at a temperature of 140 to 156 °C and with relatively low liquor concentrations. The usual temperature range for boehmitic ores is 240 to 250 °C, liquor concentrations are slightly higher. Diasporic bauxites should be tested at 240 to 260 °C, with even higher liquor concentrations and by adding various amounts of lime to determine the optimum lime addition. In the case of mixed-type bauxites usually two of the above temperature ranges have to be tried out simultaneously, and the applicability of the two-step digestion and the sweetening has to be tested, too.

Low reactive silica contents /less than 2 per cent/ indicate some difficulties to be expected during predesilication and desilication and during or after digestion. In case of reactive silica contents less than 1 per cent these difficulties may turn out to be critical. Therefore, in such cases a great emphasis has to be laid on the predesilication and desilication tests, the effect of extended digestion times and of holding the digested slurry for some hours near the atmosperic boiling point has to be tested.

Bauxites with high reactive silica content above 6 or 7 per cent can only be processed with very high caustic soda losses. The mud of such bauxites may be ecconomically causticized with burnt lime, therefore, mud causticizing has to be tested, too.

Should the sample contain a significant amount of quartz /say, more than 0.5 per cent/, tests should cover the determination of its digestion behaviour at various temperatures, liquor concentrations and holding times. Coarse quartz is usually not appreciably digested below 200 °C but some very fine types of quartz may be partially or fully digested even at 140 °C. In such cases digestion temperatures of 100 to 120 °C have to be tested, too /naturally only in the case of gibbsitic bauxites as other types can not be digested at such temperatures/.

These problems can be very complex if the ore contains gibbsite and a significant amount of boehmite and quartz simultaneously as it is the case with some West-Australian bauxites. In this case the aim of the digestion tests should be to find such conditions under which the maximum amount of boehmite may be extracted while digesting as little quartz as possible. If this proves to be impossible, sometimes the whole amount of boehmite has to be abandoned in order to avoid the high caustic and alumina losses connected with the digestion of quartz. In other cases /e.g. with Weipa bauxite/ the combination of a high digestion temperature /about 240 °C/, low caustic concentration /near 100 g/l caustic Na_2O/ and short retention time /about 10 minutes/ may help to extract most of the boehmite content with minimum extra losses due to a low digestion rate of quartz. Results of the morphological tests help to predict the behaviour of quartz during the digestion tests.

Very low Fe_2O_3 contents /below 4 per cent/ may augur settling difficulties and relatively high "soluble" iron contents /up to 20 ppm in some cases/ in the pregnant liquor. In case of such bauxites a special emhasis has to be given to the settling tests and the "soluble" iron values have to be monitored.

Very high Fe_2O_3 contents /20 per cent or more/ herald a large amount of digestion residue /red mud/, the handling and disposal of which may cause serious problems. Extensive settling, filtration and dewatering tests have to be carried out on muds of such bauxites.

The mineralogical form of the iron content is often of crucial interest. Most bauxites contain Fe_2O_3 in the form of hematite and/or goethite. While hematitic bauxites usually yield well-settling muds, digestion residues of goethitic ores exhibit poor settling characteristics in most cases. The few exceptions of well-settling goethitic muds /e.g. those of Ghanaian bauxites/ only strengthen the rule: their morphological investigation shows that they contain goethite in an unusually well crystallized form. As a rule of thumb high goethite content in the bauxite requires extended, thorough settling tests. On the other hand, the transformation of goethite into hematite not only improves the settling characteristics of the mud but it sets free its alumina content which may amount to 25 to 30 molar per cent of the goethite phase. These two advantages may make the use of a high temperature digestion profitable even with tipically gibbsitic ores such as some Jamaican bauxites. Therefore, digestion tests have to be carried out with goethitic bauxites to determine those digestion conditions under which this goethite-to-hematite phase transformation occurs. /For details see Volumes 2 and 6./.

If a significant amount of bivalent iron is present in the bauxite, it is important to determine the mineral that contains it. FeO in magnetite will probably not cause any trouble but FeO in siderite will decausticize the plant liquor and cause additional operating costs. /The really harmful component in this case is not FeO but the carbonate bound to it. The latter will show up in the CO_2 content, too./. Since aluminate liquors of alumina plants processing FeO containing bauxites usually contain more "soluble" iron, laboratory tests should extend in such cases to the determination of the latter and - if necessary - to the testing of some iron removal technics to ensure a proper product quality.

Titania bearing minerals are generally insoluble at low digestion temperatures so they usually do not require special attention in gibbsitic bauxites. TiO_2 content of boehmitic, diasporic and mixed-type bauxites partially or fully reacts with the caustic soda content of the digestion liquor under the harsher digestion conditions required by them, forming sodium-hydro-titanates of various compositions. As the rate of reaction of the titania minerals is usually lower than that of the boehmite, but higher than that of the diaspore, TiO_2 rarely affects the extraction of boehmite, but it may inhibit the extraction of diaspore and prevent the goethite--to-hematite transformation. Digestion of diasporic bauxites requires the addition of enough lime to combine with the dissolving titania in order to counteract the above inhibition, and the same applies for the goethite transformation. The amount of lime to be added can be estimated from the TiO_2 percentage of the bauxite, and the optimum lime addition has to be determined by digestion tests using different lime quantities.

For boehmitic bauxites only high TiO_2 contents may be of some significance since the formation of various sodium-hydro-titanates may increase the caustic soda losses of the process. Since the above compounds tend to hydrolize in liquors of lower caustic soda concentrations such as those in the red mud washing line, the actual losses rarely exceed a tenth of those calculated by assuming the formation of sodium-tri-, tetra- or hexatitanates. Anyway, boehmitic bauxites with high TiO_2 contents /say, above 6 per cent/ have to be tested for their Na_2O to TiO_2 ratios after digestion and after a simulated washing. Should the washed residue contain too much Na_2O bound to TiO_2, mud causticizing should be tested, too.

Bauxites of lateritic origin contain only negligible amounts of CaO, but most European and Jamaican bauxites contain significant quantities, sometimes more than 1 or even 2 per cent. CaO itself is not harmful for the Bayer process, more or less lime is usually added to the digestion or other technological steps. The harmful component is CO_2, usually associated with CaO /forming $CaCO_3$, limestone/, which tends to decausticize the caustic soda of the process liquor, especially if the bauxite requires a high-temperature digestion /as boehmitic and diasporic European bauxites do/. If the chemical and mineralogical analysis shows the presence of a significant amount of $CaCO_3$, digestion tests have to be extended to determine the decausticizing effect of the same at various temperatures, liquor concentrations and holding times.

MgO comes usually together with CaO as dolomite though other minerals may contain it, too. The same applies for the decausticizing effect of the CO_2 associated with it as for the CO_2 associated with CaO, including the necessary tests to determine its decausticizing effect. But a high MgO content /say, above 0.3 or 0.4 per cent/ may cause another problem: since a magnesium aluminium hydrosilicate of the composition of $Mg_4Al_4\ Si_2O_{10}/OH/_8$ may form during digestion, and this material may cause strong foaming along the mud washing line, muds of high MgO bauxites should be investigated for the presence of the laminar crystals of this compound and if they are found, the washing process has to be designed accordingly.

Since alumina specifications usually prescribe a ZnO content of or below 0.01 per cent, bauxites with ZnO contents of 0.01 per cent or above that have to be tested for the solubility of their ZnO content. The tests should be carried out with plant liquors since the solubility /the ratio of the dissolved amount of ZnO to the total contained in the bauxite/ usually depends of the ZnO concentration of the digestion liquor.

Manganese does usually not require special action. It is not harmful for the process since it does not contaminate the product but leaves the plant with the digestion residue. In earlier times some plants used to add manganese dioxide or sodium manganate to oxidize organic materials but this solution proved to be quite ineffective. A French patent suggests the use of manganate or permanganate for the reduction of the "soluble" iron content of the pregnant liquor. The presence of bivalent manganese may help the goethite-to-hematite transformation and replace a part of the lime required for it.

In the case of phosphate it is important to know in what mineral form it is present since the phosphate content of apatite is virtually insoluble under the usual digestion conditions /and a small amount of lime added to the digestion will precipitate the little dissolved phospate/ but that of iron or aluminium phosphate /e.g. crandallite/ will be more or less quantitatively digested. Since phosphorus is one of the undesirable contaminants of alumina, the phosphate content of the aluminate liquors has to be kept low, therefore, a roughly stoichiometrical amount of lime has to be added to the digestion. The optimum amount of lime has to be determined by digestion tests.

Vanadium content of the bauxite is usually partially dissolved during digestion, in the form of sodium vanadate. The solubility depends very much on the digestion conditions,first of all on the temperature, digestion time and the original V_2O_5 content of the digesting liquor. Its extraction yield may be significantly increased by the goethite-to-hematite transformation which suggests that at least part of it may be somehow asssociated with the goethite content of the bauxite. In case of V_2O_5 contents of 0.1 per cent and above that digestion tests should include the determination of the solubility of V_2O_5.

Cr_2O_3 content of bauxites very rarely exceeds some hundredths of a per cent, and it usually accompanies iron oxides into the red mud. In case of high chromium contents its digestibility should be tested under the chosen digestion conditions.

Most of the Ga_2O_3 content of the bauxite is usually dissolved during digestion together with alumina and builds up to an equilibrium level in the plant liquors. This level /0.1 to 0.3 g/l in pregnant liquors/ depends on the bauxite's original Ga_2O_3 content and its solubility. Gallium content of the process liquors may be extracted in various ways to win a valuable by-product. Gallium recovery is economically feasible only if the ore contains at least about 0.01 per cent Ga_2O_3. Such bauxites should be tested for the solubility of their Ga_2O_3 content.

Fluorine is not a contaminant of alumina but may cause technological troubles by forming hard crusts in some equipment, first of all in evaporator tubes. The solubility of fluorine /present in the form of various fluorides, apatite, etc./ should be tested for every bauxite containing more than 0.1 per cent of F.

Sulphate content of the bauxite /often occuring as alunite/ gets usually quantitatively digested thus decausticizing the process liquor but causes technological troubles only in very large amounts /say, above 1 per cent/ since the forming sodium sulphate may be bound in sodium-aluminium-silicate /noselite/ by the reactive SiO_2 content of the bauxite. According to newer theories small amounts of SO_3 will not cause additional caustic losses. Should a significant amount of sulphate be present as gypsum, its digestibility has to be tested under the chosen digestion conditions.

Various carbonates /as mentioned previously/ decausticize the process liquor, too. Since the decausticizing effect depends on the digestibility of the carbonates present in the ore, bauxites containing more than 0.5 per cent of CO_2 have to be tested under the chosen digestion conditions for the digestibility of their carbonate content.

The term "organic carbon" covers a wide range of compounds. The most harmful of them are oxalic acid and those compounds which may break down and form sodium oxalate during digestion because high oxalate concentration in the process liquor results in a low precipitation yield and a very fine sized product hydrate. Oxalic acid contents higher than 0.01 per cent may cause troubles. Otherwise, total organic carbon contents up to 0.1 per cent may be considered unharmful. Bauxites with higher organic carbon contents require a chromatographic analysis of the organic matter and preferably some solubility tests under the chosen digestion conditions, too. A correct testing procedure would involve repeated digestions and hydrate precipitations until the various organic compounds reach their equilibrium levels in the liquor but such tests are very rarely done because of their enormous time requirement. Bauxites with a total organic carbon content higher than 0.2 per cent should definitely undergo such a testing.

Sulphidic S /usually in the form of pyrite, FeS_2/ is a rare contaminant of bauxites. Should it be present, it may cause a wide range of troubles, e.g. settling problems, high "soluble" iron contents of the pregnant liquor, corrosion problems, etc. Bauxites with more than 0.5 per cent of sulphidic S are usually considered unsuitable for the Bayer process. For such bauxites it should be tried if they could be economically beneficiated. Bauxites with a measurable /but lower than 0.5 per cent/ sulphidic S content should be tested for "soluble" iron, preferably in repeated cycles to ensure that the liquor's sulphide content be near to the equilibrium level. Some bauxites contain some tenth of a per cent of ZrO_2. It has no known harmful effect on the Bayer process. Some analysis methods add it to the silica content, some others to the alumina percentage. This is the only reason why it is sometimes analysed separately.

EVALUATION OF CRUSHING AND GRINDING TESTS

Crushing Tests

In the course of tests performed with raw bauxite the material is passed first through a jaw-crusher of 8 mm bottom aperture, then through a hammer mill with 3 to 4 mm aperture. The granulometric analysis performed before and after crushing - which generally refers to the range between 0.1 to 6 mm in 6 sections - and the average grain size gives the first information wether pizolitic constituents difficult to crush are present in the bauxite. Plotting the grain distribution on a Rosin-Rammler diagram, straight lines are obtained in case of normal crushability, however, a curve is obtained in case pizolitic constituents are present.

Hardgrove Index

The Hardgrove Index gives a qualitative indication relative to the grindability of bauxite and has an important role in the selection of the diameter of the mill.

Hardgrove Index of hard, diasporic bauxites ranges from 50 to 60; such bauxites have to be ground in larger mills with smaller diameter. Soft bauxites, e.g. Hungarian bauxites, are characterized by a higher Hardgrove Index, 110 to 120: such bauxites are ground expediently in shorter mills having larger diameter.

Bond Index

The Bond Index can be used directly for the dimensioning of the mills on the basis of the following formula:

$$T = \frac{K_1 L_K D_K^{2.65} C}{B_d}$$

where: T = designed quantity of ground bauxite, t/h

K_1 = constant

L_K = external length of the mill, m

D_K = external diameter of the mill, m

C = degree of grinding, characterized by the following relationship:

$$C = \frac{X_1}{\sqrt[3]{\frac{X_o}{X_1}}}$$

where: X_o and X_1 = are resp. the sieve openings, μm, through which 80 per cent of the original bauxite resp. ground bauxite is passed

B_o = Bond Index

On the basis of the above formula, the length of the mill can be determined, provided the necessary diameter has already been estimated on the basis of the Hardgrove and Bond indexes.

Power requirements of the mill can be calculated on the basis of the formula below:

$$P = K_2 \cdot r.f.e.L.D^{2.5}$$

where: P = expected power consumption, kW

K_2 = constant

r = volumetric density including balls, t/m^3

f = degree of filling-up /0.3 to 0.4, in practice/

e = proportion of the actual revolution number and "critical" revolution number

In the practice mills are selected by special firms on the basis of tests performed with the bauxite.

EVALUATION OF PREDESILICATION TESTS

The main purpose of evaluating predesilication tests is to decide whether predesilication can be performed on the solids concentration of the slurry to be digested, this being the simplest technical solution though requiring more tanks.

In case predesilication performed on the concentration of digestion slurry is not satisfactory, predesilication of mill slurry can be taken into account. The actual solids concentration is determined by the grindability of the bauxite. As regards predesilication, a higher concentration can save tank capacity. In case of hard tropical bauxites, solids concentration of the mill slurry can be as high as 1000 g/l. Though these bauxites are generally of gibbsitic composition, their predesilication performed at high concentration can be advantageous from apparative reasons.

As regards the temperature of predesilication, tests show generally favourable effect of higher temperatures. As waste-heat of digestion is available for adjusting the temperature of the slurry, predesilication is performed generally at about 100 °C.

Caustic concentration of the liquor during the predesilication is determined by the optimization of the total circuit. The higher liquor concentration used in the digestion of boethmitic-diasporic bauxites is favourable in general as regards the efficiency of predesilication. There is a possibility to perform predesilication in spent liquor, too, but it has to be taken into account that dissolution of silica is slow at lower concentrations and, therefore, higher temperature and longer retention time have to be provided.

Predesilication tests give the relationship between retention time and efficiency of desilication. As regards the designing work, retention time is chosen for that point where the curve becomes horizontal. On the basis of reaction kinetics, it is reasonable to distribute the total predesilication volume in minimum three tanks, thus ensuring an even distribution of the holding time. In case the tests indicate that addition of seed is advisable the possibility of charging it has to be provided.

Summarizing the above parameters, minimum 80 per cent predesilication efficiency has to be ensured even under plant conditions.

EVALUATION OF DIGESTION TESTS

The objective of the digestion test is the determination of optimum digestion parameters in the view of optimization of the total plant. This will be detailed under chapter 4. Here the most important parameters will be enumerated which have to be supplied for optimization and for the selection of technology.

The effect of grain distribution of the ground bauxite on digestion is negligible in case of soft bauxites: in case of hard, diasporic bauxites, however, the grain distribution has to be fixed, which gives the possibility to reach an adequate efficiency in digestion. This can be as low as 60 μm.

Digestion temperature will be determined finally by optimization on the basis of characteristic curves of digestion. It has to be taken into consideration that though a higher temperature is advantageous as regards digestion efficiency and a lower molar ratio can be reached after digestion, the investment costs of both the digesting equipment and the steam generating plant necessary for producing high pressure steam will increase. Furthermore, it has to be taken into account, that silica bounds more caustic soda at a higher digestion temperature.

In case of goethitic type bauxites an additional aspect can be the improvement of settling characteristics of the red mud formed in a high temperature digestion.

Retention time can be reduced in case of high pressure, high temperature digestion and this may diminish the investment costs. In case of digestion by additives, transformation of goethite, which is advantageous from several points of view, may require a longer retention time.

Crystal structure of silica in certain types of bauxite is so compact that it dissolves slowly. In such a case the possibility of selecting double-stream digestion /otherwise disadvantageous, from energetic point of view/ as one of the variants should also be investigated, because the short retention time of bauxite in the digester may be advantageous as regards soda consumption.

The effect of liquor concentration is not of primary importance concerning the digestion parameters.

In case of bauxites forming sand during digestion the relative tests give information to help the design of the sand separation.

EVALUATION OF RED MUD SETTLING TESTS

Red mud slurry produced in the laboratory is used for the tests. During the settling gamma rays are scanning the settling tube alternately up and down in short periods and their absorption is measured. On the basis of the plots thus constructed, the mud concentration at different times and heights can be determined. Settling is continued up to 48 hours to determine the final settling concentration formed at the bottom of the settlers, too. On the results thus gained proper dimensions of settlers and washers can be calculated by computers and the optimum operating conditions can be determined, too. Fig.7.1 illustrates the relationship between the settling performance and the depth of the clear zone at given underflow solids-concentration /300 g/l/.

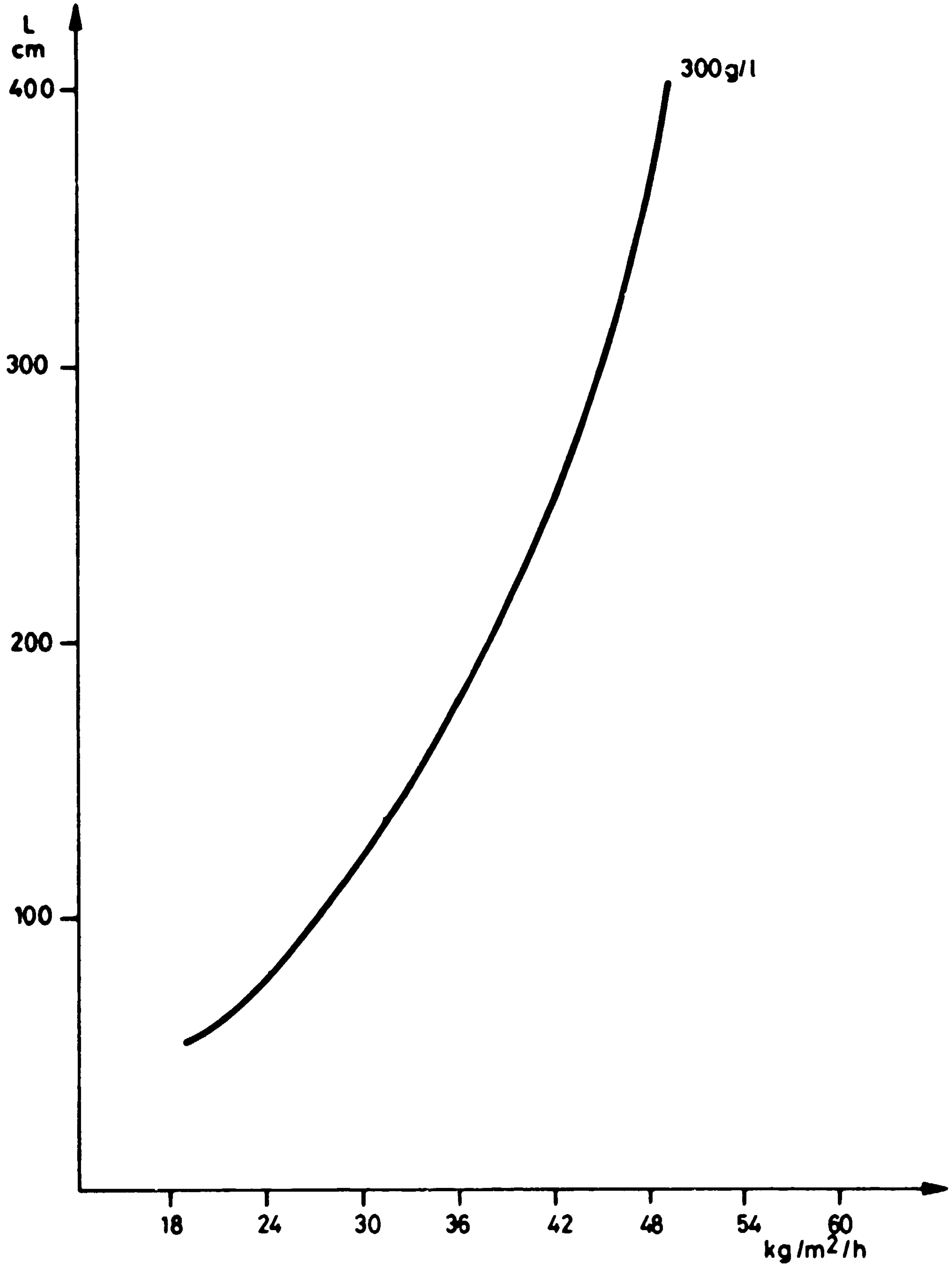


Fig. 7.1
CLEAR ZONE HEIGHT vs. SETTLING PERFORMANCE

The summary of the results is illustrated in Fig.7.2 demonstrating the expectable underflow concentration and settling performance as a function of any given clear zone height. On the basis of this set of curves optimizing calculations aiming at designing the most economic red mud settling and washing system may be done. As it can be seen from Fig.7.2 the performance of the settler may be increased by decreasing the clear zone. This procedure has certain limits, as in the case of a small clear zone the floating mud-content of the overflow increases,deteriorating the quality of the alumina. In the practice it is advisable to maintain a clear zone of 2 to 2.5 m for settlers of 6 m height.

INVESTIGATION OF THE CONTAMINATING MATERIALS

Chapter 3 describes the conclusions which can be drawn from the amount and the mineralogical form of the contaminating materials of the bauxite. The present chapter deals with some further conclusions derived from additional tests.

Digestion tests and subsequent chemical and mineralogical analysis of the residue give information about the digestibility of the calcium-bearing minerals, e.g. calcite, dolomite, etc. under various conditions. They show, how much of the bauxite's own CaO content may be subtracted from the lime requirement of phosphorus control and/or goethite-to-hematite transformation.

Should the digestion residue of high MgO bauxites contain significant amounts of the laminar crystals of magnesium--aluminium-hydrosilicate mentioned previously, caution has to be taken to prevent or at least reduce foam formation in the red mud washing equipment. A well-proven method for this is the rigorous checking of air being mixed into the slurry at pump glands by sucking slurry from empty tanks, etc.

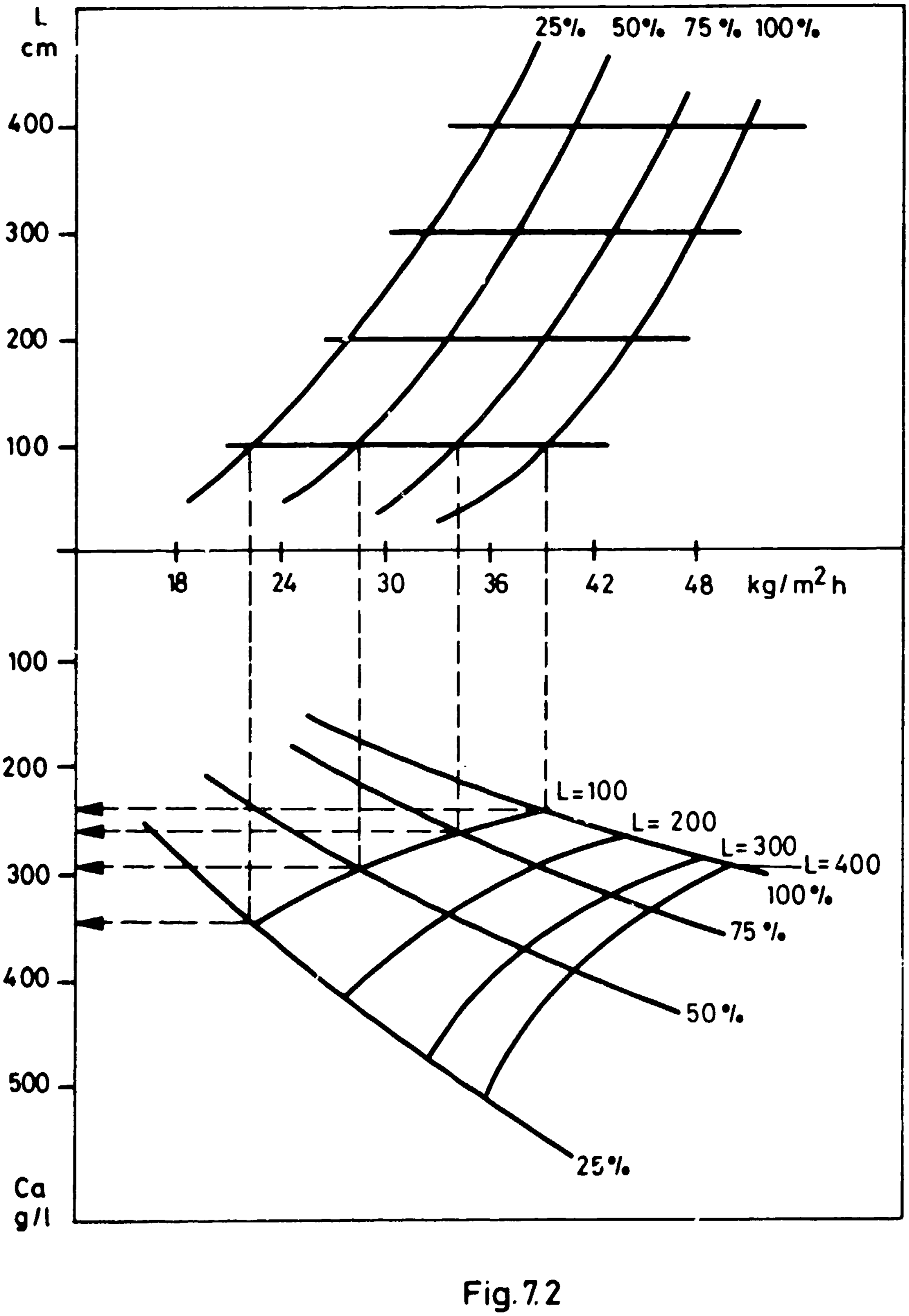


Fig. 7.2

UNDERFLOW CONCENTRATION vs. SETTLING PERFORMANCE AND CLEAR ZONE HEIGHT

If a high ZnO content of the bauxite is combined with a high solubility of it and calculations show that the ZnO content of the product may exceed the specification limits, a ZnO removal process has to be incorporated into the technology. The most widely used process consists of the addition of Na_2S to the settler overflow and the holding of the treated pregnant liquor for about 2 hours before control filtration.

Digestion tests give information whether and how much lime is required for phosphorus control. The required amount has to be fed in solid or slaked form into the process, preferably to the bauxite grinding where it can be throughly mixed with the bauxite slurry.

High V_2O_5 content of the ore and medium or high solubility of the same result in high V_2O_5 contents in the plant liquors /in some cases as high as 2 or 3 g/l V_2O_5 in the strong liquor/. The solubility of sodium vanadate strongly depends on the sodium fluoride and sodium phosphate concentration of the liquors since they crystallize in the form of double and triple salts. Therefore, when designing a vanadium removal system, the probable fluoride and phosphate content of the liquors have to be taken into consideration, too. Since the solubility of the double and triple salts varies strongly with the temperature, they crystallize at the lowest temperature points of the process, usually in the precipitators and so tend to contaminate the product hydrate. This can be prevented by using a higher amount of very hot /90 to 95 ^{0}C/ hydrate wash water and/or by putting a holding tank between the first and second stage of the product hydrate filtration where the slurry consisting of hydrate and wash water /preferably the surface wash water of the second filtration stage/ can be held for 15 to 30 minutes at a temperature near the atmospheric boiling point to enable the crystals of the double and triple salts to be dissolved. Hungarian alumina plants had good experiences with sieving the coarse /0.8 to 1 min./

crystals of the triple salt out of the precipitated slurry. Recently the phosphate level of the plant liquors decreased sharply because of the high CaO content of the bauxite processed. Since that no triple salt crystallizes and the crystals of the double vanadate-fluoride salt are much finer so the sieving lost its efficiency. Another efficient method of vanadate control can be the separate evaporation of the vanadate-rich alkaline hydrate wash water and the crystallization of the double or triple salt after cooling the resulting strong liquor to 30 or 40 °C. There is a possibility to remove the excess vanadium content of the process liquors together with the carbonate salt if such is precipitated from the strong liquor, though in this case the V_2O_5 content is usually lost whereas the two previous methods give salts with high /10 to 20 per cent/ V_2O_5 contents which can be economically processed to pure V_2O_5 or sodium polivanadate. The most economic method of vanadate-removal has to be chosen by calculating the V_2O_5, P_2O_5 and F balances of the projected plant on the basis of the chemical analysis and solubility tests carried out on the representative sample and comparing the costs and possible benefits of the available methods.

Chromium rarely requires any action.

Gallium is not a harmful contaminant of the aluminium for most practical uses, therefore, few customers prescibe a maximum Ga_2O_3 content for the alumina. On the other hand gallium can be a profitable by-product of an alumina plant. For practical purposes at least 0.1 kg Ga_2O_3 should be dissolved per tonne of alumina produced to support a viable Ga-extraction, i.e. the product of the specific bauxite usage, the bauxite's Ga_2O_3 content and the solubility of it /the two latter expressed in per cents/ should be at least 1,0, otherwise the equilibrium concentration of the plant liquor will be too low. Should this minimum requirement be met, the calculation of a preliminary material balance will help to estimate the amount of the extractable gallium which is usually between 10 and 20 per cent of the dissolved quantity. Economic calculations may be carried out to decide if the extraction is economically feasible and which of the known processes should be applied. /For details of the gallium extraction processes see Volume 2./.

On the basis of the fluorine solubility tests a preliminary F balance can be calculated. Comparing this balance with those prepared for V_2O_5 and P_2O_5 it can be decided whether the crystallization of the double and/or triple salts mentioned above will keep the fluorine level of the plant liquors within acceptable limits /say, 2 g/l F in the strong liquor/ or a separate fluorine removal process has to be designed. If the technology contains a step of Na_2CO_3 crystallization from the strong liquor, the excess fluorine will crystallize in the form of NaF together with the carbonate salt, expecially if some extra holding time /preferably 6 to 8 hours/ is provided to promote the crystallization of sodium fluoride. A salt with a relatively high NaF content could be crystallized from medium concentration Hungarian plant liquors /200 to 220 g/l caustic Na_2O/ during a holding time of 10 to 12 hours as at such concentrations sodium carbonate has not yet precipitated. This technology was profitable when a consumer /a manufacturer of synthetic cryolite/ could be found for the high-fluorine salt.

In case of high sulphate content in the bauxite a rough sulphate balance has to be calculated taking into consideration its solubility and the reactive silica content of the ore, too. If the balance shows that the sulphate content of the plant liquors would reach unacceptable levels, some sodium sulphate has to be removed from the process. If the carbonate balance of the plant is maintained by crystallizing sodium carbonate from the strong liquor, sodium sulphate will crystallize together with the carbonate. The trouble is that sulphate can not be causticized as easily as carbonate and, therefore, the mixed salt either has to be discarded or its values can be recovered only in a sophisticated way. So it may be advisable to try to crystallize the carbonate and sulphate salts separately.

A CO_2 balance has to be calculated for most projected alumina plants on the basis of the bauxite's carbonate content, the digestibility of it, the probable amount of CO_2 to be bound in cancrinite /a carbonate containing mineral in the desilication product/, the probable carbonation of the liquors from the atmosphere /strongly depending on the agitation system - airlifts or mechanical agitation - applied in the precipitation and in some other large tanks/, the degradation of the bauxite organics and of the flocculants applied at the red mud settling and washing and some other CO_2 sources, e.g. the water returned from the red mud disposal area, etc. If the total of the "ins" exceed that of the "outs" by some 5 to 10 kg per tonne of alumina, the balance may be maintained by causticizing the overflow of the second or third /or in some cases that of the first/ red mud washer with lime. When using the proper amount of lime /half to two thirds of the stoichiometric quantity/ and carefully controlling the lime addition this can be done without high alumina losses. Lime can be added for the same purpose to the digestion, too, but it will work there efficiently only if the caustic concentration is low and the carbonate to caustic ratio /"carbonate level"/ is high /i.e. the "liquor causticity" is low/. Should the total of the CO_2 inputs exceed that of the outputs by more than 10 kg, the balance can be restored by crystallizing sodium carbonate from the strong liquor, separating it from the same by filtration or centrifuging and causticizing the separated salt with lime /usually at a temperature of 80 to 90 ^{o}C and at a concentration of less than 100 gpl Na_2O/. This process is much more expensive because of the costs of evaporation /except if evaporation is required anyway to maintain the water balance of the process/ but it has the advantage that the carbonate content of the separated soda can be causticized with a yield exceeding 90 per cent and that the alumina losses connected with it are negligible. If required, the two suggested processes for carbonate removal may be combined.

If the oxalic acid content of the bauxite exceeds 0.07 per cent, steps should be taken to remove sodium oxalate from the process liquor. Since its solubility greatly varies with the temperature, it can be crystallized from cooled strong liquor, or it can be separated by washing the fine seed, on the surface of which it tends to accumulate. The Na_2O content of the sodium oxalate may be recovered by causticizing it with lime.

Some of the other compounds in the bauxite's organic content /e.g. simple compounds like formic and acetic acid, etc./ cause little trouble but those with high molecular weights tend to increase the viscosity of the plant liquors quite significantly. So the results of the chromatographic analysis give some clues about the troubles to be expected. The saturated liquor from the repeated digestion and precipitation tests may be used for viscosity tests and various oxidation and other purification technologies may be tried on it /e.g. oxidation with sodium hypochlorite, adsorption on charcoal or activated carbon, etc./.

The testing of the liquor originating from the repeated digestion of sulphidic bauxites will show what type of action has to be taken to improve settling, reduce "soluble" iron, etc. These measures have to be incroporated in the plant design. There are suggestions to precipitate sulphide with zinc compounds but we feel that such a solution would be too risky since an overdosage would mean the contamination of the product with zinc, one of the worst contaminants.

ZrO_2 in the bauxite does not require any action.

4. SELECTION OF PROCESS TECHNOLOGY ON THE BASIS OF THE TECHNOLOGICAL TESTS

In the previous chapter, the major parameters to be selected from the preliminary tests of bauxite for elaborating the final technology of the plant were described. In the following distinction will be made between those parameters which can be regarded as final already during the tests and those which only serve as starting variants for the joint optimization of the total plant.

Crushing and grinding tests provide the opportunity for the final selection of technology and equipment of bauxite crushing and grinding. Though the concentration of digestion liquor - which is only determined after optimization - affects the concentration of the grinding liquor, too, but the question can be solved right at the beginning by performing the grinding tests both at higher and lower liquor concentrations /e.g. 180 and 120 g/l Na_2O/. The two different liquor concentrations generally do not give such a difference as regards grinding, that the selected equipment should be modified.

In case of diasporic bauxites, the raw material should be ground to an extra fine size in view of effective digestion - in this case final selection of the grinding equipment can be performed only after the digestion tests have been finished.

Determination of the final technology of desilication is related to the digestion technology, consequently the desilication technology is finalized only after finishing the optimization. It is expedient to check variants of heating of the slurry going to desilication in surface or flash condensers.

As regards digestion tests, all variants have to be taken into account as basic data, which can be advantageous at least in one aspect. For example, high temperature brings about low molar ratio and the flashing of a great amount of water; low temperature decreases the equipment cost and the caustic soda consumption, whereas low digestion liquor concentration may result in evaporation savings, etc. Spare digester series or spare digesters and preheaters, single and double stream digestion, shorter or longer flashing series, digesters of smaller or greater dimensions, etc. may be taken into account.

As regards settling and washing, the calculations described under chapter 3. determine dimensions of settlers and washers. However, aiming at good product quality, it is expedient to oversize a little the settlers and to reckon with one spare washer which can replace the others during the maintenance period.
The objective of the optimization is the number of the washing stages.

Both the filtration and causticization of red mud can be considered as surplus variants against the open washing series.

In the course of elaborating the technology of red mud washing, the causticization in the washing series and the utilization possibilities of wash water recoverable from the red mud pond have also to be taken into account.

The equipment of aluminate liquor control filtration is determined by the heating surface area which can be calculated from the given amount of the aluminate liquor: there are mostly two variants that can be reckoned with in this case, depending on whether the concentration of the filtered aluminate liquor corresponds to the production of floury or sandy alumina.

There are two basic variants of aluminate liquor cooling: surface /in general, plate/ heat exchangers and flash cooling. It is expedient to take both into account among the variants to be optimized.

Variable parameter of precipitation is the dimension and number of the precipitation tanks, the related number of stages and the precipitation time. The seed ratio of the sandy technology can be varied within rather narrow limits, consequently, the necessary equipments of seed classification and product hydrate filtration can be dimensioned as final and they should not be included into the optimization.

In the floury technology, however, separate optimization can be performed by varying the seed ratio, as it can significantly affect the precipitation ratio and the number of filtration units.

Dimensioning of equipments for calcination does not constitute part of the optimization: both for sandy and floury alumina production "ready to wear" equipments are available in wide capacity range. Here at most the rotary kiln and fluid--bed variants can be compared, on the basis of operating and investment costs.

The amount of evaporated water is included into the optimization in form of several variants. This is determined by the selected digestion and precipitation technology but, at the same time, also reacts on the digestion technology and affects red mud washing. For both basic types - multistage or flash evaporation - equipments are available in various dimensions.

The contaminants of the circuit liquors must also be taken into consideration and, principally in cases the bauxite has high CO_2 and/or organic material content, it is expedient to select units operating at high concentration in order to intensify salt separation.

In case of evaporation, those advantages should also be taken into account which arise from the utilization of the exhaust steam of the turbine, and which are taken into account in the form of varying price of the counter-pressure steam. Apart from this a significant item can be the amount of steam originated from the flashing of condensate of high pressure steam used in the digestion, too, which is used for heating the evaporation process.

On the basis of the above, starting parameters of the variants to be optimized are constructed.

Calculation of Material and Heat Balances

Calculation of material and heat balances is performed by computer programs, which calculate the detailed composition, volume, mass, density, heat-capacity and temperature of 60 different materials.

Most important input data of the program are:

- major constituents of bauxite, for more types of bauxite-qualities or bauxites mixed in different ratios, if required
- digestion temperatures on the basis of laboratory tests
- number of flashing stages
- underflow concentrations of settlers and washers in different variants, based on the relationships obtained from the settling tests
- number of the washing series, in several variants
- parameters of red mud causticization
- parameters of red mud filtration
- two basic variants of aluminate liquor cooling /surface heat exchange and flash cooling, resp./
- dimension and number of the precipitation tanks, in several variants
- different variants of seed ratio /floury alumina production/
- quantity of evaporated water, in different variants.

The blocks installed into the program /digestion, counter-current mud washing and filtration, causticization, precipitation, evaporation/ are based principally on the relationships elaborated in Volume 2.

The blocks can be replaced or substituted on the basis of recent research results, elaboration of theoretical relationships and plant achievments. Relationships built into the blocks involve the widest possible range of parameters, so that the calculation could be carried out among conditions that differ from the usual plant practice, too. The program is static and it practically involves the expectable general values of a longer operation period. Obviously, fluctuations also occur in the plant practice, their effect is contained in the program on the basis of statistical estimations.

The program is not meant to describe transient phenomena /starting of a plant; downtime,etc./, it is suitable, however, to process several operation variants occurring in the practice: during maintenance time of a digester line e.g. the remaining digester lines can be overloaded to a certain extent, in order to decrease the production loss, and/or the digestion liquor concentration can also be increased without inflicting any major changes in the plant parameters. Special attention is called to the fact that though the program calculates the heat content of solid materials, solutions and slurries, it also provides the opportunity to realize several different heat schemes based on the above. Different power plant schemes calculated by a special computer program belong to each heat scheme of this kind.

As a matter of fact, the program calculates total material and heat balance for each input variant, and on this basis the specific consumption values of the most important raw materials, moreover, the quantitative data of energy consumption can be determined. Their utilization possibilities are discussed in the next chapter.

For sake of example the number of independent variables can be estimated as follows:

Independent variable	Number of variables	Value of indep. variable
Digestion temperature	2	140-250 °C
Number of flashing stages	2 /2/	2, 3, or 8, 9, resp.
Digestion system	2	1 or 2 stream, resp.
Number of digester lines	2	2, 3
Number of washing stages	3	6, 7, 8
Aluminate liquor cooling	2	flash, surface
Dimensions of precip.tanks	2	2000-3000 m^3
Precipitation time	2 /2/	30, 40 or 60 70 hours
Evaporated water	4	1, 2, 3, 4 m^3/t

According to the above, the number of total variants exhibits 1000 order of magnitude. In practice, however, after having some variants run, the number of variants to be tested can be diminished, if eliminating those variants by preliminary estimations which are not expected to be satisfactorily economical. The method of evaluating the remaining variants is described in Chapter 4.

Examination of Material and Investment Costs

In posession of the mathematical program calculated by the computer, the next objective is to feed the input data into the computer. Part of the data is constructed by the independent variables enumerated in Chapter 4.; apart from them, several data necessary for the calculation must be fed in, but their value does not undergo considerable modifications in the individual variants or it can be determined with a simple method.

As it was already mentioned in Chapter 4., some trial runs are performed at the beginning with the basic variants in order to estimate the expectable range of optimization, thus the number of variants is diminished.

After this all the variants worth to be tested are fed in; based on them the computer prints the material and heat balance and provides at the same time the expectable specific values of all the important materials. Multiplying this values by the known unit prices, the specific material cost per variants for the most important materials is got.

Completing the material costs by the costs of wages and administration costs gives the operational costs. In practice, it is generally unnecessary to mark the wage and administration costs per each variant. Calculations start from the variant having the lowest wages and only the rise in wages of the other variants compared to the basic variant is taken into account, if necessary /e.g.: variant without and with filtration/.

Evaluation of steam consumption costs corresponding to the variants necessitatees running of a separate power plant computer program and determination of the costs of high and low pressure steam and electric energy produced on the basis of fuel costs, other operational costs and investment costs. Costs of purchased electric energy is generally known but it has to be taken into account that a fee corresponding to different consumption levels has to be added.

Evaluation of investment costs of the individual variants means a hard engineering task. Capacity of the alumina plant machinery and equipment can not be varied continuously and prices of equipment available in machine factories or manufacturable on the basis of finished designs have to be taken into account. Therefore, the most reasonable capacity of the equipment has to be determined for each variant, selected from the available assortment if possible, as designing or manufacturing of new types of equipment is generally more expensive.

In the frame of investment costs, land and site development, building and civil works, construction, transport and other costs have to be taken into account, too. Working capital is taken into consideration only in case of variants in which significant change is anticipated.

Both for the operation costs and investment costs the so-called discounted value is calculated and the sum of the two gives the characteristic value of the variants to be compared. It is expedient to examine the vicinity of the optimum variants in more details in order to determine the final optimum.

The computer program is suitable for the evaluation of different operational manners. Economic effect of taking out certain equipment for general overhauling can be pre-estimated this way. This calculation is indispensable in case of elaborating a long term production program.

On the basis of the computer program the economy of the expansion of an existing alumina factory can be worked out, too. Expansion programs have, in general, several variants, too, though often technical limits are set to some of them by local conditions.

As regards the optimum variant selected on the above basis, the material and heat balance, material consumption are available in the print of the computer program, and the necessary equipments are selected already. On this basis the final technology can be elaborated in detail and the list of equipment suitable for the invitation of tenders can be prepared.

Remark

An interesting application of the computer program is the comparison of the bauxite quality to the average lifetime of given bauxite reserves. Processing of the total reserves gives generally a lower quality bauxite and higher material costs of the alumina production, as a consequence. However, lifetime of a given capacity alumina plant becomes longer, or a bigger alumina plant can be constructed for a given lifetime - 30 to 35 years, in the practice.

On the other hand leaving out low quality bauxite from the mining, the bauxite quality will be improved, but the lifetime of the factory, resp. its capacity will decrease.

5. DETAILED DESCRIPTION OF THE CHOSEN PROCESS TECHNOLOGY

In order to demonstrate the usual method of describing the process technology, a general model is given referring to no specified alumina plant processing gibbsitic bauxite and producing sandy alumina. Fig.7.3.a and b.

The process technology is generally independent from the plant size. Even in case of several capacity variants, the individual variants differ mainly in material and heat flow/hour and the amount or capacity of the equipment installed.

The design of the hourly alumina production is calculated allowing down time required for the maintenance of the various equipment. The actual production is generally 90 to 92 per cent of the capacity calculated on the basis of continuous production.

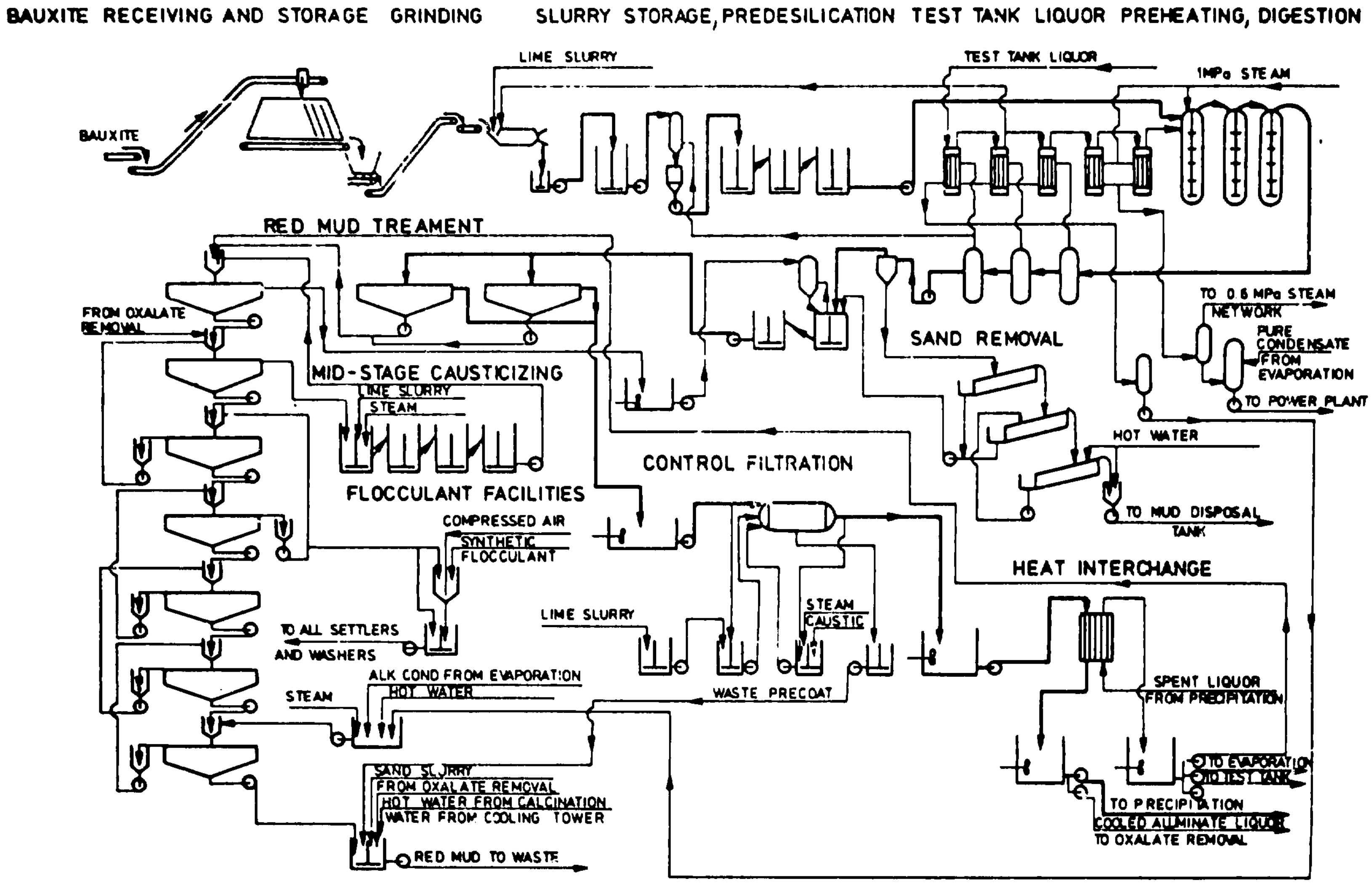
DETAILED MODEL DESCRIPTION OF INDIVIDUAL PLANT UNITS

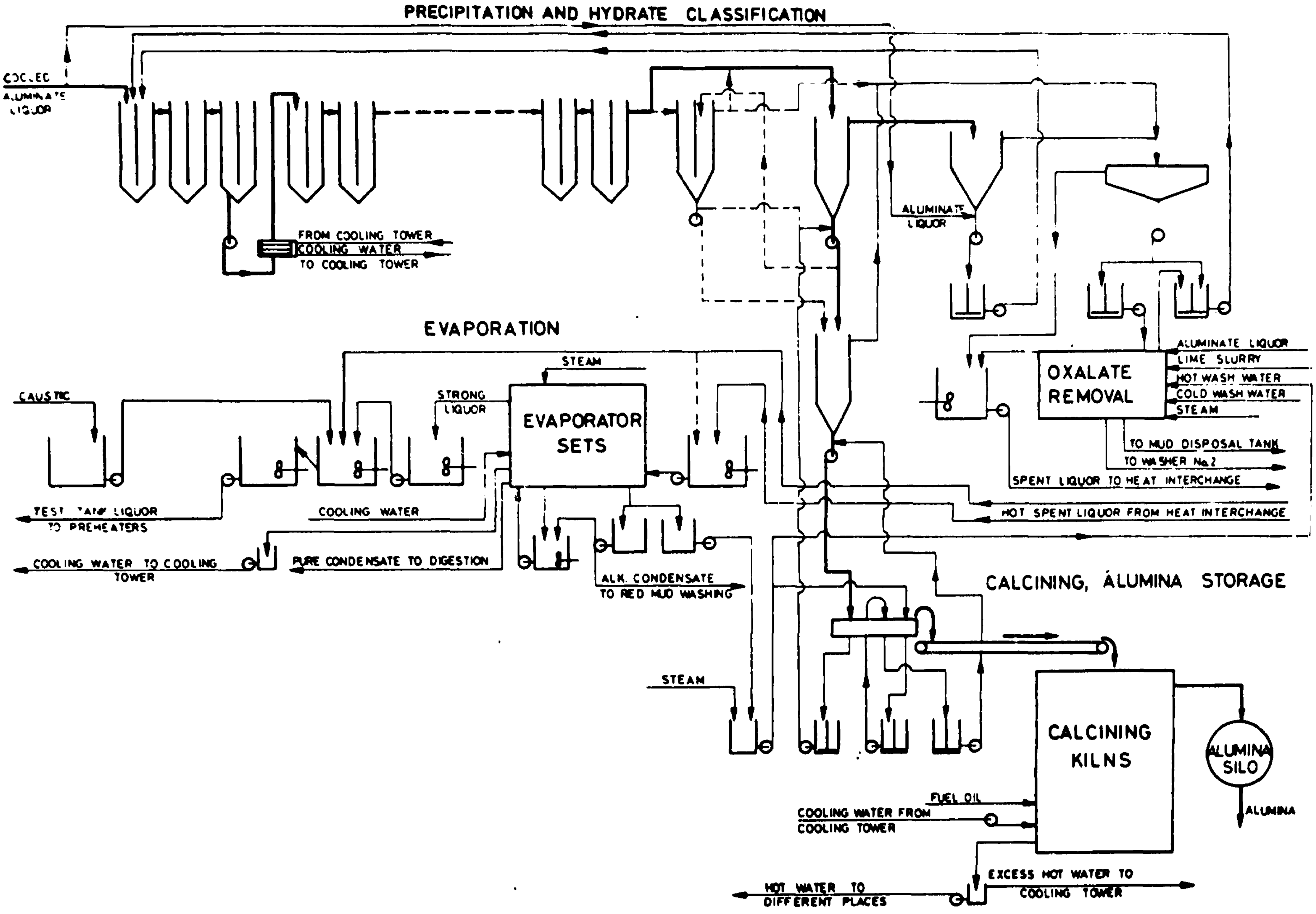
Bauxite reception, storage

Bauxite with an adherent moisture of about 9 per cent and maximum 30 mm lump-size is moved by a conveyor belt to the storage area. The capacity of this system assures the receiving of the bauxite quantity delivered by the mine.

Bauxite is stored in 2 blocks, while one block is filled, the other supplies the bauxite for the process. The storage area holds one week's bauxite stock.

CONCEPTUAL TECHNOLOGICAL PROCESS FLOW-SHEET Fig.7.3.a





CONCEPTUAL TECHNOLOGICAL PROCESS FLOW-SHEET

Fig 7.3.b

Wet grinding, predesilication

Bauxite is recovered from the storage area by front end loaders through chutes located below the ground level. Then it passes via apron feeders and conveyor belts to the wet grinding ball mills.

One mill is in operation - the second serves as a spare.

The quantity of bauxite fed into the ball mill is measured and grinding liquor is added in proportional quantity so that the solids concentration of the ground slurry would be 600 g/l. About 25 per cent of the test tank liquor is used as grinding liquor.

Lime at a rate of 0.1 per cent CaO of dry bauxite is also fed into the ball mill in the form of lime slurry containing 200 g/l CaO.

The slurry flows from the mill into a slurry surge tank from which a centrifugal pump delivers it to the storage tanks.

From the storage tanks the slurry is transported by a centrifugal pump into the slurry heating condenser. Here it is heated to about 100 ^{0}C by a part of the steam released from the last flashing stage of the digester line. This ensures the necessary temperature for predesilication.

The heated slurry flows into a conical tank from which it is pumped into the first tank of the predesilication tank line.

Predesilication of the preheated mill slurry is carried out in 3 series-connected tanks.

Slurry delivered into the first tank of the predesilicating tank line flows continuously over the tank line, while the dissolved SiO_2 content of the liquid phase decreases to a suitable level.

The line ensures the minimum holding time of 8 hours which is necessary for predesilication.

Test tank liquor preheating, digestion, sand removal, dilution

Test tank liquor is pumped from the test tank into the preheater series. After the second stage part of the liquor is branched off /at about 106 °C/ to the ball mill, the balance is heated up to about 156 °C and then enters the first digester of the digester line.

The first three preheaters of the series are heated by flash steam, the last two by 1 MPa live steam.

Slurry from the last tank of the predesilicating tank line is fed by centrifugal pumps into the first diegester of the digester line, too.

Slurry is directly heated by 1 MPa steam injected into the first digester of the digester line to the required temperature of 140 °C. Two subsequent digesters of the line ensure the necessary retention time at the digestion temperature.

Slurry digested at a temperature of 140 °C is flashed in 3 stages to 110 °C. The flash steam heats test tank liquor and mill slurry.

Alkaline condensate leaving the preheaters heated with flash steam is carried by centrifugal pumps into the red mud wash water tank.

The condensate of the preheaters heated by 1 MPa steam is returned to the power plant after flashing into the 0.6 MPa steam network.

Sand is separeted from the digested slurry in hydrocyclones, then fed to rake classifiers, where its soluble Na_2O and Al_2O_3 content is washed with red mud wash water in a counter-current system, then it is repulped and pumped to the red mud pond.

The overflow of the hydrocyclones is diluted in tanks by the overflow of the 1st washer and the sand wash to 105 g/l caustic Na_2O concentration. Diluted slurry of about 103 ^oC is pumped by centrifugal pumps to the red mud settlers.

The red mud content of the diluted slurry is separated from the aluminate liquor in two parallel operating single comparment settlers. Aluminate liquor obtained as an overflow of the settlers is fed into surge tanks and from there it is pumped to the control filtration.

The underflow of the settlers is pumped into the counter--current washing system, where the greater part of its soluble Na_2O and Al_2O_3 content is washed out. The washing systems consist of 7 series-connected washers. During the maintenance or repair of any of the equipment the washing line operates in 6 stages.

Spent liquor is introduced into the 1st washer in order to decrease autoprecipitation losses. The solution obtained during salt removal is pumped to the 2nd stage of the red mud washing line.

In order to maintain 88 per cent causticity of the process liquor the 2nd washer overflow is heated to about 85 ^oC by live steam and causticized with the necessary quantity of lime. The causticized solution is pumped to the first stage of the red mud washing line.

To promote settling a synthetic flocculant is added to the settlers and washers.

The overflow of the 1st washer flows into a surge tank from where it is pumped into the diluting tanks. The underflow of the last washer is pumped through surge tanks to the red mud pond.

In order to decrease the contamination of the aluminate liquor obtained as an overflow of the settlers it is filtered on Kelly-type pressure filters on a lime precoat. After filtration the used precoat is removed by industrial water from the filter surface and the slurry obtained is lead to the red mud pond.

The aluminate liquor flows from the filters into the storage tanks from where it is pumped to the aluminate coolers. It is cooled with spent liquor in plate heat exchangers to 75 ^{o}C, while the spent liquor is heated to about 88 ^{o}C.

The cooled aluminate liquor flows into storage tanks from where it is pumped into the first tanks of the precipitator tank lines.

The heated spent liquor flows similary into a storage tank. One part of it is pumped to the 1st washing stage of the red mud washing line, while the second part into the spent liquor storage tanks of the evaporation plant unit and the third part into the test tanks.

Precipitation, hydrate classification

Precipitation of the dissolved Al_2O_3 from the cooled aluminate liquor in the form of crystalline alumina hydrate is carried out continuously in series connected,air agitated precipitator tanks with conical bottoms. Eack tank line consists of 11 series-connected tanks from which 1 holding tank in each line serves as spare. Holding tanks will store hydrate during maintenance of the calcining kilns.

The cooled aluminate liquor as well as the coarse and fine seed introduced into the first tanks passes through the tank line in about 40 hours, during which period hydrate precipitates from the aluminate liquor and agglomerates to the required grain-size.

In order to ensure better precipitation efficiency the slurry leaving the third tank of the series is cooled by water by about 5 ^{o}C in heat exchangers.

A three-stage classification serves to separate from the precipitated hydrate slurry the coarsest grained product hydrate and the finer hydrate fractions which are recycled as seed.

The hydrate classification system consists of primary thickeners, secondary thickeners and tray thickeners.

The precipitated slurry flows from the last tank of the precipitator lines through a channel system into the primary thickeners which separate the product hydrate. The overflow enters through a channel system the secondary thickeners which separate the coarse seed, while the underflow and the injected alkaline hydrate wash water is transported by pumps into the hydrate storage tanks.

The coarse seed from the underflow of the secondary thickeners is injected by aluminate liquor, pumped into the secondary thickener underflow tanks and from there into the first tanks of the precipitation line.

The overflow of the secondary thickeners flows through a channel system into the tray thickeners. The overflow of the hydrate holding and storage tanks is fed into the same tray thickeners.

The underflow of the tray thickeners - the fine seed - is pumped to oxalate removal. The seed returned from there is charged into the first tanks of the precipitation lines.

The overflow of the tray thickeners - the spent liquor - flows into the tray thickener overflow tanks and then is pumped into the plate heat exchangers.

A caustic descaling system is designed to quickly remove scales formed in the precipitation and classification tanks and piping.

The product hydrate is filtered on pan filters. The first filtrate is pumped into the underflow of the primary thickeners. The filtered hydrate is washed on the surface of the filters in two stages by warmed-up alkaline evaporator condensate and is transported by belt conveyors to the calciners.

To remove sodium oxalate the fine seed or a fraction of it is filtered, washed with hot water which dissolves the oxalate and then refiltered. The filtrate is treated with lime slurry to form calcium oxalate. The obtained slurry is settled, the liquor is pumped to the red mud washers and the thickened calcium-oxalate slurry is delivered to the red mud pond.

The oxalate-free fine seed is slurried with aluminate liquor and recycled into the fine seed storage tanks.

Evaporation

Evaporation is carried out in a quintiple effect evaporator. Spent liquor heated up in the plate heat exchanger is pumped into spent liquor tanks from which the evaporator is supplied.

From the evaporator liquor is pumped into the strong liquor storage tank, from which it is fed into the test tanks.

The mixture of spent, strong and make-up caustic liquor is delivered from the test tanks into the tube and shell heat exchangers of the digestion by centrifugal pumps.

The pure condensate of the evaporator is pumped indirectly to the power plant, while the alkaline condensate formed from secondary vapours is used for hydrate and red mud washing.

Calcination

The filtered and washed hydrate is calcined in fluid-bed /flash/ calciners.

The calciners are fired by fuel oil. The calcined alumina is cooled by water in fluid coolers and it is transported pneumatically into the alumina silo.

During the repair or maintenance work of the kiln excess hydrate is stored in the last tanks of the precipitator tank line.

Lime burning and slaking

Lime consumption of the alumina plant is fulfilled by burning limestone. Burnt lime is transported into the lime slaking drum. Lime is slaked with hot water. Lime slurry containing 200 g/l CaO is pumped into the storage tank; the required quantity of lime slurry is pumped into the individual plant units through a recirculating loop.

Caustic storage

Caustic soda losses of the process are made up by a 50 per cent NaOH solution. Caustic arrives by ships at the port, it is discharged and fed by pumps into the storage tanks.

The liquor is pumped from the storage tanks partly for descaling purposes into the various equipment, partly as a make-up into the test tanks.

Fuel storage

Fuel oil arrives by ships to the port where it is discharged and fed by a pump into the storage tanks in which one week's fuel requirement is stored. Fuel oil will be pumped to the daily fuel tanks of the power plant, calcination and lime works.

Alumina storage

A 50,000 t capacity silo is provided. Alumina is transported by belt conveyor to the ships.

Compressor station

Compressed air is supplied by turbocompressors at a max. 0.7 MPa pressure. Air dryer units located in the compressor house provide proper air quality for the pneumatic instruments.

Power plant

Steam is supplied by a power plant characterized by the initial parameters of 6 MPa and 480 °C. Overheated steam is produced in 3 residual fuel oil fired boilers and expanded in extraction/backpressure turbines. The 1 MPa steam requirement of the digestion is covered by extraction, the 0.6 MPa steam for evaporation and other plant units by the back-pressure of the turbines.

The power plant produces as much power as corresponds to the technological steam consumption, the balance is taken from the national grid.

Process control

Process control system of the Alumina Plant is composed of analogue electronic measuring control loops. Control is effected by servomotors using pneumatic auxiliary power. The control system is supplemented with a low performance digital computer for data logging and techno-economic calculations. The number of measuring and control loops has been determined so as to enable the plant to meet up-to-date operational requirements. Six decentralized control rooms are established throughout the plant comprising the central instruments of 2 or 3 plant units each.

Laboratory

The laboratory is equipped and instrumented to carry out the work enlisted below:

Analysis of raw- and auxiliary materials and quality control of the final product.

Systematic analysis of samples /liquors and slurries/ taken

from various points of the process circuit.
Research activity for technological development.

Red mud pond

The specific quantity of dry red mud amounts to about 1.25 ton per ton of alumina and its average moisture to 50 per cent which give a storing capacity requirement of 1.6 m^3/t of alumina.

Red mud is pumped into the storage area, the pipeline is constructed to make possible uniform, complete filling up of the area. Dams for the red mud storage area are made of local material.

Water is recycled from the clear upper zone of the pond to the alumina plant.

Water economy

Part of the fresh water is passed through a purification plant to the drinking water network, the rest is pumped to the industrial water softening plant.

Cooling water requirement is satisfied by a recirculating cooling water system. The cooling facilities are forced ventilated, cross-stream water film units with steel structure.

Alkaline contaminated rainwater is separated from the rest, collected in an alkaline rainwater reservoir and used for technological purposes.

Rainwater from other areas /roads, pavements, roofings, etc./ is drained to the collecting ditch at the periphery of the plant.

DESIGN PARAMETERS

Production

Alumina production,	tpy	500,000
Hourly design rate,	t	62.5
Design operating factor,	%	92.0 /8,000 hrs/year/

Bauxite
/average sample/

Al_2O_3; total,	%	48
in gibbsite,	%	40
in boehmite,	%	4
SiO_2 ; total,	%	3
in kaolinite,	%	2
in quartz,	%	1
Fe_2O_3,	%	25
TiO_2,	%	3
P_2O_5,	%	0.1
V_2O_5,	%	0.1
Organic carbon,	%	0.2
L.O.I.,	%	23.
Free water in wet bauxite, /year's average/	wt%	9
Lump size of ore,	mm	max.30

Grinding, predesilication

Solids content,	g/l	600
Lime added,	% of dry bauxite	0.1
Predesilication holding time,	hrs	8
Predesilication temperature,	^{o}C	100
Test tank liquor caustic Na_2O,	g/l	140
Test tank liquor caustic molar ratio		2.8
Temperature of grinding liquor,	^{o}C	106

Digestion

Temperature,	^{o}C	140
Holding time at 140 ^{o}C,	hrs	0.5
Digestion efficiency for gibbsite,	%	98
Soda losses at digestion:		
for reactive silica,	$kgNa_2O/kgSiO_2$	0.69
carbonation,	$kgNa_2O$/t dry bauxite	0.5
Bound in other salts,	$kgNa_2O$/t dry bauxite	0.9
Digestion residue,	t mud/t dry bauxite	0.5
Sand/mud,	%	5
Mud specific gravity,	g/cm^3	3.5
Final caustic molar ratio,	caustic Na_2O/Al_2O_3	1.4

Red mud settling, washing

Caustic Na_2O content of the settler overflow,	g/l	105
Molar ratio of the settler overflow,	g/l	1.55
Solids content of the settler underflow,	g/l	500
Solids content of the washer underflows,	g/l	500
Flocculant addition to settler,	g/t dry mud	50
Flocculant addition to washers,	g/t dry mud	60

Settling temperature,	°C	102
Temperature of interstage causticizing,	°C	85
Retention time at causticizing,	hrs	2
Lime addition,	kgCaO/t alumina	3
Temperature of red mud wash water,	°C	80
Wash water for sand washing,	t/t	3
Moisture of sand,	%	30

Control filtration

Flow rate,	m^3/m^2h	0.5
Lime precoat,	kg/m^3 aluminate liquor	0.2

Heat Interchange

Aluminate liquor,	°C in	99
Aluminate liquor,	°C out	75
Spent liquor,	°C in	65
Spent liquor,	°C out	88

Precipitation

Aluminate liquor:		
Caustic Na_2O,	g/l	105
Caustic molar ratio		1.55
Causticity, caustic Na_2O/total Na_2O,	%	0.88
Average seed ratio		1.0
Holding time,	hrs	40
Molar ratio of spent liquor		2.8
Mid-stage cooling of precipitators,	°C	5
Solids content as $Al/OH/_3$ in tray thickener overflow,	g/l	1.0
Various dilutions,	t water/t alumina	0.5

Product washing and calcination

Moisture of product hydrate,	%	12
Wash water to filters,	m^3/t alumina	0.6
Na_2O in alumina,	%	0.4
Kiln and loadout losses,	% of product	0.5
Product purity,	%	99.4

/calculated on an ignited basis/

Evaporation

Evaporated water,	t/t alumina	4.2

Oxalate removal

Wash water,	m^3/t alumina	0.4

6. LOCATION AND LAYOUT

The location of the alumina plant must carefully be selected, based first of all on the aspects discussed in details in Volume 2. The aptitude of the selected territory, its eventual slope - which may be even advantageous as regards layout of the plant - the soil structure, connections of the territory with the transport and storage facilities of bauxite, auxiliary materials, products and wastes /principally red mud/ are all important factors in selecting an adequate location for an alumina plant.

Expropriation costs of the territory belonging to the investment costs, or its rent, being part of the production costs can not either be neglected in certain cases.

The most important aspect is to transport the bauxite from the vicinity of the alumina plant, if possible, consequently the plant is generally located close to the bauxite mine or, in case of sea transport, close to the port. This way the transportation costs of bauxite of 2 to 3 times greater weight than the product alumina can significantly be reduced.

Obviously, another important aspect is that the product alumina should not be transported to a long distance from the plant. Consequently, the plant should be located close to the port or railway or a good quality high road /Almásfüzitő-Tatabánya/.

Transportation of other materials necessary to the alumina production - first of all the fuel oil amounting about 40 per cent, and caustic soda of about 10 per cent of the weight of alumina - can not be neglected, either. In case of power plant based on coal, the transportation possibilities of coal must also be reckoned with. Here it is mentioned that, though the red mud pond can be situated even 5 to 10 kms off the plant, its subsoil must also be carefully selected in order to prevent environment contamination by the leakage of alkaline solution. However, the long distance of the red mud storage from the plant requires excess pipeline and pumping capacity.

In case of locating the plant at the port, alumina leaving and the fuel oil and liquid caustic soda arriving in tankers require all the necessary facilities for loading in and out and for storage.

Due to the above facts, locating the alumina plant is a difficult task which can only be solved by taking the local conditions, the alumina production technology and the transportation possibilities into consideration simultaneously.

According to the above considerations it is expedient to carry out preliminary soil mechanics investigations on the selected place. Loose soil e.g. requiring piling may significantly increase the investment costs.

Layout of the plant units and auxiliary shops on the selected area must be decided principally on the basis of the above facts but, at the same time, care must be taken to realize the most logical technological connections of the plant at the lowest possible cost requirements /e.g. minimum costs of pipe network, low pumping requirements, short cables, etc./.

Bauxite reception and storage has to be close to the place of the bauxite's arrival and the bauxite grinding and predesilication section have to be connected to it at short distance. At the same time, transport of bauxite dust by the prevailing wind to the "white" section of the plant has to be avoided. Proceeding with the layout of the plant units, the logical order of the Bayer circuit, and the shortest possible connection are further kept in view. The digestion, red mud settling and washing, control filtration and aluminate liquor cooling section have to be located subsequently. Out of these the red mud settling and washing sections should be arranged to a corner of the selected area, so that no difficulties arise in pumping the red mud to the storage area. Situating the red mud settlers and washers on a sloping area, significant electric power can be saved by gravitational transport of the overflows /Ajka/.

Aluminate liquor control filtration and cooling sections have to be located close to the precipitation and hydrate classification plant sections, which require generally considerable area and impose the highest load on the soil. Situating precipitation on a sloping area, gravitational transport of the "white" slurry can also save electric power.

Hydrate filtration must be located close to the hydrate classification plant, and to the calcining section.

The evaporation plant unit and the relevant cooling towers are located close to each other, neither forgetting that the evaporator is connected in the technological circuit to the digestion and bauxite grinding sections. Generally, liquor storage tanks are arranged so as to solve this problem.

Locating the power plant is one of the most difficult problems because the transport of combustibles /fuel oil, coal, gas/ has to be ensured on one hand, and the power plant should not be far from the major steam consuming sections, on the other hand. Especially the high pressure steam pipe connected to the digestion requires high investment costs.

Central electric distribution station supplying the whole plant must be located so that its distance from the transformer substations and the distance of the latter from the individual plant units be minimum.

The water plant has to be located close to the cooling towers, taking into consideration the distance of the water source supplying the plant. Canalization system shall comply with the natural slope of the territory.

The central workshop servicing the whole plant must not be far from the plant sections requiring the most intensive maintenance: bauxite preparation, digestion, power plant, etc.

Naturally the warehouses, the garage and the laboratories must also be located to the best suitable places.
Change rooms, bath , dining hall, management building have to be situated to close access.

In locating the instrumentation, both the central control room and the control rooms by plant sections have advantages and disadvantages. This will be discussed in details in the next chapter.

In actual designing work of layout the magnetic tables prooved suitable. It is generally expedient to elaborate more layout drafts for a plant, and to analyse them by taking their photos. Then calculations can be done relative to the total length and costs of the technological pipelines and the distances to be covered during maintenance.

Based on the layout the inside road network of the plant can also be drawn with regard to the aspects of servicing the plant units and the minimum investment costs as well. The possibilities of transporting the required minor materials /refractories, fittings, sealings, lubricants, etc./ from the store house to the plant have to be considered.

Master plot plans representing the final layout of the plant are prepared generally in 1:2000 scale and form an essential part of a Feasibility Study. An example is given in Fig.7.4.

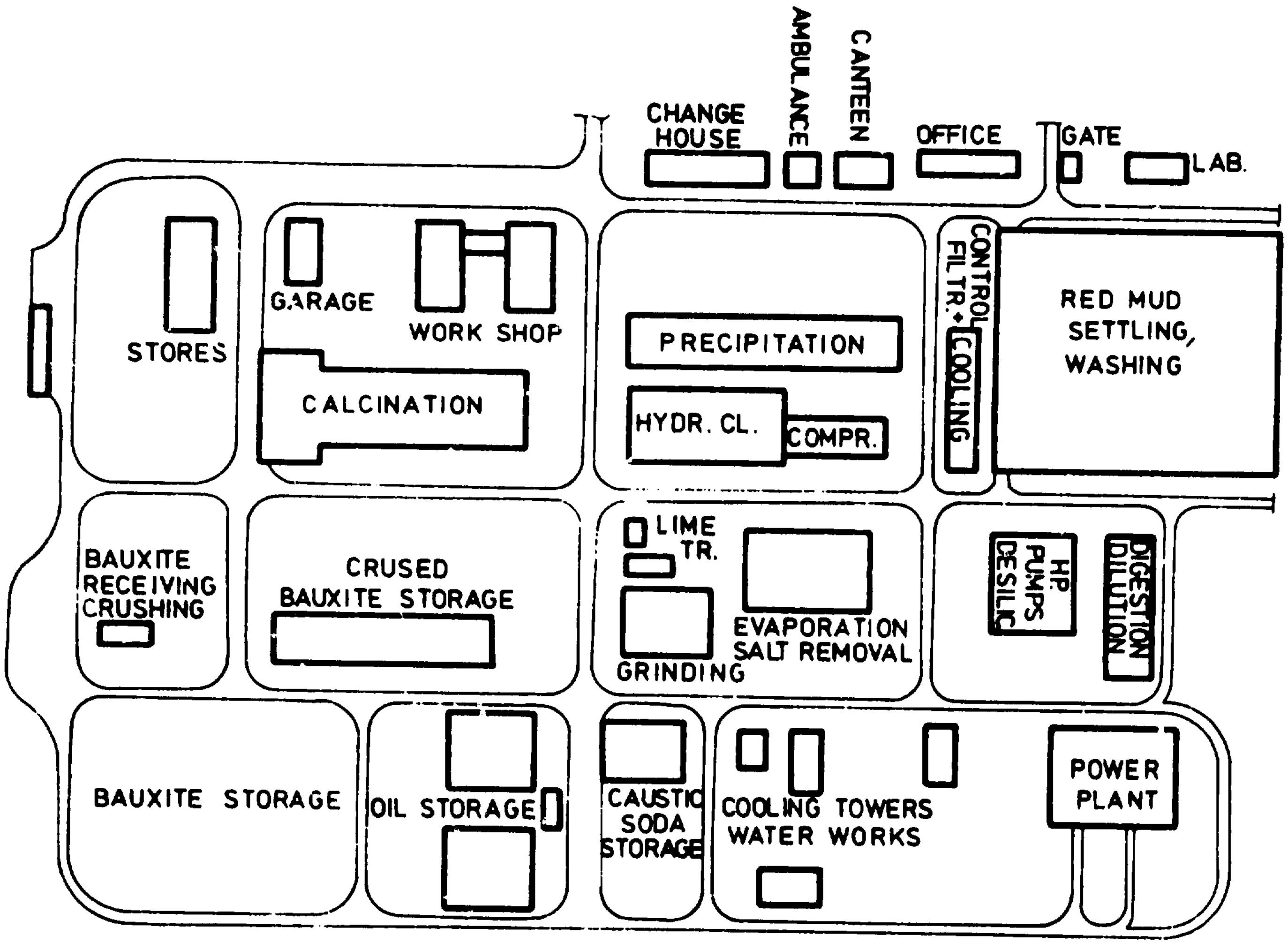


Fig. 7.4

LAYOUT OF ALUMINA PLANT

7. PROCESS CONTROL AND INFORMATION SYSTEM

The system has the following tasks:

- to control the essential parameters of the technological process maintaining the desired values
- to produce all the necessary information about the process based on measured data
- to signal and record the extreme values of the measured parameters
- to record the data of mass and energy streams, pressures, and temperatures
- to provide communication between the operational personnel and plant management.

The measuring and control system built up from electronic analogue elements makes possible the controlled run of plant units. Decentralized control rooms supervise the major technological units, collecting the information necessary for running the plant.

The central alarm systems provide information about the exceeding of extreme values of parameters. The loudspeaker system transmits orders for the operational personnel. The central data logger accomplishes the systematic logging of the data available.

The fire alarm network facilitates the quick localization of accidental fire events. The time-signalling system controlled by a central unit, the industrial TV-chain, and telephone network completes the process control system of the alumina plant.

PROCESS INSTRUMENTATION

The measuring and control loops are built up from electronic analogue transmitters, central devices, and signal converters.

The character and lay-out of technology calls for the application of sensors and final control elements of rugged construction, erected under the open air. The peculiar characteristics of fluids to be modified require the use of special final control elements /e.g. high pressure drop in control valves handling flashing slurries, erosive slurries with considerable flow rates in pipelines, etc./.

The central elements of measuring and control loops - controllers, receiver instruments, recorders etc. - will be mounted on the panels of control rooms. The control rooms are air-conditioned, double-floored with double doors.

DESCRIPTION OF A PROCESS CONTROL SYSTEM

Grinding

Ratio control loops provide the quantitative ratio control of bauxite to liquor in the mill. A separate ratio control loop controls the liquor fed after the mills, in the function with the total bauxite flow. The levels of mill slurry tanks and bauxite slurry tanks are controlled.

Predesilication

In order to ensure the required molar ratio after digestion, the adjustment of bauxite to liquor ratio is controlled before digestion. The control loop for regulating the adjusting liquor is constructed to take into account the slurry flow rate of the digester lines, the concentration and flow rate of the adjusting liquor, and in addition, the lab analysis data feedback of the slurry samples taken at the end of digester line. The latter discrete data are fed manually into the loop. The level of slurry tank which feeds the slurry pumps is controlled, too.

Pump Station

The slurry pumps are provided with rotary speed regulation by thyristor control units. Pressure measuring loops are established, and interlocked with the overpressure protecting system of pumps.

Digestion, Dilution

The flow rate of slurry fed into each digester line is measured. Temperatures of digester lines are checked by multi--point recorders. Temperature and pressure control loops hold the two important parameters constant. Flash tanks are supplied with level control loops. Conductivity measuring loops ensure purity of condensate water fed into the Power Plant. Control loops are designed to maintain specific gravity of slurry and to control the level of pure condensate receivers, diluting tanks, second washer overflow tanks, etc.

Red Mud Thickening and Washing

Settlers and washers are provided with transition zone level control loops. The turbidity of settler overflow is continuously measured. The wash water flow is controlled, the flow controller is tracking the signal coming from the level indicator of the causticizing tank. The levels of transition zones of settlers and washers, the overflow tanks, and wash water tanks, are controlled.

Control Filtration

The operation of filters is accomplished by interlocked and remote controlled on-off valves. The tanks are provided with level measuring loops.

Heat Exhange

The plate heat exchangers have overpressure protection on both sides. Pressure control loops are built up, interlocked both at the aluminate liquor and spent liquor inputs. The aluminate liquor - delivered to the precipitator lines - is flow-controlled. A cascade control loop may be formed using the level signal of the cooled aluminate liquor to be tracked.

The pressures of aluminate and spent liquors, and the level of the cooled aluminate liquor tanks are controlled.

Precipitation

The pressure of agitating air is controlled, its flow rate is measured. Temperature of interline cooling is maintained by a control loop. Hydrate level is measured in the hydrate storage tanks. The underflow density of hydrate storage tanks is controlled.

Hydrate Classification

The primary and secondary thickeners are provided with hydrate level measurement and underflow density control. The required seed hydrate flow rate is adjusted.

Hydrate Filtration

Hydrate level measuring loops measure the height of hydrate in the storage tanks.

Control loop maintains the balance between the hydrate filtration production and calcination consumption taking into account the flow rate and density of hydrate slurry to be filtered, and the mass flow of hydrate to be fed into calcining kilns. The flow rate of hydrate slurry is controlled.

Calcination

The fluid-bed type calcining kilns are delivered with complete process control system. The plate heat exchangers are protected against overpressure at both sides.

The water tanks and soft water tanks are provided with level control loops.

Evaporation

The evaporators are supplied with measuring and control loops specified by the manufacturer, e.g.: evaporator body level control loops, spent liquor feed-flow control loops, flash tank level measuring loops, concentration measuring loops. Ratio control loop performs the appropriate mixing of spent and strong liquors. The continuous measurement of test tank liquor concentration supplies the signal to be tracked. Conductivity measurements protect the quality of pure and alcaline condensates.

Salt Removal

The pressure filters are provided with independent automation. The technological unit is provided with tank level measuring loops and a temperature control loop.

Lime Slaking

Density control loop keeps constant the lime milk density. Samples are taken continuously from the delivery pipe of the pump. A nuclear density gauge measures the recirculated sample, while a control valve modifies the water fed into the pump suction pipe.

Summary

The process control system of an alumina plant may contain not far more than 300 measuring and about 265 control loops.

8. NON-TECHNOLOGICAL UNITS

SUPPLY OF ENERGY

Several possibilities for the heat and electric energy supply of the alumina plants exist, depending on the applied technology and surroundings of the site taking in all cases the economy into consideration.

a/ Purchased steam and electric power /Fig.7.5.a/

In case a communal or heat-supplying power plant operates in the close vicinity /2-3 kms/ of the site, there is an opportunity for direct purchase of both the steam and electric energy. In this case, pipe line for the steam supply and a reception station for the electric energy supply are to be built /e.g. Ajka Alumina Plant/.

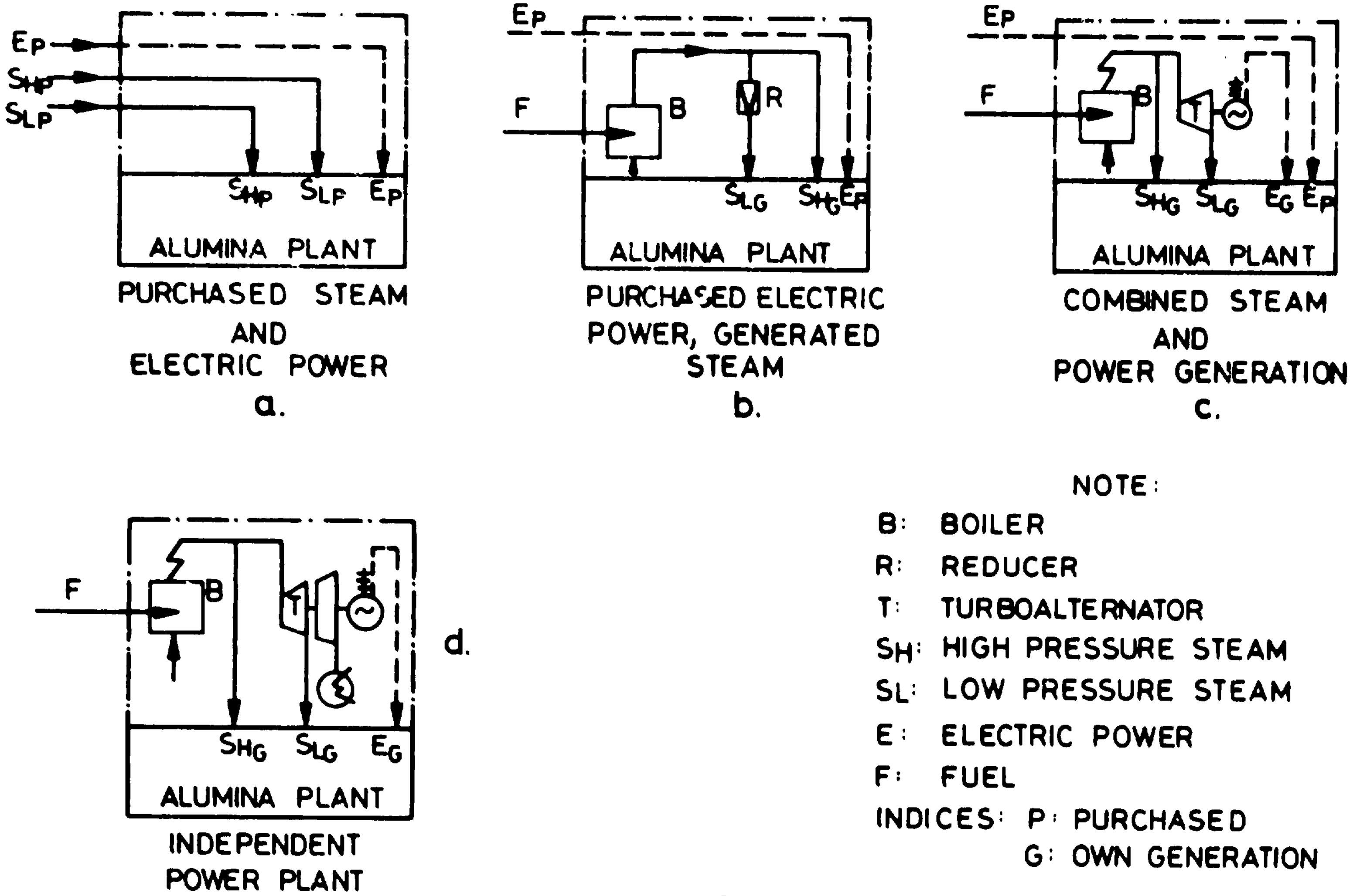
If a reliable electric energy network exists at the site, it is expedient to supply, from it the electric energy requirement of the plant. Based on economic considerations, choice should be made between two basic variants:

b/ Purchased electric energy and own steam production /Fig.7.5.b/

Total electric energy requirement of the plant is covered from the national grid. For steam supply a boiler plant is constructed for the pressure required by the digestion technology. Heat requirement of evaporation and other processes is covered from this steam by pressure reduction /e.g. Korba/.

c/ Combined heat- and electric energy production /Fig.7.5.c/

A power plant is erected in the territory of the plant for own electric energy production by a back pressure turbine. This variant makes possible to utilize part of the technological steam /mainly that used for evaporation/ for electric



PURCHASED STEAM AND ELECTRIC POWER

a.

PURCHASED ELECTRIC POWER, GENERATED STEAM

b.

COMBINED STEAM AND POWER GENERATION

c.

d.

INDEPENDENT POWER PLANT

NOTE:

B: BOILER
R: REDUCER
T: TURBOALTERNATOR
S_H: HIGH PRESSURE STEAM
S_L: LOW PRESSURE STEAM
E: ELECTRIC POWER
F: FUEL
INDICES: P: PURCHASED
G: OWN GENERATION

Fig. 7.5

VARIANTS OF HEAT AND ELECTRIC-ENERGY SUPPLY OF ALUMINA PLANTS energy production. Only the difference has to be purchased from the national grid /e.g. Almásfüzitő, Obrovac Alumina Plants/.

In case of low temperature digestion technology the total electric energy can be produced in the plant, if adequate boiler pressure is selected, and an extraction/back-pressure turbine is installed. The national grid in this case serves only for compensating the load fluctuations, and for providing emergency energy in case of break-down.

The increase of energy costs works in favour of variant c/ because the combined process makes possible cheap energy production, thus compensating economically the excess investment required.

d/ Independent power plant. /Fig.7.5.d/

In case the alumina plant is located to a site where the national grid is not reliable or available, an independent power plant has to be established.

In this case the power plant is basically the same as that described under point c/, with the supplementation that the electricity requirement exceeding the capacity of the back-pressure or the extraction back-pressure plant has to be produced by the installment of a condensing turbine.

In this case higher spare capacity has to be provided for the safe energy supply of the alumina plant, moreover a Diesel aggregate for emergency energy in case of power plant breakdowns, and for re-starting the power plant has to be installed.

DISTRIBUTION OF ELECTRIC ENERGY

The electric energy requirement of the alumina plant is produced in its own power plant and/or is taken from the national grid.

In the combined system the medium voltage e.g. 6 kV busbar of the power plant switch gear is fed by the turbo-alternator. This can be interconnected to the national grid e.g. by a 70/6 kV transformer.

For electric energy distribution, two voltage levels can be selected. For medium voltage e.g. 6 kV insulated system, for low voltage a 380/220 V direct earthed system may be chosen.

Motors of the heavy-duty machinery and equipment consuming electric energy above 160 kW are generally directly connected to the medium voltage, e.g. 6 kV switchgears. Such machinery and equipment are e.g.: compressors, feeding pumps of boilers, pumps of aluminate liquor cooling, control filtration, hydrate classification and filtration, and water works. Motors of 90-160 kW load are fed by the 0.38 kV switchgears of the 6.6/0.38/0.22 kV transformer stations, while smaller motors are supplied by indoor plug-in motor control centres. Transformers are located outdoors, the 0.38 kV switchgears indoor in the switching houses of the transformer stations.

Consumers are connected to the power supply system by junction boxes, and safety push button stations are required in the plant for their operation. Control rooms of the plant are provided with control desks, containing control and locking devices.

Cabling throughout the plant consists of an overhead system with cable racks mounted possibly on pipeline supporting system.

ILLUMINATION

In up-to-date plants on-off switching of the yard area illumination is effected by photoelectric switches operating on 20 Lux. Yard area and some plant departments are illuminated by mercury vapour lamps, other departments by electric bulbs. Illumination system is fed by two independent sources.

POWER FACTOR CORRECTION

Power factor correction of the 6 kV system is performed by turbogenerators and synchronous motors, that of the 0.38 kV system by capacitors linked to the busbars of the transformer stations.

CONTACT PROTECTION AND LIGHTING PROTECTION

Earthing network of steel strips and pipe electrodes are set up within the plant area.

In the 6 kV system, consumers' body is linked to the earthing network.

Medium voltage system equipment is protected by a selective earth-fault protection, while 380/220 V system is earthed directly.

For portable lamps a 24 V safety system is used.

All outdoor steel tanks, columns, pipelines, steel structures of buildings are connected to the protective earthing network.

COMPRESSOR STATION

Compressed air requirement of the alumina plant is met by turbocompressors operating at 7 bars pressure. Air requirement depends mainly on the precipitation system used. Normally two compressors are installed, one in operation, the other a standby. Compressors are provided with coolers, lubrication and automation.

For air supply of pneumatic instruments air drier units are mounted.

LABORATORY

Up-to-date control of the process circuit is the precondition of proper running of the alumina plant.

The task of the laboratory is:

- collection and preparation of representative samples at prescribed places, in adequate quantity any frequency;
- chemical and physico-chemical investigation of the samples;
- registration of all analysis data in log-sheets;
- performance of technological control tests and research work at particular points of the process in order to clarify special problems arising in the plant;
- checking of measuring instruments installed at particular points of the process.

WORKSHOPS, STORES, GARAGE

The farther the alumina plant is situated from other chemical plants, the more the necessity of having its own workshop arises. The staff of the plant maintenance can amount up to 40 per cent of the total personnel requirement of the alumina plant and can be reduced only if outside contractors are available in the vicinity.

Normally, a central workshop is built, consisting of 2 to 6 halls, and provided with cranes, offices, social premises and an adjacent open-air mounting area.

The halls accomodate maintenance groups for:

- machinery and equipment
- buildings and contructions
- electricity, instrumentation and control
- repair of vehicles.

Stores are built for maintenance and building materials, spare parts, hazardous materials, gas cylinders, chips and waste.

SAFETY PROVISIONS

Adequate safety equipment has to be installed throughout the plant. Staircases and guard rails are installed in such a manner as to ensure speedy exit from dangerous areas.

The most important safety equipment installed at different points of the plant are: safety showers, eye-wash fountains, strechers, etc.

9. STANDARDIZATION

Three main groups of alumina plant equipment can be distinguished:

1. "Standard equipment" means all equipment produced in mass by several manufacturers throughout the world, having specific dimensions of components to allow for easy interchangeability.
2. "Non Standard Equipment" means equipment produced by certain specific manufacturers and having components which are not easily inter-changed by components from other manufacturers.
3. "Proprietory Equipment" means equipment designed and manufactured solely by the Contractor and/or its Sub-Contractors and manufactured by agents, under licence of the Contractor and/or Sub-Contractor.

Standardization refers mainly to the machinery and equipment belonging to the first group. These are: pumps, electric motors, driving units, rubber belt- and apron belt- conveyors, valves and fittings, vehicles and lifting devices, etc. A large number of these machinery and equipment is installed in almost all sections of the alumina plant.

Based on the analysis of the material balance of the alumina plant it can be stated that the quantity of the transported, handled, stored or controlled materials ranges from some cubic meters or tons to several thousand cubic meters or tons. Insisting on selecting the above machinery and equipment in strict accordance with the quantities found in the material balance when designing the alumina plant would necessitate the selection of a large number of machinery and equipment of different parameters. Though this solution would give the minimum of investment costs, experience proves, however, that more favourable results are attained even as regards the investment costs in case of purchasing more units of identical type of equipment from the same producer. Therefore it is reasonable to divert from meeting the exact requirements stated in the material balance, and to determine standard ranges of performance which make possible the instalment of a reduced number of types of machinery and equipment. The use of these machinery and equipments types is advantageous principally during operation, because a higher safety can be achieved with less spare parts. Maintenance costs are also more favourable: fewer types of machinery and equipment can be maintained with lowe investment cost.

Machinery and equipment of the second and third group serve for special technological processes of the alumina plants. They are generally used is small numbers, and their use is restricted to individual plant sections. These equipment are: mills, digesters, settlers, calcining kilns, evaporators, etc. Standardization of these machinery and equipment can principally be of interest in connection with capacity extensions, when it is expedient to install the same type of new equipment as the existing one.

Beyond the advantages discussed in the above, the installment of the same type of machinery and equipment as the existing one has a further advantage, namely that the operators do not need training, the machinery or equipment can be put on stream without troubles in the operation.

10. INFRASTRUCTURE AND SOCIO-ECONOMIC ENVIRONMENT

Beyond the industrial development policy of the state and the location of the raw material sources and of the plants processing the final products, in selecting the site of the alumina plant the local conditions, namely the infrastructure and the socio-economic environment have to be considered also.

INFRASTRUCTURE

The indispensable precondition of establishing and operating a plant is the existence or realization of the infrastructure, energy supply, transport facilities, water supply, communication and housing colony.

When selecting the site of the plant, first of all the possibilities of the energy supply have to be studied. The operation of the alumina plant requires about 3 t/t steam and about 300 kWh electric power per ton of alumina. In the chapter on Non-Technological Units, the four main variants of energy supply have been discussed in detail. The selection of the optimum variant is always based on economic calculations.

Transport of materials used for alumina production and of the final product/s/ leaving the plant can be done on road, railway or water. When selecting the site, it has to be studied whether the existing lines are suitable for transport as regards load bearing capacity, utilization of capacity, availability of loading and unloading equipment, storage and expansion possibilities.

In case of river transport, the fluctuations of the water level have to be taken into consideration in order to determine the maximum draft of the ships to be used.

In case of sea transport, the water depth of the existing port and its dredging conditions, ebb and tide levels and weather conditions partly determining the size of the ships have to be investigated. If the port has to be closed temporarily due to certain weather conditions, this has to be taken into account when determining the storing capacities for the materials and products.

Transportation problems of the operating plant, and those arising in the course of construction, erection and mounting have to be solved.The outline dimensions of the equipment and the weight of the biggest machine must be known, and the suitability of the existing roads /e.g. existence of sharp curves/ for the transport of the machinery and equipment to the plant has to be investigated. Prescriptions for the transport of equipment with great dimensions have to be studied. For railway and river transport, the prescriptions and the existence of adequate loading and unloading facilities at the station or port and of the connection between the railway or the port and the public road must also be checked.

Water requirement of the alumina plant, 4 to 6 m^3/t alumina, for technological, cooling and social /bath and drinking/ purposes is quite significant. The availability and quality of water from surface or underground sources has to be checked and the costs of water extraction and treatment have to be determined.

Communication possibilities of the site - existence of telephon and telegram network - is also an important factor. Their existence on the area is advantageous during the construction period, as in opposite case provisions have to be established involving higher investment costs.

Existence or proximity of a housing colony means that the necessary labour is available during construction, erection and mounting as well as during operation period. If this is not the case, still the necessary social establishments /shops, sport- and cultural facilities, communication, etc./ are partly available for the work-force resettled from rural areas, and this means an other reduction possibility of the investment costs.

SOCIO-ECONOMICAL ENVIRONMENT

In the frame of socio-economic environment, geographical and climatic conditions, waste disposal availability of labour, of local contractors, legal questions, and other questions posed by the owner have to be studied.

In the frame of geography, data relative to the following information have to be collected: altitude of the territory above sea level, its configuration, slope, loadability, composition, earthquake frequency, etc. These factors can affect considerably the costs of investment. Uneven configuration may raise the costs of terrain correction, a poor load bearing capacity or frequent earthquakes require special foundations. In case there is no impermeable layer in the soil, the red mud disposal can be realized only applying artificial insulation. Sometimes, slope of the territory can be advantageous in locating certain plant units /see in Chapter on location and layout/.

As regards climatic conditions, characteristics of the territory such as wind, precipitation, temperature have to be studied. In case of wind, information on the characteristic and prevailing wind directions, average and maximum wind velocity has to be collected. Wind velocities and prevailing wind directions have to studied in connection with disposal of materials emitting dust, from environmental protection point of view. The role of the wind can not be neglected in compiling investment costs, either; in case of high wind velocities excess investment costs have to be taken into account, especially for the high buildings.

As regards precipitation, annual average, maximum and minimum values have to be studied and compared to the corresponding data of the natural evaporation from the territory. On areas where the annual precipitation is restricted to a shorter period of the year /monsoon period/, it is reasonable to make provisions for separate drainage of the precipitate water, thus avoiding excess evaporation of the precipitation water and saving evaporation steam.

The proportion of precipitation and natural evaporation can affect the water requirement, too. In tropical regions the quantity of recycled water from the red mud pond is the function of the natural evaporation. In case of higher rate of evaporation, the make-up water requirement increases, and it decreases in monsoon periods.

Knowledge of the annual average, maximum and minimum values of temperature is necessary from the point of view of technology and of the protection of personnel.

During erection and mounting of the alumina plant, contractors, skilled workers and different maintenance work are necessary. It has to be investigated cautiously, whether contractors are available in the vicinity, what is their quality, and their facilities and whether the labour necessary to the operation is available. The part of the maintenance work that can be assigned to constractors has to be estimated. All these questions make necessary to investigate fiscal and legal regulations, right of labour, as working time, overtime, service requirements, as supply of electric energy and water, dining possibilities, boarding prescriptions, transport of labour force, etc.

Parallel to the more and more strict environmental prescriptions, disposal and devastation of wastes have to be considered.

11. FINANCIAL AND ECONOMIC EVALUATION

The time horizon of the financial and economic evaluation is the life of the Project, determined by the useful life of the main equipment and, sometimes, by the quantity of bauxite reserves, too. In case of alumina plants the life of the Project is usually 25 to 30 years. Therefore a dynamic calculation is necessary, which has the drawback that cost and profit data emerging in different points of time can not be compared directly, they have to be transformed for the point of time at which the implementation of the Project starts, by discounting methods. The result of the calculation gives the net present value /NPV/ of the project. The project is profitable in case the NPV is positive. For the measurement of the exact profitability of the project, the internal rate of return /IRR/ is used.

CAPITAL COST ESTIMATES

The capital cost is divided into three major categories, namely:

- Direct Costs
- Indirect Costs

The sum of the two is the fixed capital constituting the resources required for constructing and equipping an investment project.

- Working Capital Costs

Theycorrespond to the resources needed to operate the project.

DIRECT COSTS

Costs of Building and Construction Work

are based on complex final unit prices obtained from the Owner during construction of other alumina plants, and gathered in the course of designers' and contractors' consultations. The most important and most frequent items are as follows:

- Earthmoving
- Concrete
- Reinforced concrete
- Buildings
- Roofing and siding
- Steel structures
- Heavy and light road constructions
- Railroads
- Construction and sealing costs of red mud pont, etc.

Costs of Erection and Mounting of Machinery and Equipment

These costs are estimated on the basis of manhour requirement and on average hourly wage of erection and mounting. The manhours are determined from experience gained during the construction of other alumina plants and from data obtained from the suppliers of the main equipment.

The corrected total manhours are then multiplied by the average hourly wage of erection and mounting.
Other costs included in this category are:

- Auxiliary mounting material cost
- Renting fees for mounting machinery
- Vendor's mounting managerial costs
- Vendor's mounting managerial local costs

Outside battery Limits costs /e.g. Port facilities, Water intake, Pipelines, etc./.

Cost of power plant and transmission lines from the Power plant and the national grid /if any/.

Cost of acquisition, preparation and improvement of land.

Freight and marine insurance cost from imported sources to the site.

Cost of uninstalled spares.
Contingency.

Indirect Cost include the following:

- Pre-investment studies, preparatory investigations, conceptual design, tendering.
  - Cost of transfer of technology and know-how, detailed engineering design, training and tendering.
  - Cost of administration, supervision, construction management, living costs of the experts, equipment supplies and facilities for plant development.
- Bureau machines, furnishing, etc.
- Cost of start-up and complex trials.

This contains unfavourable specific consumptions, i.e. higher costs during the filling-up and start-up periods, when the Al_2O_3 is dissolved into the process stream. Additionally, part of the required seed material /alumina hydrate/ has to be purchased from external sources.

Costs of cold, and hot water running tests of equipment, electric energy, wages as well as necessary temporary solutions or modifications, and the initial filling-up of lubricants will be charged to this account too.

- Contingency
- Preliminary and capital issue expenditures.

Remark: As soon as the capital costs are summarized, an investment schedule is prepared showing capital cost emerging in half year periods.

Working capital costs include:

- Materials inventory and spare parts.

The value of the materials necessary for the continuous operation is determined on the basis of the required stock and the frequency of the supply.

- Materials in process, semifinished goods /hydrate/. On the basis of the material balance and list of equipment, the materials in process /NaOH and Al_2O_3, including Al_2O_3 in seed/ are calculated for each machinery and equipment and summarized.
  Alumina hydrate stored in the plant /if any/ is added.
- Finished goods /alumina/
- Cash on hands
- Net receivables

SOURCES AND APPLICATIONS OF CAPITAL COST

Sources and applications of capital costs are summarized for half year periods up to the point of time of commissioning of the plant. The most important items are:

Sources:

Long term loans /suppliers' credit, financial loan, etc./
Short term loans
Equity /cash/

Applications:

Fixed capital /fixed assets/

Working capital

Financing costs /current liabilities/

Sources and applications have to be distributed between local and foreign costs, too.

OPERATING COST ESTIMATES

Material Costs

In determining the material cost, the specific material consumption values as given in the material and heat balance are taken into consideration.

All prices are calculated on the basis of informations gathered from the potential suppliers, transport costs included. Bauxite price may include the cost of bauxite levy, too.

Cost of bauxite, caustic soda, fuel oil, coal, settling aid, lime or limestone and water are worked out generally as separate items of the operation costs per 1 ton of alumina and for one year. Filter cloth, grinding balls, Na_2S, H_2SO_4, lubricant, diesel oil, etc. required in the process are summed up under "other materials" item.

Cost of maintenance and repair materials are taken at say 2 per cent of the capital investment cost of the plant.

Excess costs are taken into account until the total capacity is achieved /say 3 years/ for the following specific material consumptions:

Bauxite, lime, limestone up to 10 per cent.

Caustic soda up to 20 per cent.

Fuel oil, coal up to 30 per cent.

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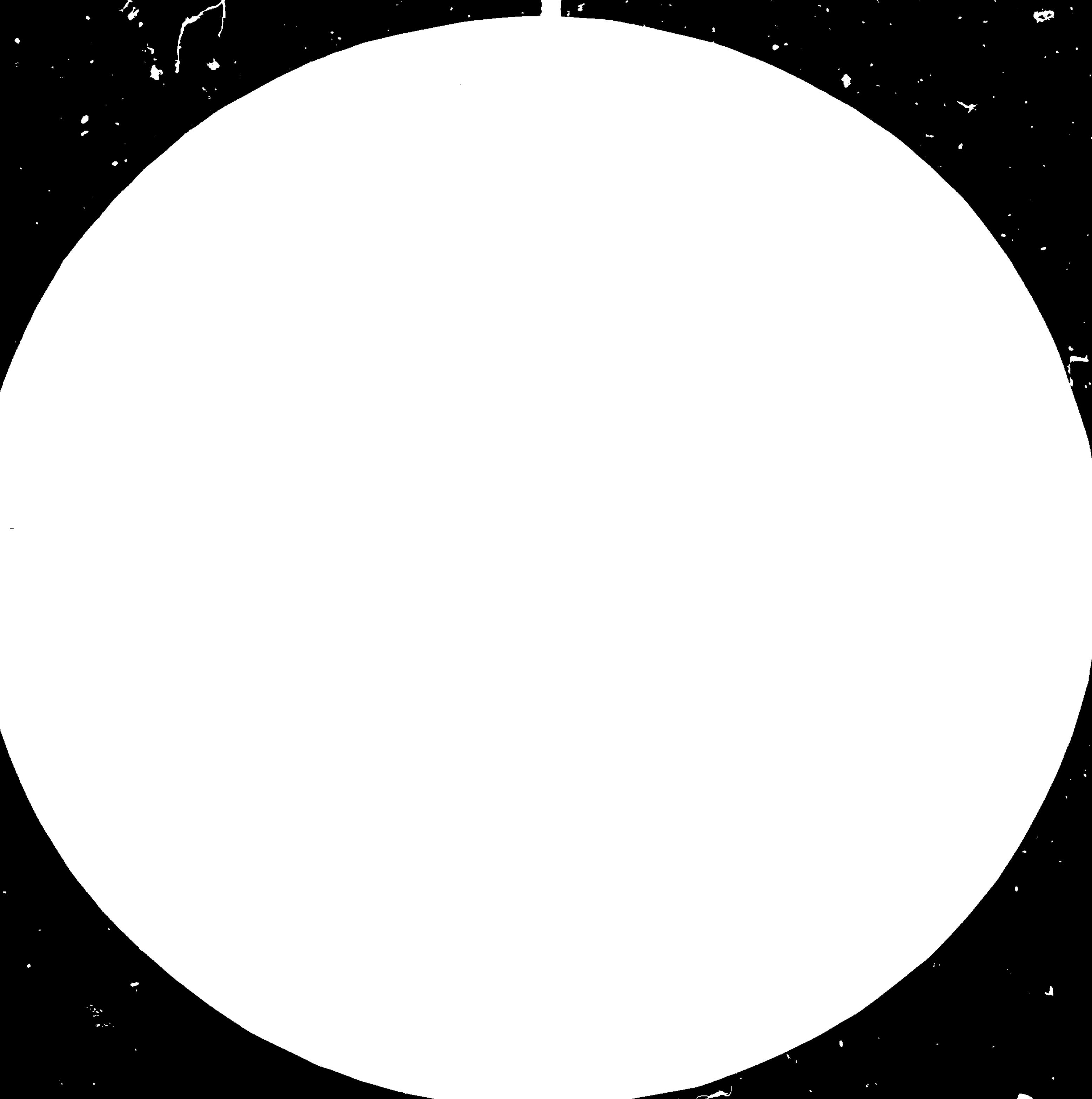

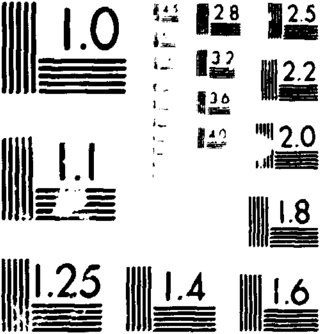
1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

The sum of the operating costs for each year is taken into consideration in the cash flow analyses.

WAGES AND SALARIES

The required number of operating personnel is planned for a modern and advanced level of technology and plant organization. The basis of the planning are generally 5 man-days per week and an 8 hour shift per day, i.e. 260 man-days annually. The wages are broken down in the following categories:

Category:

I. Technical and financial management
II. Engineers, technicians, foremen, booking clerks, officers
III. Skilled and unskilled workers
IV. Non-skilled workers

In the cash flow analysis it is assumed that the employees are required from the second half of the 4th year. As general orientation the total number of employees is estimated as follows:

Alumina production tpy	Estimated total number of employees
600,000	600
1,000,000	750
2,000,000	1,000

All wages and salaries include benefits, as NHT, pensions, NIS, Health etc.

TOTAL OPERATING COSTS

Over and above the material costs and wages, the total operating costs include:

insurance costs, say 0.5 per cent for the total invested capital, properties tax on the basis of the area and value of the land acquired, and administration costs, say 2 to 3 US $ per ton.

PROJECT FINANCING

A Feasibility Study has to be backed by the assurance that resources are available for the project if the conclusions of the study proved positive and satisfactory. Initial capital investment are covered by equity and long term loans /suppliers' credit and loan/, to varying extents, working capital requirements are met by short- and medium term loans from national bank sources. Equity is raised by issuing shares that can amount to 30 to 60 per cent of the investment.

Interest rate of long term loans is generally 9 to 10 per cent, that of short term loans above 10 per cent.

FINANCIAL VIABILITY

Sales price of alumina

As no world market for the alumina exists and consequently no world market price for the alumina is available, the expected sales price of alumina has to be estimated for the economic calculation of the project. This is made in practice on the basis of forecasts of the price of aluminium and of the exchange ratio of alumina to aluminium 5 to 6 for long term contracts, and fairly constart for longer periods of time. Besides covering operating costs the price has to support debt services and profit too. Low alumina prices have contributed significantly to the postponement of investment projects of alumina plants in the last 5 years.

DEPRECIATION

Depreciation charges are calculated on the original value of fixed capital, according to methods and rates adapted by the tax authorities of the country. They form part of the total costs, are, however, not influencing the value of cash flow, only that of the net profit before taxation.
The average depreciation time in an alumina plant is 15 to 20 years.

CAPITAL REPLACEMENT

It is calculated for the replacement of fixed assets worn off yearly in an average of 1 to 2 per cent. Besides, investment costs of periodical expansion of red mud storage are figuring also under this item.

INCOME TAX

It is determined by the law of the country and may amount to 50 to 55 per cent of chargeable income.

CASH FLOW ANALYSIS

The inflow of funds from financial resources and sales revenue must be synchronized with the outflow of expenditures and production costs.

A cash flow table has to be prepared for this purpose, particularly important in the early years of operation, when output is usually below capacity, while the burden of debt service is usually the highest. Cash flow table should be prepared for all possible alternatives of financing, indicating the amounts and timing of finance needed.

The cash flow cumulative cash balance should never become negative!

NET PRESENT VALUE

The net present value /NPV/ of a project is defined as the value obtained by discounting, separately for each year, the difference of all cash outflows and inflows throughout the life of the project at a fixed, pre-determined interest rate to the point at which the implementation of the project starts.

$$NPV = N_1 + N_2 \times a_2 + N_3 \times a_3 + \dots N_n \times a_n$$

where: N_i is the net cash flow of a project in the i^{th} year and a_i the discount factor of the same year obtained from present value tables.

The discount rate /or cut-off rate/ reflects the opportunity cost of capital, the possible return on the same amount of capital invested elsewhere. The discounting period should be equal to the useful life of the project, e.g. 25 years in case of alumina factories.

PROFITABILITY

For the measurement of the exact profitability of the project, the internal rate of return /IRR/ is used. It is the discount rate at which the present value of cash inflows and outflows is equal, and the net present value /NPV/ is zero. The procedure used to calculate the IRR is the same as the one used to calculate the NPV. The internal rate of return is calculated for both the investment /return on investment, R.O.I./ and the equity /return on equity, R.O.E./ and constitutes the best way for comparing project variants.

SENSITIVITY ANALYSIS

In the frame of sensitivity analysis, the rate of change of R.O.I. and R.O.E. is determined on the effect of revenue, operating costs, capital costs and credit conditions. Data are plotted in a spider diagram.

BREAK-EVEN POINT

The break-even point is the capacity utilization at which sales revenue and production costs match each other. As for its calculation, certain conditions should be observed /e.g. production costs are proportional to, fixed operating costs, however, independent from the volume of production; etc./ which will not always exist in practice. Data from a normal year of production are taken. The analysis of break-even point should only be considered as a tool supplementary to other evaluation methods.

12. MARKETING

Prospective upgrowth of the alumina market.
In case of alumina industry the indirect method of marketing, i.e. "assesing the current demand and projecting it into the future" is not feasible for different reasons and the forecast of the prospective upgrowth is one of the most embarrassing tasks when preparing a Feasibility Study for an alumina plant, for several reasons.

First of all the alumina market is not independent, it is connected strongly to the aluminium market and the present market policy of the latter - holding back of the investment - has a decisive influence on the alumina market too.

Besides there is no open market for the alumina, the majority of the big firms use their alumina for their own smelters and therefore the marketing and the price of alumina is determined in most cases by the business policy of the firms, first of all of the "big six". /Alcoa Alcan, Alusuisse, Pechiney, Reynolds and VAW/.

Finally the oil price raise in 1973 had a detrimental effect on the development of the alumina/aluminium idustry as the rise of oil price affected seriously the cost of production of this high energy consuming industry and raised considerably the costs of investment too.

As a consequence of the above, the average successive annual rate of increase of production of 8 to 9 per cent of the years between 1955 and 1975 came to a standstill in 1975 and the stagnation of production has continued since. The extension of the existing plants and building of new plants planned for the end of the '70-ies has been postponed with a few exceptions to the first years of the '80-ies.

According to the opinion of economic investigators, however, this recession of the increase of alumina/aluminium production is of temporary character only. Though the rate of increase of aluminium production will be less after 1980 than it was before 1975, it might rise again to about 6 to 7 per cent per year in the 80-ies and this trend will be kept up to the end of the century.

This optimistic opinion is motivated by several reasons, first of all by the fact, that the stagnation of the production is not caused by market conditions and the demands are still increasing continuously. The cautios retention of the extensions and new investments has lead to a considerable decrease of the stocks in aluminium metal even in the most industrialized countries and this is already animating the market.

Aluminium is still one of the most favoured metals due to its low price and advantageous characteristics Aluminium has high strength, low specific gravity, comparatively good resistance to corrosion and good electric and thermal conductivity. It has wide application in the building, packaging, aircraft and motorcar industries, and is widely used in the electric industry.

Comparing the increase of the aluminium production to that of the other non-ferrous metals gives a still more convincing picture of the above mentioned optimistic forecast. World aluminium production exceeded copper and zinc production, and has been keeping its second place behind steel since the early sixties.

Thus in spite of the present stagnation, the future growth of the aluminium demand at about 6 per cent rate of increase may be forecast up to the end of the century and this may form a reliable basis of alumina/aluminium marketing.

PRICE FORECAST OF ALUMINA

Another important fact affecting the alumina market is that alumina tends to get released slowly from the control of big companies. While in the early fifties only 4 to 6 per cent of the world alumina production was sold and bought at open market, this proportion has exceeded 30 per cent since, parallelly with the efforts made by developing countries possessing large bauxite reserves or abundant sources of energy to develop their national industry. Thus a more realistic world market price is expected to be formed parallelly to the increasing share of developing countries in the world market of alumina.

The realistic price of alumina in the future can be deduced from the more reliable forecasts of the price of aluminium ingot on the basis of the usual rate of exchange of 5:1 to 5.5:1.

As for the aluminium, the estimated trend of its world market price is found in Fig.7.6.

The chapter on marketing has to be supplemented with tables generally containing the following informations:

- world bauxite, alumina and aluminium production in the previous 5 to 10 years;
- latest bauxite, alumina and aluminium production capacities;
- current and planned capacity increases in bauxite, alumina and aluminium production;
- distribution of alumina production on the basis of further processing;
- inter-area seaborn trade in alumina.

All these information contributes to the reliable detection of favourable marketing possibilities of the produced alumina.

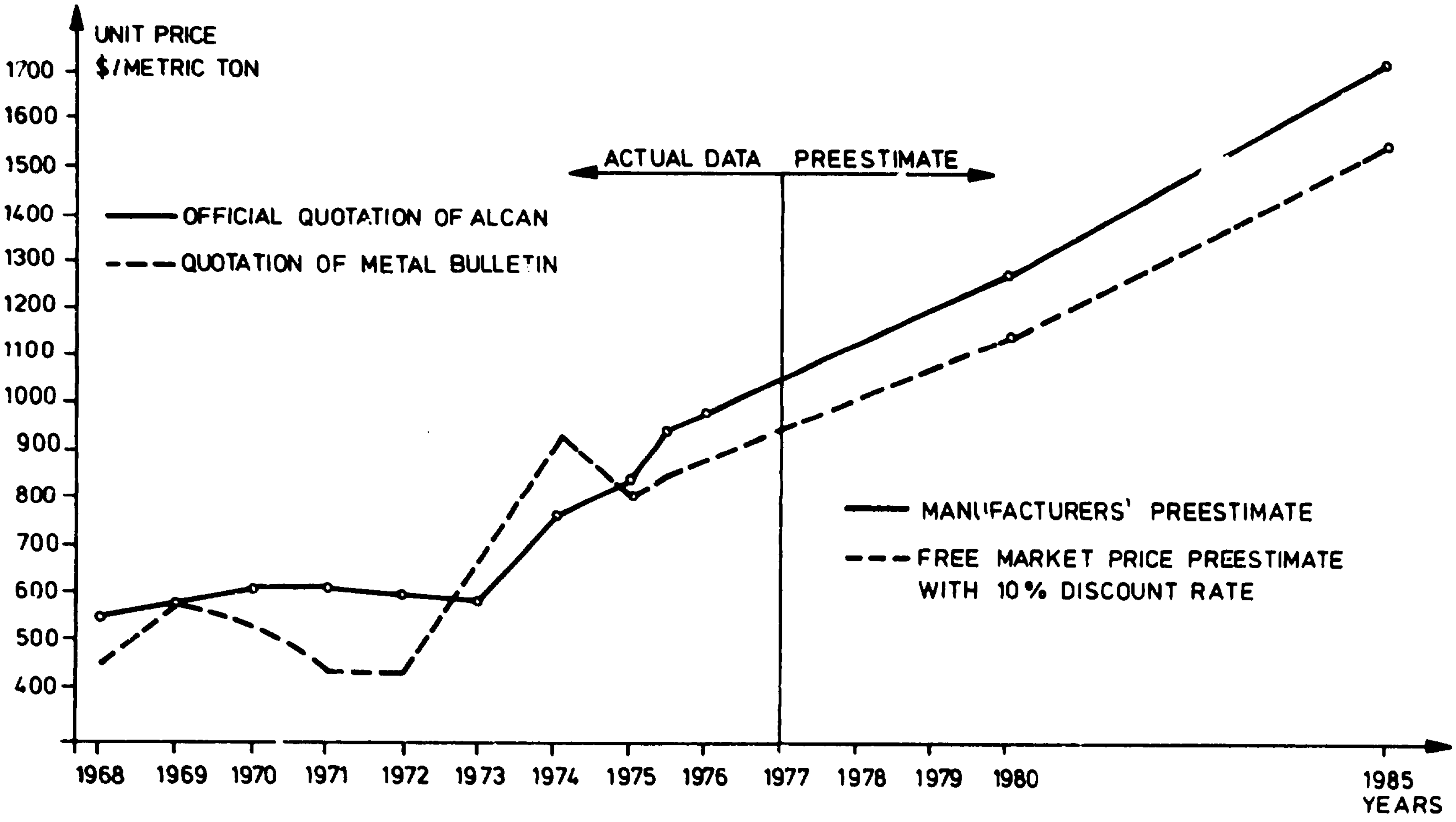

Fig. 7.6
TREND OF ALUMINIUM WORLD MARKET PRICES

13. ENVIRONMENTAL PROTECTION

An accompanying phenomenon of the development of industrialization is the increase of air-, water- and soil contaminations. These contaminations rise at certain industrial districts to values delaterious to the living organisms. Therefore, prescriptions and laws have been elaborated for environmental protection in more and more countries of the world, which must strictly be kept when designing new establishments.

Though the detailed description of the environmental protection is not the principal objective of a Feasibility Study, still the problem can not be neglected, and a chapter has to deal with those siting, technological and mechanical solutions which must be considered from the point of view of environmental protection.

In case of alumina production the main environmental contaminants are: dusts of different solid,raw and auxiliary materials /bauxite, lime, lime stone, coal/ and of the alumina; injurious SO_2 and CO content of the flue gases of fuels /coal, fuel oil/; dusting of coal--ash, the waste of coal-firing; soil- or water contaminating effect of liquor solutions of alumina production and of acids used for cleaning of equipments; dusting of red mud, the waste of the alumina production,and its soil- and water contaminating effect due to its liquor content. Beyond the above, environmental contamination is also caused by fecal waste waters.

In order to eliminate or reduce environmental contamination, the followings have to be taken into consideration for the elaboration of the Feasibility Study:

1. It is expedient to determine the site of the alumina plant in a few km's distance from the habitation, on consideration of the prevailing wind direction.
2. It is expedient to introduce forest belts between the habitations and the plant.
3. Offices and maintenance shops within the plant should be located far from the objects causing environmental contamination.
4. Raw- and auxiliary materials and final product susceptible to dusting should be disposed in closed storehouses, and care must be taken for avoiding dust formation of these materials during transportation /e.g. dust exhaustion, minimum slope at transmission points, covered conveyor belts, etc./.
5. Application of effective dust collectors at firing equipment and selection of adequate stack-height can ensure to keep the released dust and toxic gases below the prescribed value.
6. Red mud and slug deposits causing dust-formation should be drenched with water to prevent dusting. After the red mud- and slug ponds are filled, it is expedient to plan their rehabilitation for agricultural purposes e.g. by covering them with arable soil.
7. In order to prevent liquor contamination of the soil, the territory of the alumina plant has to be covered with liquor-proof concrete, and adequate drainage has to be provided for collecting the spilled liquor and to re-charge it into the system.
8. In order to prevent soil contamination the red mud pond has to be selected so that its base soil be formed if possible by a natural impermeable layer. In case this is not possible, artificial insulation has to be realized for preventing the liquor contamination of the soil.

Protection of the landscape and of valuable agricultural territories also belong to the frame of environmental protection. The protection of landscape is particularly important in regions of intensive foreign tourist traffic. In such cases special care must be taken for reducing the detrimental effects of industrial location on the environment. One solution is to surround the industrial site by forest belts.

14. EXAMPLES OF BREAKDOWN OF INVESTMENT AND OPERATING COSTS

INVESTMENT COSTS

For illustration, the breakdown of estimated investment cost of a 500,000 tpy capacity is given in the Table 7-I. The prices are calculated on 1979 price basis.

The plant is supposed to process a gibbsitic/boehmitic type bauxite, at high temperature with medium concentration digesting liquor. The precipitation is performed at relatively low concentration and molar ratio, and the final product is sandy alumina.

Capital costs include all costs inside the fence with power plant and a red mud pond built for 8 years of procudtion. Besides, it includes all indirect costs as design and know-how, erection and mounting, management, training and start-up costs, etc.

Excluded are: capital costs of port and port facilities, external roads, railway, conveyors, external water system power transmission line - if any contingencies and housing colony.

Indirect costs were calculated on the basis of actual data of plants realized under Hungarian guidance and on the basis of international standards and regulations.

Working capital was partly calculated on the basis of material balance and frequency of deliveries, partly estimated based on experience.

Table 7-1

CAPITAL COST ESTIMATE OF 500,000 TPY ALUMINA PLANT

/In terms of 1979. prices, Million US$/

Area	Building work	Machinery and equipment	DIRECT CAPITAL COSTS Erection and mounting	Others	Total
Terrain correction land acquisition	6.0	-	-	-	6.0
Preparation work of the investment	1.2	-	-	-	1.2
Road network inside the fence	0.8	-	-	-	0.8
Waste water, sewers	0.5	-	-	-	0.5
Alumina plant	10.5	88.8	6.5	-	105.8
Alumina storage	0.8	0.3	-	-	1.1
Power supply	0.3	12.7	1.8	-	14.8
Power plant	2.1	26.3	2.8	-	31.2
Measurement, control	-	7.0	1.1	-	8.1
Water treatment	2.0	5.6	0.8	-	8.4
Compressor station	0.9	1.6	0.1	-	2.6
Yard piping	0.6	4.2	1.1	-	5.9
Workshop, stores, garages	1.4	2.4	0.5	-	4.3
Management and welfare building, laboratory	1.5	1.2	-	-	2.7
Steel structures /building/	-	10.1	4.2	-	14.3
Red mud disposal /for 8 years/	5.8	-	-	-	5.8
Spare parts	-	4.0	-	-	4.0
Mounting auxiliary materials	-	-	6.4	-	6.4
Freight	-	-	-	4.8	4.8
Total direct capital costs	34.4	164.2	25.3	4.8	228.7

Table 7-1 /cont/

Area	Building work	Machinery and equipment	Erection and mounting	Others	Total
Hire fees of mounting machinery	-	-	8.0	-	8.0
Manufacturer's supervision	-	-	6.0	-	6.0
Design + know-how, training abroad	-	-	-	19.4	19.4
Construction management	-	-	-	5.7	5.7
General project management	-	-	-	3.3	3.3
Training costs	-	-	-	0.5	0.5
Local costs of manufacturer's supervisers	-	-	-	1.0	1.0
Insurance	-	-	-	2.0	2.0
Cost of start-up, complex trials	-	-	-	3.3	3.3
Total indirect capital costs	-	-	14.0	35.2	49.2
Total direct + indirect capital costs	34.4	164.2	39.3	40.0	277.9

WORKING CAPITAL

Materials stored	2.7
Materials in the process	5.9
Alumina	4.5
Cash on hand	5.7
Net receivables	7.7
Total working capital	26.5
Financing costs	11.6
Total applications	316.0

Cash on hand and net receivables are estimated values. Financial costs were calculated on the basis of credits at actual rates of interest.

OPERATING COSTS

Total operating costs is the sum of materials cost, wages and salaries, insurance cost, property-tax and administration costs.

Material Costs

In determining the material costs, the consumption figures are taken from the material and heat balance including the energy balance of the power plant.

The prices of materials are average 1979 prices of a country having its own bauxite reserves, but importing all other materials.

As regards costs of bauxite production, 10 $/t were taken into account, corresponding to the estimated costs of production. It should be kept in mind, however, that bauxite levy in some countries can be as high as 20 $/t.

MATERIAL COSTS

Item	Unit	Specific consumption per ton	Annual consumption /tons/	Unit price $	Costs specific US$/t	Costs annual million $
Bauxite	t	2.8	1,400,000	10.0	28.00	14.0
Caustic soda	t	0.08	40,000	200.0	16.00	8.0
Fuel oil	t	0.40	200.000	100.0	40.00	20.0
Limestone	t	0.16	80.000	5.0	0.80	0.4
Other materials	t	-	-	-	1.60	0.8
Maintenance materials	t	-	-	-	16.00	8.0
					102.40	51.2

WAGES AND SALARIES INCLUDING BENEFITS

Category	Average $/person/year	Persons	Costs on wages million $	
I.	30,000	10	0.3	
II.	24,000	150	2.1	
Wages and salaries I.+II.			2.4	
III.	6,000	350	2.1	
IV.	4,000	100	0.4	
Costs on wages /III+IV/				
Total		610	4.9	
US$/t				9.80

TOTAL OPERATING COST

Taking the insurance costs at 0.15 per cent of the total invest capital, and administration costs at 2.00 $/t, the total operating costs are:

	Million $
Material cost	51.2
Wage cost	2.5
Total direct production cost	53.7
Wages and salaries	2.4
Insurance cost	0.4
Administration cost	1.0
Total operating cost	57.5
$/t	115.00

REFERENCES

/1/ Manual for the Preparation of Industrial Feasibility Studies.
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