## OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

## DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

## FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

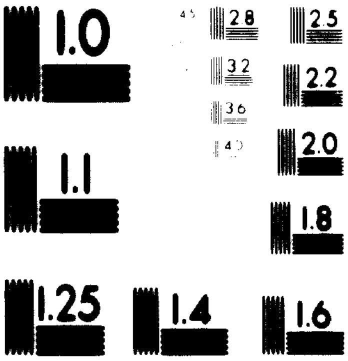
## CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

1 OF 2



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

24x
F

Chemokomplex-Aluterv
Budapest, Hungary

04538

# FINAL REPORT

## ON PRE-FEASIBILITY STUDY FOR AN INTEGRATED ALUMINIUM INDUSTRY IN MALI

UNIDO CONTRACT No. 72/11

PROJECT No. SIS 71/1219 MALI-13

Budapest, November 1972.

Chemokomplex-Aluterv
Budapest, Hungary

# FINAL REPORT

## ON PRE-FEASIBILITY STUDY FOR AN INTEGRATED ALUMINIUM INDUSTRY IN MALI

UNIDO CONTRACT No. 72/11

PROJECT No. SIS 71/1219 MALI-13

. . . . . . . . . . . . . . . . . .
/Máhig László/
Head of the Alumina
Plants Design Bureau

dr Sigmond
. . . . . . . . . . . . . . . . . . .
/Dr'Sigmond György/
Deputy. Head of the Alumina
Plants Design Bureau

Budapest, November 1972.

# WRITERS OF THE REPORT

| Name | | Field of Activity |
|---|---|---|
| Dr'Sigmond György | Team Leader | Alumina Technologist |
| Maetz Ervin | | Civil Engineer |
| Dr Balkay Bálint | | Geologist |
| Sejteri Vjekoszlav | | Smelter Technologist |
| Farkas György | | Economist |
| Molnár András | | Economist |

---

Printed by ALUTERV 1972/1199

# CONTENTS

# INTRODUCTORY STATEMENT

Establishing an alumina-aluminium industry in Mali can be technically and economically feasible

if

- investment finance in the amount of 100 to 150 million dollars can be made available to realize the alumina plant; (and the smelter, if any).
- the multipurpose Manantali dam and hydroelectric project are realized, and
- as a result, the Senegal River becomes navigable at least between Kayes and Kaolack,
- the necessary infrastructure including roads, bridges, etc. is realized in the amount of 25-40 m$

## Preliminaries

The coming into existence of the Contract under which the present Report has been written, and the activity of ALUTERV's team in Mali had been described in an Interim Report submitted to UNIDO in June 1972, as had been also the briefing and debriefing of the Team Leader in Vienna.

On base of material collected in Mali and on baluable hints received in the course of debriefing our "Draft Final Report" had been prepared by drawing economist and other experts into this work and the Report was submitted to UNIDO in August 1972. UNIDO in his letter dated 18. September 1972 intimated its comments comprising recommendations for some minor corrections and still more detailed elaboration of certain items.

UNIDO's letter was received in ALUTERV on 2. October 1972.

On base of the valuable comments and recommendations the complementary work and adaptation of those has been done. Some desirable minor corrections in the text has also been carried out.

## Meteorological conditions.

The wide-spread country belongs to the Sudan big region. On its southern part is the Sahara, in the south, however, there are grassy prairies. The southern and central areas (here are the bauxite deposits) belong to the single stage rain zone, in the north in turn, no systematic precipitate occurs. The yearly precipitate measured is 1100 to 1400 mm exceptionally 1900 mm for the south and 200 to 300 mm in turn for the north and there are certain areas being in lack of any rainfall for some years time.

The mean temperature is 24-26$^{o}$C in general, however, while the fluctuation at areas close to the equator is about 3-5$^{o}$C in the north, in turn, the mean temperature of the hottest month exceeds 30$^{o}$C.

The dry hot season lasts from March to May sometimes at a temperature of 42$^{o}$C ; rainy season lasts from June to October at times at a temperature of 32$^{o}$C, while the cold season lasts from November to February at temperatures of 14-12$^{o}$C .

## 1. Feasibility of an alumina-aluminium industry in Mali

As seen against the background of the country's overall economic situation. Mali, the largest West African country, is land-locked. Owing to its geographical situation compounded with a long colonial past, its economic development is considerably retarded. Inflation in the last several years has further contributed to this retardation. Exports are small-scale and largely connected with agriculture, animal husbandry and fishing.

On the other hand, the Government of Mali has, in recent years, made a substantial effort to consolidate the economic situation, with, among others, the aim of improving the investment climate and attracting investment funds from developed countries and international agencies. The Three Years' Plan for 1970-1972 prescribes investment totalling 77500 million Mali Francs (some 160 million $US), of which 85 percent is envisaged to come from abroad.

Gross domestic product, 116,1 thousand million MF in 1968/68, was envisaged in the Plan to rise to 155 thousand million MF by 1973 (about 300 million $US).

Without any desire to provide in the present Report a detailed analysis of the economly of Mali we have stated the above figures merely to outline the frame into which an alumina-aluminium industry in Mali will have to be fitted. Notably, the investment required to realize said industry and the connected infrastructure is on the same order of magnitude as the total of Mali's gross domestic product over the Three Years' Plan.

This immediately raises the question as to why it is worth while at all to study the possibilities of establishing an alumina-aluminium industry in Mali. There are two arguments in favor of doing so.

/1/ The bauxite resource of Mali is significant on a world scale and Malian bauxite exceeds in grade the bauxite of many a developed country.

/2/ The heavy outlay required for the infrastructure of an alumina-aluminium industry would not serve said industry alone: indeed, it would bring an incomparably greater benefit in terms of improved agricultural, animal-husbandry and fishery production, of opening up wast areas and integrating them into the country's money economy, and of laying foundations for other industries which, in turn, would need much less infrastructural investment.

All this, however, leads to a conclusion emphasized already in our Interim Report:

- if the alumina-aluminium industry to be established is expected to bear the brunt of all these investments, then it will not, under any circumstances and conditions, turn out to be economically attractive or even feasible.

- if the cost of said investments is distributed evenly among the sectors of economy that will benefit by it, then, as will be shown below, the alumina-aluminium industry might well prove to be an attractive proposition.

Some of the items of infrastructural investment required by the alumina-aluminium industry have already been scrutinized by various Mali Goverment agencies (including the Manantali dam and power plant, the navigability of the Senegal River, etc.) Information as to the state of these projects shall be discussed in a separate section of the present Report.

Clearly, however, the projects mentioned above have not at the present time been geared as yet to the realization of an alumina-aluminium industry, all the more so since, as far as we are aware, the present Report is the first systematic investigation into the feasibility of such an industry.

For the reasons just outlined, it was one of our main aims to separate sharply the invesments required to establish an alumina-aluminium industry in the strict sense of the word, and those required for infrastructural purposes. In Chapters 3, 4, and 6. we have accordingly examined the aluminium industry as if it were to be established in a landlocked, but otherwise economically advanced country. In this context, we have taken into account the (higher) materials and transportation costs realistically, and also the influence of the foreseeable future trends of these upon the economics of an alumina-aluminium industry.

The infrastructural investments mentioned above have on the other hand, been taken into account in Chapters 5 (partim) and 6. (4.) It is these chapters that expound the relationship of infrastructural investment and of the alumina-aluminium industry, according to the principle laid down above, notably that the establishment of an alumina-aluminium industry in Mali is not technically or economically feasible unless it is connected with accessory and infrastructural investments serving various other purposes indispensable for the economic evolution of Mali.

The present Report is not concerned with problems of procuring finance for the investments referred to above. As far as we are aware of the options available to the Goverment of Mali, however, we suppose that most of the investment would be financed by credit from outside sources, consequently debt servicing has invariably been taken into account in our economic calculations.

In conclusion, we should like to point out two factors that justify some optimism concerning the establishment of an alumina-aluminium industry in Mali. One of these is the enhanced interest in the development of Mali of developed countries and international organisations including UNIDO. The other is the substantial bauxite resource of Mali. Some of the large aluminium-industry investments, notably in Australia, have been started under auspices not significantly better than those prevailing in Mali:

nevertheless, the increasing raw material needs of the aluminium industry have attracted enormous investments in rather brief periods in these areas, investments which were proved to be economically justified in rather a short time. We are of the opinion thet the laws governing the economics of these plants and investments will, mutatis mutandis, operate in Mali too.

## 2. Geology, reserves

There is a vast horseshoe-shaped West African bauxite belt that extends from Mokanji (Sierra Leone) through the Los Islands, Fria and Boké (Guinea) into the southern reaches of Western Mali up to about the Dakar-Niger railway. The bauxite occurrences in this part of Mali are contiguous with the deposits of Northeast Guinea (Dabola-Tougué).

Bauxite in Mali occurs on dissected remnants of an old peneplain, whose mean altitude, 600 to 650 m near the Guinean border, drops off to about 3-400 m close to the Dakar-Niger railway. These peneplain fragments are sculpted in Precambrian, Infracambrian or Palaeozoic silica-rich rocks, largely sandstones and quartzites, that do not lend themselves well to bauxitisation. Most of them are, however, capped with dolerite sills exposed by erosion, and this dolerite is a good parent rock of bauxite. Prospection carried out so far reveals a tendency for bauxite grades to improve towards the south (towards the large Guinean deposits), as the peneplain fragments grow taller and rains become more abundant.

Malian bauxites occur either on the surface or at very shallow depth, under a soil and/or ferrallite cover typically one or two metres thick. Their open-cast mining should thus be fairly simple.

As to chemical composition, the average Malian bauxite is rather high in iron with a mediocre alumina content. Even so some deposits are exceptionally high-grade owing to a very low silica content (less than two or even one percent). Mineralogically Malian bauxites are largely trihydratic but they usually contain non-negligible amounts of monohydrate (boehmite).

### 2.1. History of prospection

The first mentions of bauxite in Mali date back to before World War I. but industrial-scale prospecting was started just a few years before Mali's accession to independence. The documents of these campaigns are not fully available in Mali. Prospection was performed essentially by two agencies, BUMIFOM (Bureau Minier de la France d'Outre-Mer) and SAREPA (Société Africanie de Recherches et Etudes pour l'Aluminium, a subsidiary of Pechiney-Ugine).

### 2.1.1. BUMIFOM's campaigns

The first industrial-scale prospection campaigns by BUMIFOM were the Badet Missions of 1955-56 and 1957-58 that examined some plateaux about Faléa with 50 loosely scattered pits. Documents on this mission are not available in Mali.

In 1959 was started the Mission Bauxites Soudan under M. Donnot, in cooperation with Reynolds Metals Corp. Concentrating on the plateau of Sitadina, cited among the most hopeful by the Badet Mission, the Donnot Mission outlined a reserve of 54 million tons of 46,0/4,2[x] average grade by pitting on 400-m centers.
A fairly detailed report on this campaign is available in Mali.

Work was continued in 1960/61 with 69 boreholes on Sitadina plateau and 17 on Koumassi plateau. All we know about this campaign is that it outlined a further 100 million tons of bauxite at 46% alumina content on Sitadina and 15 million at 49 % alumina content on Koumassi. No further data are available in Mali.

### 2.1.2. SAREPA's campaigns

SAREPA used to be concerned largely with Guinea, where it prospected, among others, the Dabola-Tougué deposits. Its work in Mali was largely an extension and completion of its Guinean work.

In 1958-59, prospection was performed on the leases Koulikoro-East and West. All we know of the results is that the bauxite found is similar to the Dombia bauxites near Kéniéba (that is, it is of an indifferent grade).

In 1957-58, SAREPA prospected the plateau Sintefouka near Kéniéba. The report on this prospection is typical of all SAREPA reports.

---

[x] This symbol means 46,0 percent $Al_2O_3$ and 4,2 percent $SiO_2$.

It gives only pit (or borehole) averages of silica and alumina contents, and no mineralogy except for the information that low values of L.O.I suggest the presence of some boehmite (up to 24%) in addition to gibbsite. Silica contents are stated numerically; alumina contents graphically only.

Prospection by pitting gave here 10 million tons of mediocre ore Also in 1957-58 were prospected some permits in the Bamako-East and Bamako-West groups. No data on this work are available in Mali. In the Kéniéba region, the plateaux Dombia East and South were prospected by borehole profiles of 150 and 300 m spacing in 1959-60. This prospection gave 2-3 million tons of fair grade ore.

Likewise in 1959-60 SAREPA prospected the so-called Baléa group of deposits by sondages largely on 150-, less extensively on 300 m centers. The plateaux prospected and the reserves outlined are listed in Table 1.

In the Bamako-West group of leases, the campaign of 1959-1960 prospected the plateau Sandambakourou, Kéniélando, Sorokourou, Kourouko, Koulala and Ouro Néna. Reserves are likewise listed in Table 1.

In the same year some of the Bamako-West leases were also prospected. No data about this campaign are available in Mali.

### 2.2. Reserve situation

1. Prospection performed prior to the independence of Mali covered only the most hopeful areas. Further unprospected areas with some hope of finding bauxite are listed in Table 2.

2. Documents concerning a substantial part of the prospecting campaings cited above are unavailable in Mali.

3. Therefore, the prospected reserve of the country must be somewhat more than stated in Table 1. on the basis of the documentation available.

4. The resource prospected as it is known to us is amply sufficient to supply a large-scale aluminium industry. The only problem is that it tends to lie far from the Bamako-Kayes axis where run most of the transport routes.
However, as stated above, the probability of finding good grade bauxite diminishes from north to south; it is therefore not very likely that further prospecting will turn up bauxite of grade and tonnage comparable to those now known, but significantly closer to the Bamako-Kayes axis.

5. Hence, prospection of further deposits of bauxite, although hopeful, is not a high-priority job in the context of the present Report.

## 2.3. Reserve basis of the present Report

Of the reserve groups shown up by prior prospection, we have taken as promising three groups, viz.

A. Sitadina (+ Koumassi) near Faléa

B. Koubaya, Sitaouma and Gangaran (the Baléa group)

C. Ouro Néna and Koulala (Bamako-Ouest group).

The other deposits lack either industrial interest or documentation on prospection performed.

On the consideration that the main problem of exploiting Mali bauxite is transportation, and that selective mining will improve the value of bauxite without raising freight costs, we have recalculated the reserves of these three groups with selective mining in mind. The results are also listed in Table 1.

In the recalculated reserves, cutoff grades have been disregarded locally where below-cutoff bauxite is embedded in above-cutoff ore.

That part of the Sitadina-Koumassi reserve for which total tonnage and alumina content are only known (BUMIFOM campaign of 1960-61) was reduced in the same proportion as the reserves for which detailed data are known. (campaign of 1959-60).

## 2.4. Sampling in the field

During our one-month stay in Mali, the geologist member of our team, dr Balkay, visited two of these groups of deposits, notably

1. Sandambakourou, Ouro-Néna and Koulala of the Bamako-Ouest group, and

2. Sitadina and Koumassi of the Sitadina group.

Lack of time precluded a visit of the third group of deposits (Baléa).

ad 1. The drill grids of the three plateaux mentioned were reconstructed. With the aid of some drillers employed by SAREPA, now living in the neighbouring villages, the drill holes were comparatively easy to find. Check pits were sunk and check samples were taken at four places:

1. Sandambakourou, next to an unspecified drill hole (no drill hole location map is available for Sandambakourou)

2-3. Ouro Néna, next to SAREPA boreholes I.15 and K.16. None of our pits could, for lack of time and equipment, be sunk deeper than 1 m.

4. We have also sampled the chip heaps next to an ancient pit, close to grid point I.19.

**ad 2.** The pit grids on Sitadina and Koumassi plateaux were reconstructed as under 1. above. Two pits (Sitadina Q 4400 and 6400) were emptied of debris thrown in; their walls were cleaned with chisels on two opposite sides, and channel samples were taken metre by metre from the fresh rock thus exposed. On Koumassi we have sampled the chip heaps next to an unspecified pit of BUMIFOM, lying about 2300 m to the East of Koumassi village ("Puits Donnot"). (Each such heap is known to represent one metre of pit).

A list of sampling localities is given in Table 3.

### 2.5. Beneficiation potential of the bauxite samples collected

In order to gain information about possibilities of beneficiation, we have divided all bauxite samples as collected in two fractions on a 1,6 mm screen. The weight percentages of the fractions are given in Table 3. These fractions were subjected to a quick-analysis procedure unsuited for giving absolute values but suitable for comparing fractions of one and the same bauxite. (This is why these values are different from the ones listed in the Appendix on laboratory testing results). These analyses reveal that all the bauxites examined lend themselves well to beneficiation by crushing and screening. A point to be made in this context is that the samples denoted "Koumassi Puits Donnot", were taken "sur les tas", from the chip heaps that were exposed to rain for a number over a number of years. Their fine fraction is very scarce, as it was washed out by rain, but still of very much lower grade than the coarse fraction.

Table 1.

| | ORIGINAL RESERVES | | | | REDUCED RESERVES | | | |
|---|---|---|---|---|---|---|---|---|
| | $Al_2O_3$ | $SiO_2$ | Depth | Tonnage $10^6$ | $Al_2O_3$ | $SiO_2$ | Depth | Tonnage $10^6$ |
| **Bamako West** | | | | | | | | |
| **Koulala** | 44,40 | 3,50 | 7,5 | 75 | 46,25 | 2,51 | 7,91 | 50,1 |
| **Ouro-Néna** | 42,00 | 3,50 | 6,5 | 30 | 43,70 | 2,88 | 6,87 | 24,2 |
| **Sandambakourou** | 40-41 | 3,00 | 6 | 10 | no maps available for more detailed reserve calculation | | | |
| **Kéniélando** | | | 6 | 10 | " | " | | " |
| **Sorokourou** | 39-40 | 3-3,50 | 7 | 40 | " | " | | " |
| **Kourouko** | 39-40 | 3-3,50 | 7 | 20 | " | " | | " |
| | | | | 185 | 45,50 | 2,64 | 7,56 | 74,3 |
| **Baléa** | | | | | | | | |
| **Koubaya West** | 43 | 1-1,5 | 10 | 70 } | | | | |
| **" East** | 40 | 1,5 | 11 | 60 } | 45,1 | 0,91 | 10,15 | 46,9 |
| **Sitaouma** | 40-41 | 1-1,5 | 10 | 100 | 42,9 | 1,33 | 10,55 | 34,5 |
| **Gangaran** | 40 | 1,77 | 12 | 170 | 40,4 | 1,35 | 12,42 | 95,8 |
| | | | | 400 | 42,1 | 1,23 | 11,43 | 179,2 |
| **Kéniéba** | | | | | | | | |
| **Dombia West** | | negligible | | | | | | |
| **South** | 55 | 4-5 | | 2-3 | | | | |
| **Sinlafouka West** | 40,4 | 5,2 | | | neglected because of indifferent grade and tonnage | | | |
| **Southwest** | 45-50 | 5-6 | | 9,2 | | | | |
| **Faléa** | | | | | | | | |
| **Sitadina I** | 46,0 | 4,2 | 54,4 | | 46,1 | 3,0 | 4,0 | 33,6 |
| **" II** | 46,0 | ? | 100 | | 46,00 | | | 61,6 |
| **Koumasai** | 49,0 | ? | 17 | | 40,00 | | | 10,5 |
| | | | | | 46,5 | ? | ? | 105,7 |

Table 2.

| Name of 200 000 scale topo sheet | prospected zone or prospective area | lat. N. deg. | lat. N. min. | long W deg. | long W min. |
|---|---|---|---|---|---|
| Sandaré | southern part above 450-m contour | | | | |
| Kossanto | the highest bowés in a triangular area to NE of Tanbaoura scarp | 13 | 0-30 | 11 | 0-25 |
| Bafoulabé | dolerite capped plateaux | 13 | 38-52 | 10 | 13-40 |
| | south of the Bakoye near Bagni from the Bakoye to | 13 | 30 | 10 | 10-25 |
| Kéniéba | 150 million tons of bauxite prospected by BUMIFOM on part of 26 leases | 12 | 0-21 | 11 | 0-25 |
| | plateaux of Dombia and Sintefouka - 13 leases of Péchiney partly prospected without encouraging results | 12<br>13 | 40-<br>00 | 11 | 0-15 |
| Bafing Makana | Dolerite-capped plateaux unprospected, with traces of bauxite | | | | |
| | Sikoto | 12 | 45 | 10 | 58 |
| | Dakounta-Kimai | 12 | 18-22 | 10 | 34-41 |
| | NW of Madina-Talibé | 12 | 25-31 | 10 | 45 |
| | Kouragué | 12 | 14-25 | 10 | 0-10 |
| Sirakoro | 400 million tons of bauxite on 6 | 12 | 8-11 | 9 | 45-54 |
| | leases of Péchiney ("Baléa") | 12 | 13-18 | 9 | 33-37 |
| | Unprospected plateaux of Ségouma-Sitaouli | 12 | 19-30 | 9 | 45-58 |
| | Plateau of Sitaouma adjacent to the Péchiney leases from the Guinean border to | 12 | 14 | 9 | 40-59 |
| Bamako-Ouest | 83 leases of Péchiney (prospection unachieved) | 12 | 13-51 | 8 | 35-59 |
| | plateaux between Siguiri highway and Dakar-Niger railroad | 12 | 20-40 | 8 | 01-35 |
| Bamako Est | the entire zone between Point G | 12 | 40 | 8 | 00 |
| | and the point | 13 | 00 | 7 | 00 |
| | could possibly be prospective | | | | |

Table 3.

| Plateau and Sample number | | Sampling locality[x] | Depth m | + 1,6 mm % | + 1,6 mm $Al_2O_3$ | + 1,6 mm $SiO_2$ | - 1,6 mm % | - 1,6 mm $Al_2O_3$ | - 1,6 mm $SiO_2$ |
|---|---|---|---|---|---|---|---|---|---|
| OURO-NÉNA | 1–2 | K-16 | 0.5–0.6 | 88,82 | 59,2 | 0,2 | 11,18 | 57,8 | 3,2 |
| " " | 3–4 | I -15 | 0.6–0.7 | 83,52 | 53,3 | 0,2 | 16,48 | 47,7 | 3,1 |
| " " | 5–6 | K-16 | 0.75 | 79,74 | 59,0 | 1,6 | 20,26 | 53,3 | 5,2 |
| " " | 7–8 | I -15 | 0.75 | 80.30 | 54,3 | 0,5 | 19,70 | 48,5 | 2,0 |
| " " | 11–19 | old pit | 0–3 | 84,22 | 37,8 | 6,6 | 15,78 | 36,4 | 15,0 |
| " " | 13–14 | K-16 | 0.9 | 90,04 | 59,1 | 1.3 | 9.96 | 57.6 | 5.1 |
| " " | 15–16 | I -15 | 0.9 | 78,70 | 48,6 | 0,9 | 21,30 | 46,6 | 3,5 |
| SANDAMBA-KOUROU | 9–10–12 | new pit | 0.8 | 86.85 | 40,2 | 1,6 | 13,15 | 46,4 | 2,7 |
| " " | 17–18 | " " | 1.0 | 91.66 | 47.9 | 0,7 | 8,34 | 50,0 | 1,4 |
| KOUMASSI | 1–2 | Puits Donnot | 0–1 | 99,22 | 65,0 | 0,5 | 0,78 | 58,3 | 5,1 |
| " " | 3–4 | " | 1–2 | 98,82 | 41,3 | 7,9 | 1,18 | 40,2 | 18,8 |
| " " | 5–6 | " | 2–3 | 98,89 | 50,9 | 4,5 | 1,11 | 45,0 | 13,3 |
| " " | 7–8 | " | 3–4 | 99,24 | 41,1 | 5,2 | 0,76 | 38,6 | 18,1 |
| " " | 9–10 | " | 4–5 | 98,75 | 40,9 | 6,3 | 1,25 | 36,7 | 16,8 |
| SITADINA | 11–12 | Q 6400 | 4–5 | 89,84 | 50,2 | 3,3 | 10,16 | 45,7 | 10,7 |
| " " | 13–14 | Q 6400 | 3–4 | 88,62 | 55,2 | 1,6 | 11,38 | 49,7 | 7,7 |
| " " | 15–16 | Q 4400 | 2–3 | 85,20 | 57,7 | 3,2 | 14,80 | 58,2 | 4,7 |
| " " | 17–18 | Q 6400 | 2–3 | 88,23 | 55,7 | 2,8 | 11,77 | 49,2 | 9,3 |
| " " | 19–20 | Q 4400 | 1–2 | 72,70 | 49,6 | 5,3 | 27,30 | 51,9 | 6,9 |
| " " | 21–22 | Q 4400 | 0–1 | 86,85 | 45,6 | 6,0 | 13,15 | 38,4 | 10,1 |
| " " | 23–24 | Q 6400 | 1–2 | 87,91 | 59,1 | 3,1 | 12,09 | 48,7 | 11,5 |
| " " | 25–26 | Q 6400 | 0–1 | 87,56 | 39,6 | 3,3 | 12,44 | 33,4 | 13,9 |

x I-15 and K-16 are Péchiney grid points

Q 4400 and 6400 are BUMIFOM grid points

## 3. Aluminium industry siting

### 3.1. Alumina plants

In possession of data concerning the bauxite deposits and the existing envisaged and possible transportation facilities, and after having personally inspected a considerable portion of the transport routes involved, we have chosen a number of possible locations for alumina plants. Although the prime consideration in such cases is to site the plant as close to the bauxite mine as possible (as in the absence of arguments to the contrary this is likely to be the siting with the lowest aggregate freight cost), in the Malian case problems of transportation of raw and accessory materials and intermediate products, of water and electric power supply, and the spatial relation to a smelter, should one be built, made us envisage a total of eight different locations. Four of these were based on Sitadina bauxite, two on Baléa and two on Bamako-Ouest bauxite. The main principal traits of said eight variants are as follows.

#### 1/1. Sitadina bauxite treated in alumina plant at Kayes.

This siting would have the advantages of a comparatively developed urban environment with a railroad and airfield. All transportation except that of bauxite would be on the Senegal River or prior to the realization of the Manantali Project by the Dakar-Niger railroad. Water can be taken from the river; power could be adducted from Manantali by high-tension line. Labour could, in view of the urban environment, be avilable more readily than at more virgin sites.

#### 1/2. Sitadina bauxite treated in Mahina

The railroad and something of an urban environment are present, but transportation is complicated by a railroad or trucking leg interposing itself between the plant and the riverport of Kayes. Water can be taken from the Senegal river; electricity, as above. Labor would be available more or less as in Kayes.

### I/3. Sitadina bauxite treated at Moussala

The main advantage of this choice is the short bauxite transportation leg, which would reduce transportation volume by one and a half times the alumina plant's output (by hauling alumina rather than bauxite between Moussala and Kayes). The environment is sparsely inhabited, rural, but the climate would be more favorable than e.g. at Kayes. Transportation: Kaolack-Kayes and return, by barge; Kayes-Moussala and return, by truck. Water supply would require a small dam on the Falémé. Power supply by insular power plant. Housing of labor would require more investment than in more urban areas.

### I/4. Sitadina bauxite treated at Manantali.

The main advantage of this site is that, as shall be expounded below (3.2), the only logical site for a smelter is Manantali. Siting the smelter next door to the alumina plant entails a considerable saving in first cost and personnel. Water supply and power would be no problem at Manantali. Transportation - bauxite by truck from Sitadina to Manantali, all else by truck from Manantali to Kayes and return, and by barge on the river - is not as simple as some others. A point in favor of this choice is that the labor attracted for the construction of the Manantali Project could presumably be persuaded to stay for smelter and alumina plant construction and operation, in housing built during the Manantali Project operations.

### II/1. Baléa bauxite treated at Manantali.

Generally as above, except for the shorter haulage route for bauxite.

### II/2. Baléa bauxite treated at Boulouli.

This site is on the railroad. Water could be taken from a dam to be built on the nearby Bakoy river. (Water is the reason why Boulouli is to be preferred to the more important town of Kita, where water would be a serious problem). The environment is rural; availability of labour would be low; electric power would have to be generated by an insular facility.

III/1. Bamako-Ouest bauxite treated in Bamako.

Advantages; availability of labor, the most urban environment of all, the presence of the railroad and of water in the Niger river. Power could be taken by cable from the Sélingué power project Bauxite would be brought in in trucks; all other transport by railroad to and from Kayes and by barge to and from Kaolack.

III/2. Siting the alumina plant at the small village of Baoulé

at the intersection of the railroad trace with the Baoulé river for the treatment of Bamako-Ouest bauxite would reduce the distance of transportation of both bauxite and other commodities against the above variant. Environment sparsely inhabited rural; low availabity of labor. Water supply from a dam to be built on the Baoulé. Power from an insular facility.

## Alumina plant siting variants

| Bauxite to be taken from | Alumina plant at | Smelter |
|---|---|---|
| I. Siladina | | |
| | 1/1 Kayes | none |
| | 1/2 Mahina | at Manantali or none |
| | 1/3 Moussala | " " " |
| | 1/4 Manantali | at Manantali |
| II. Baléa | | |
| | II/1 Manantali | at Manantali |
| | II/2 Boulouli | none |
| III. Bamako-Ouest | | |
| | III/1 Bamako | none |
| | III/2 Baoulé | none |

### 3.2. Aluminium smelting

In the production cost of aluminium smelting, the most important components after depreciation and debt servicing are the costs of alumina and of electric power. Conventional aluminium smelting technologies demand that both alumina and power be continuously and uniformly available. The preconditions of economical smelter operation are, therefore, cheap alumina and low-cost power. Consequently, the realization of an aluminium smelting industry in Mali must be based on a local alumina industry and a suitable hydroelectric power source.

#### 3.2.1 Sources of electric power

Mali does not actually possess a countrywide electrical power grid and the capacity of the existing power plants is small. All the power produced by the existing plants - Diesel plants and Sotuba hydro-power plant near Bamako, and many other similar ones - is tied down by consumers: indeed, there is a power shortage in most areas; the envisaged expansions to the existing power generating facilities and the new facilities to be realized are already earmarked for domestic and industrial consumption regardless of an alumina-aluminium industry, with the important single exception of the Manantali power project. Moreover, the cost of power generated at the existing and envisaged facilities is high - e.g. 3 ¢/kWh for the Diesel power plant at Bamako.

On the other hand, the two principal drainage systems of Mali, those of the Senegal and the Niger Rivers, do possess certain hydroelectric potentials, and some locations have already been envisaged for power projects. The projects in the most advanced stage of study include the following:

| Location | River | Drainage system | Installed capacity, projected | Guaranteed sustained (year-round) output, projected |
|---|---|---|---|---|
| Sélingué | Sankarani | Niger | 40 MW | cca 30 MW |
| Manantali | Bafing | Senegal | 150 MW | 100 MW |

The Sélingué power plant site is about 150 km to the south of Bamako. The finance needed to realize this project seems available, and the power plant is to enter into full out operation by 1980. Power to be generated here is earmarked to about 70 percent for domestic consumpiton in and for the developing industry of Bamako and the Bamako region. Even if the full output could be made available for aluminium smelting, it would not be sufficient to sustain a smelter of economical size.

The main aim of the Manantali Project would be to further irrigation agriculture in the Senegal River basin. Its realization is in the interest of all three riverine states, notably Mali, Senegal and Mauritania. In addition, the Manantali dam would render navigable the Senegal river downstream of Kayes, another point of benefit to all the riverine states. Finally, in addition to the Manantali hydroeletric scheme proper, the dam would considerably improve the hydroelectric potentials of various sites along the Senegal River, some of them (Gouina, Félou) within the borders of Mali.

The dam and the hydroelectric project would be realized in three stages, characterized by the following figures :

| | First stage | Second stage | Third stage |
|---|---|---|---|
| Least (regulated) discharge at Bakel | 100 $m^3$/sec | 200 $m^3$/sec | 300 $m^3$/sec |
| Guaranteed year-round power output | 30 MW | 40 MW | 100 MW |
| Guaranteed year-round electric energy supply | 240 GWh | 320 GWh | 800 GWh |

The cost of realizing the entire dam and hydroelectric project (with 150 MW installed power capacity) has been estimated as 115,4 million $ US at 1970 prices. Of this the dam would cost 76,5 million without the power generating facilities. The cost of power would be 0,91 ¢ US per kWh referred to the total investment, but only 0,3 ¢ US if the dam were to be depreciated against agricultural production and other benefits, and only the power generating facilities were to be depreciated against the power generated.

It may be stated that the Manantali Project would, both as to power output and location, satisfy the conditions raised by an economically feasible aluminium smelter.

### 3.2.2 Recomendations concering smelter location

The only rail road station of some importance close to the Manantali site is Mahina on the Dakar-Niger railroad, which would serve as the railhead for both the Manantali project and the smelter. It is at a distance of 80 Km from Manantali as the crow flies. Power transmission losses would be prohibibitive if the smelter were to be situated at Mahina, or at any other point on the railroad. Since the Manantali project demands the construction of an all-weather road betwen Mahina and Manantali anyway, it is indicated to site the smelter at Manantali and to bring in the materials required by the smelter and take out the aluminium produced by it by truck on said road.

All these factors suggest the optimum location for the smelter to be at Manantali proper. The economics of this location would be further improved if the alumina plant, too, were to be located at Manantali, as in that case the alumina required to supply the smelter would cost practically nothing to shift from plant to smelter. Investment in intermediate storage facilities such as alumina silos could also be avoided, and some auxiliary facilities such as workshops, water supply plant, laboratory etc. could be designed so as to serve both plant and smelter.

### 3.2.3 Choosing the optimal smelter size

First cost and economy of operation of an aluminium smelter are both heavily dependent on smelter size, because the cost of a great deal of equipment increases as a less-than-linear function of plant capacity. On world-wide experience, the least economical smelter size would be 20 000 to 25 000 tpy. A 25 000 tpy size smelter of up-to-date design and operation, may be predicted to consume 46 to 48 MW (50 to 53 MVA) of a.c. power.

As a first stage in the realization of a smelter at Manantali, the size of 25 000 tpy can be envisaged. In that case at the time the third stage of the Manantali power project would come onstream, the smelter would consume about 30 percent of all the power generated in the country. A 25 000 tpy output of aluminium would, if consumed entirely in Mali, give a per capita consumption of 5 kgs per year, which is on the level of an economically developed country.

As regards the exportation of aluminium smelted at Manantali, the thing to be kept in mind is the huge aluminium smelting capacities lately put onstream all over the world; consequently, a state of saturation is being experienced on the market of primary aluminium. Even if the situation were to improve in the near future, it would be unjustified to reckon with sale of primary aluminium from Mali on the world market. The most logical option in this situation would be to envisage the consumption of Malian aluminium in the country itself and in the neighbouring areas; this, however, requires additional investment in semi-fabricating and fabricating facilities.

If the market situation were to change for the better, smelter output could be doubled by the installation of another potline exactly like the first one - the auxiliary facilities would in that case require marginal expansion only and this would improve smelter economics.

In summary, the realization of an aluminium smelter in Mali presupposes the realization of the Manantali Project and of a nearby alumina plant.

For reasons of economy, the location of the Manantali Project determines also the smelter site, which is likewise to be at Manantali. As a first stage, a smelter of 25 000 tpy output is to be envisaged. Doubling this capacity can be recomended as a second stage. The total projected power production of the Manantali Project would just be sufficient to supply the doubled smelter.

### 3.2.4 Materials required for constructing and supplying a smelter

Auxiliary materials for the smelter would be procured by importation in their overwhelming majority. This includes the raw materials of the anodes (petroleum coke and coal tar pitch), cathode blocks, insulators etc. Cryolite and aluminium fluoride might possibly be produced in Mali (a fluorspath deposit is known to exist at Denkuira, no detailed information about this depbsit was available to us, but its investigation is to be recommended in any case. If the deposit is of sufficient commercial interest, the domestic production of fluorine salts might be envisaged).

In view of the present state of industrialization in Mali, including also the development projects in hand, the electric and mechanical equipment needed to build the smelter would also have to be procured abroad.

Of the construction materials, cement is available at the Diamou Plant of 50 000 tpy capacity, and part at least of the concrete reinforcement would presumably come from the 25 000 tpy steel rolling mill to be set up at Bamako.

## 3.3. Semifabrication

### 3.3.1 Actual situation

On the markets of Bamako and Kayes one will often see comparatively large, cast aluminium pots and kettles of attractive form. These are produced by simple means in foundries of 20 to 30 $m^2$ ground plan area by local masters of considerable experience.

Actually, a central aluminium foundry is being established in Bamako, with the aim of bringing together in a sort of cooperative the masters now working individually in scattered small shops. The foundry now has a personnel of 17; a smallish electrically heated crucible furnace is being installed. The metal used is aluminium scrap, seldom primary metal. The latter costs 0,8 to 0,9 $ per kg. There is another, smaller aluminium foundry in operation at Maruala.

The company "Industries du Mali" is engaged in assembling, glazing and providing with mosquito netting window frames prefabricated in the USA, and in selling them at prices of $ 12 to 40 depending on size. The Three Years' Plan prescribes the production of 20 000 such windows per year.

There is actually no aluminium consuming industry in Mali outside those just mentioned.

### 3.3.2 Estimation of demand

It would be vain to start from consumption figures established in technically developed countries. The data surveys available in Mali start from the assumption of imported, high-priced aluminium and are therefore underestimated in terms of locally available, cheaper metal. The estimation to follow is therefore based on general information concerning geographic, ethnographic and economic conditions.

Long range planning has set the following main development targets :

- irrigation agriculture,
- expansion of electric power production,
- industrial expansion.

The three main trends envisaged for industrial expansion include

- industries using local raw materials, primarily agricultural,
- industries promoting agricultural productivity,
- import-substituting industries.

Demand for aluminium products may therefore be expected to arise in the following fields.

- in irrigation: irrigation pipe and fittings,
- in construction: scaffolding, aluminium cladding, corrugated sheet, doors and windows etc., fittings and fixtures, railings, stairs, ladders and the like,
- in agriculture: packaging (foil, cans, etc., ) aluminium pieces for machinery and implements
- household: holloware including water bottles etc.

To give a general idea, this demand in fabricated products may be estimated e.g. to entail the following demand in semis :

| | |
|---|---|
| sheet and plate | 10 000 - 12 000 tpy |
| electric bus and rod | 2 000 - 3 000 tpy |
| extrusions | 3 000 - 4 000 tpy |
| cast products | 400 - 600 tpy |
| foil | 200 - 300 tpy |

Temporal development of demand upon semiproducts is first of all a function of manufacturing possibilities. The general situation concerning demand upon aluminium products is that the starting of production furthermore the increasing supply not only enables covering the fulfilment of demand but actually calls demands into being and sets up requirements not existing so far.

Such a way general demand generally develops along with the production possibilities, however, market will merely gradually accommodate to the new product.

Under such conditions and taking into consideration the general economy of the country and its progressive characteristics, upon the present knowledge there is no possibility for specifying in time the demand upon aluminium semiproducts.

Farther a possible way of development of semifabrication is being suggested by means of which the production realized according to the planned subsequent stages would meet the most probable requirements. (See para 4.4. )

## 4. Plant technology equipment, construction

### 4.1. Alumina plant

#### 4.1.1 Alumina technology

The following technological description is of informative character , as final technology may be given in the detailed engineering only.

The main technological parameters of the bauxite deposits considered as plant feed are the following.

| Deposit | $Al_2O_3$ % | $SiO_2$ % | Module |
|---|---|---|---|
| Sitadina | 46,5 | 3,00 | 15,5 |
| Baléa | 42,1 | 1,23 | 34,2 |
| Bamako-Ouest | 45,5 | 2,64 | 17,2 |

These figures qualify all three bauxites as highgrade Bayer alumina plant feed. However, boehmite content is too high in all three to permit treatment by the so-called Americanstyle or low-temperature Bayer process; the higher-temperature European-style Bayer process must be chosen in order to recover the alumina from the boehmite. Digestion temperature is envisaged at 240° C, which is sufficient to digest boehmite but does not entail the rather steep rise in investment cost above 250°C.

The differences among the three bauxites are slight enough to enable a common technological description to be given for all three.

/a/ Bauxite storage and preparation.

In order to facilitate transportation, bauxite will either have to be won in, or crushed to -300 mm size. Bauxite arriving from the mine will be stored in a storage area. Storage capacity equivalent to one month's consumption is to be envisaged.

Prior to digestion, bauxite will be crushed, and then ground to - 300 microns in plant liquor. After grinding, more liquor will be added so as to constitute a slurry containing 200 to 240 grams of solids per litre.

/b/ Desilication, digestion

Digestion liquor is prepared by mixing desalted strong liquor, spent liquor and fresh makeup liquor. The quantity of makeup liquor, to be used equals the total caustic $Na_2O$ loss in the Bayer plant cycle. Makeup liquor, prepared of either solid or liquid caustic, has a concentration of 450 to 550 gpl $Na_2O_c$. Digestion liquor contains 170 to 200 gpl $Na_2O_c$, with a caustic molar ratio of 3,6 to 3,8.

The slurry will be desilicated prior to digestion in a series-connected tank battery, in order to prevent the formation of deleterious scale on the heating tubes of the digestion equipment, out of the Na-Al silicate dissolving in the digestion liquor. Prior to entry into the desilication stage, the slurry is heated by flash steam in tubular heat exchangers.

A 300.000 tpy plant capacity requires, in view of the higher retention times envisaged and the time needed for maintenance, two digester batteries operated in parallel, each composed of say 12 vessels of 50 $m^3$ capacity. The first seven vessels are heated with flash steam, the next four with live steam at 70 at pressure, and about 300 to 320°C temperature.
The remaining one vessel is unheated and serves merely to ensure the retention time required for digestion to become complete.

Heat imparted to the slurry is recovered by flashing. The thermal energy thus won is used to heat the first seven digester vessels and the heat exchangers heating the slurry before desilication.

### /c/ Dilution, red mud settling, washing and filtration

Slurry discharged from the last stage of expansion has a temperature of 110 to 130°C, with a final caustic molar ratio of 1,5 to 1,6. Digestion efficiency is 87-90 percent. This slurry is diluted so as to adjust its solids content and $Na_2O_c$ concentration (140 to 150 gpl) to the values most favorable to precipitation and red-mud settling. This is performed by dilution with the overflow of the first red-mud washer, whose $Na_2O_c$ concentration is 60 to 80 gpl. To prevent precipitation of alumina hydrate from this diluted liquor, caustic molar ratio is raised to between 1,7 and 1,75 by adding spent liquor to the slurry.

Red mud settling, washing and filtration have for their main aim the production of high-purity aluminate liquor that will yield alumina pure enough to permit the smelting of electric-grade aluminium. A secondary aim almost as important as the first one is to recover to the maximum possible extent the values contained in the rejects (the "red mud"), among which caustic, a decisive factor of the alumina-plants production cost, is the most important.

The units performing these tasks include one or two settlers, three series-connected countercurrent washers, and a filtration unit. Settling and washing are performed in large (cca 35-m- diameter) single-compartment gravity settling tanks.

The overflow of the settler is hot aluminate liquor containing no more than 20 to 40 mgpl $Fe_2O_3$; its underflow is a red-mud slurry containing 350 to 450 gpl solids. This slurry is exposed to multistage countercurrent washing in order to remove all chemical values contained in it. Finally, its liquid content is removed in vacuum drum filters. The filter cake contains about 40 percent adsorbed moisture, whose $Na_2O$ content is not more than 0,5 to 0,8 percent on dry mud weight. The cake is then slurried with water to make it suitable for pumping, and pumped to the red-mud disposal pond.

The hot aluminate liquor overflowing from the settler is of insufficient purity to permit the production of high purity alumina. Its content of fine solid particles is to be reduced to below 10 mgpl, expressed in $Fe_2O_3$ content, in a process called control filtration. This is achieved by means of filter presses whose filtering efficiency is improved by means of a suitable precoat implanted on the screens. Six filters have been envisaged for control filtration.

/d/ Cooling of aluminate liquor

Liquor discharged from control filtration is at a temperature of 95 to 97°C. In order to increase its degree of saturation and to facilitate the precipitation of alumina hydrate, it is cooled to between 50 and 55°C. Its excess heat is used to warm spent liquor from 40 to 45°C to about 80 to 90°C. This is achieved in 8 plate heat exchangers, each of about 400 $m^2$ heat exchange surface. Cool aluminate liquor is ready to precipitate its alumina content; it is therefore called pregnant liquor. It is stored in tanks, then pumped directly into the first stage of the continuous precipitation battery.

/e/ Precipitation

Alumina dissolved in plant liquor on digestion is precipitated in the form of $Al_2O_3 \cdot 3H_2O$. Its precipitation is promoted by the addition of so-called seed, which is fine grained crystalline alumina hydrate. by further cooling the pregnant liquor by 8 to 10° C during its passage through the precipitator battery, by intense agitation and by a suitably chosen retention time.

Precipitation is performed in two batteries, each including 12 series-connected tanks of 2000 $m^2$ volume. Retention time envisaged is 50 to 70 hours, during which 46 to 50 percent of the alumina content is precipitated. The final caustic molar ratio of the spent liquor is 3,2 to 3,3.

/f/ Hydrate classification, filtration, washing and settling.

Hydrate slurry discharged from the precipitator battery is classified e.g. on an arc screen into a fine and a coarse fraction. The fine fraction is recycled to be used as seed, whereas the coarse fraction is the product hydrate from which alumina is made.

Product hydrate is processed in a washing-filtering unit including three series-connected vacuum drum filters of 60 $m^2$ filtration surface each. The filter cake on the screens is exposed to countercurrent washing with pure hot alkaline condensate. This removes all but traces of $Na_2O$ and other water-soluble impurities from the hydrate entering into calcination.

Hydrate emerging from filtration contains 10 to 12 percent absorbed moisture. It is either fed directly into the calcining kilns or stored.

/g/ Evaporation, desalting, caustification

Liquor is diluted rather considerably with water in the various washing stages. In order to restore its concentration to a value which permits its recycling into the process, part of its water content has to be evaporated. Water removed by evaporation is 2 to 2,5$m^3$ per ton of alumina. Evaporation is performed by counter- or parallel-current vacuum evaporators in 4 or 5 stages. Evaporators are heated with low-pressure steam, at 4,5 to 5 at pressure and 170 to 200°C temperature. Modern equipment makes this process very efficient, consuming about 0,3 t of steam per ton of evaporated water. During the alumina plant cycle, liquor becomes enriched in various salts irrelevant to the Bayer process proper, which are referred to by the common term "soda salt". Its most abundant single component is $Na_2CO_3$ (45 to 50 percent). Soda salt is usually precipitated out of the caustic liquor discharged from the evaporation stage. In order to reduce the caustic loss of the plant cycle, expecially where fresh caustic is high-priced, it may be indicated to caustify the $Na_2CO_3$ content by the addition of slaked lime.

/h/ Calcination

The filtered and washed alumina hydrate is turned into dehydrated alumina ($Al_2O_3$) by calcination in a rotary kiln at about 1200°C. The product emerging from the kiln consists of two crystalline varieties of alumina, alpha – $Al_2O_3$ and gamma – $Al_2O_3$. The residual heat of the alumina is recovered in a fluid-bed cooler. Alumina cooled to 100 to 120°C is fed to storage silos.

Stack gases issuing from the kiln carry with them a considerable quantity of alumina dust. This is recovered in a two-stage dust precipitator. In modern equipment, the heat of the stack gases is also recovered.

Calcination requires about 1000 Kcal per kg of alumina.

Keeping in mind also maintenance requirements, a 300.000 tpy alumina plant is usually equipped with two 500 ton-per-day calcining kilns and suitable accessory facilities.

4.1.2 Calculation of specific material consumptions

The laboratory tests detailed in the Appendix give alumina recoveries of 90 percent (or slightly more or less) for the bauxites tested, for digestion at 240°C and an IMR of 1,45. We have assumed the samples tested to be sufficiently representative in mineralogy, and hence in digestion and settling behaviour, of the deposits considered, although of course further testing will have to be carried out if and when the alumina-aluminium project is to be scrutinized in more detail. It is, then, on the basis of the test results now available that we have calculated specific consumptions.

Specific consumption of bauxite

Theoretical recovery is

$$\frac{Al_2O_3\% - SiO_2\% . 0,85}{Al_2O_3} . 100 \text{ percent}$$

where the factor 0,85 accounts for the $Al_2O_3$ loss (in kg) per each kg of $SiO_2$ in the bauxite. The actual recoveries stated above are less than the theoretical recoveries, primarily because the theoretical formula does not account for alumina hidden in iron-mineral lattices, unrecoverable by digestion at 240°C. We have calculated actual recovery in percent of theoretical recovery, finding values ranging from 96,3 to 92,6 percent. To be on the safe side, we have used the 92,6 percent value for all deposits. The quantity of bauxite needed to make one ton of alumina is, then, for the three groups of deposits envisaged,

2,6 t/t for Sitadina,
2,8 t/t for Baléa, and
2,6 t/t for Bamako-Ouest.

Specific consumption of caustic

Caustic losses will accrue at several points of the Bayer alumina plant flowsheet. The decisive loss factor is the so-called bound loss, in which caustic is bound to silicon and titanium during the digestion process, and the compounds thus formed are evacuated in the red mud.

Our tests have revealed the bound loss to be 0.8 $Na_2O/SiO_2$ in the red mud for Sitadina bauxite, and more than 1,0 for Bamako-Ouest bauxite. The higher value in the latter case is presumably due to a rather high percentage of $Na_2O$ attaching itself to titanium. In plant scale conditions this compound is usually decomposed by hydrolysis. We have therefore left this higher value out of consideration for the time being, all the more so since the Bamako deposit has turned out rather unfavorable for reasons detailed elsewhere. Hence, the consumption of caustic per ton of alumina produced would be

| | |
|---|---|
| 0,100 t/t | for the Sitadina deposit |
| 0,060 t/t | for the Baléa deposit |
| 0,090 t/t | for the Bamako deposit |

Specific fuel oil consumption

This value is practically independent of the grade of bauxite treated. If the alumina plant is sited so that it can buy electric power, fuel oil will be required for steam raising and calcination only. If, on the other hand, the alumina plant has to generate its own power, - this is the situation termed "insular power generation" then the generators will also burn fuel oil. Hence, two distinct fuel-oil consumptions will arise

- if electric power is bought: 0,350 t/t
- if electric power is generated in insular facility: 0,400 t/t including calcination

Specific consumption of electric power

Power required per ton of alumina produced is 300 kWh. In economic calculations, only bought power is evaluated as expense, whereas an insular facility entails an increase in first cost and in the cost of fuel.

### 4.1.3. List of main items of
### a 300.000tpy alumina plant equipment

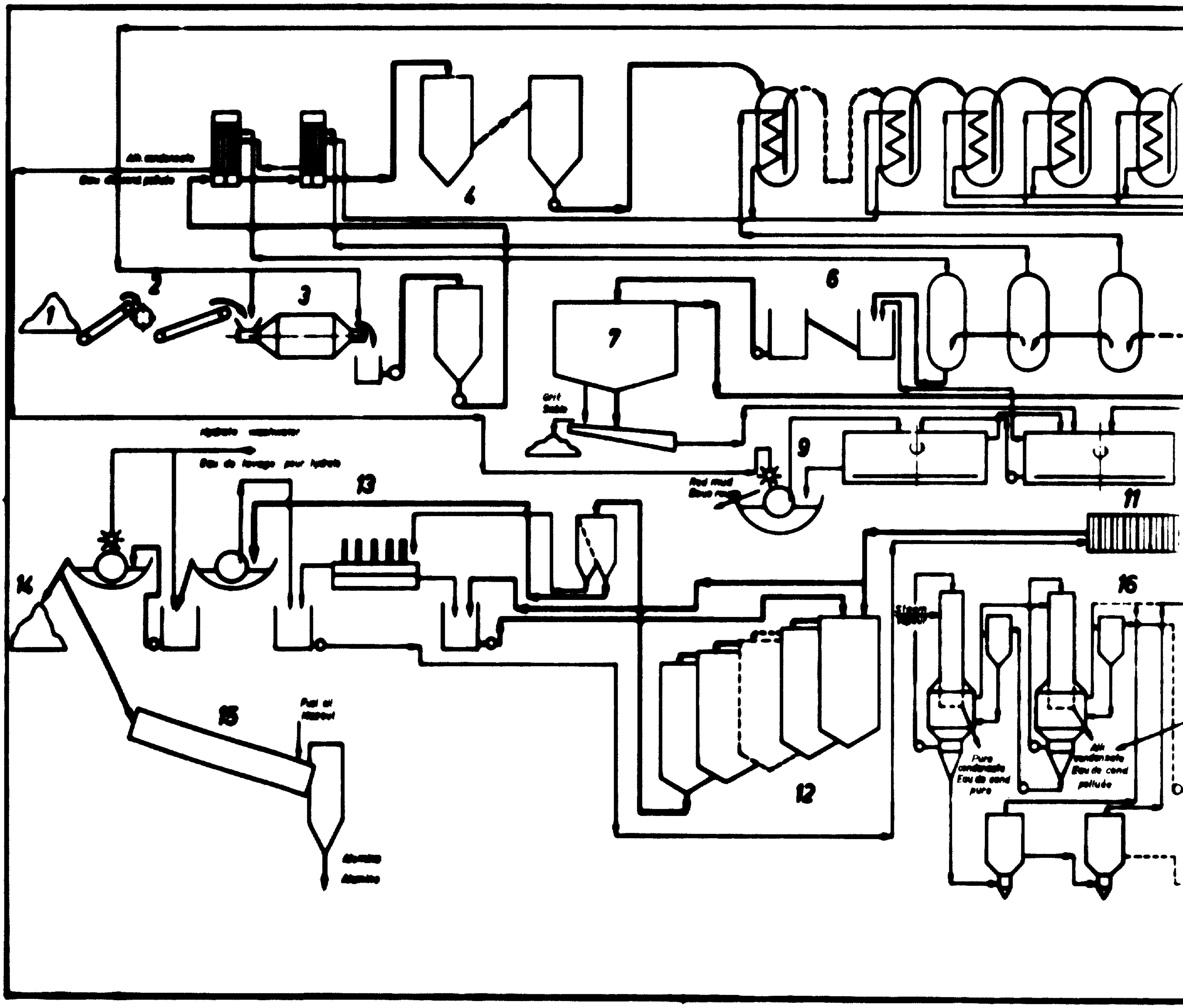
**Table 4.**

| No | Digestion | Technical data | No. of pieces | Plant unit |
|---|---|---|---|---|
| 1. | Differential crusher | output 120 t/h | 1 | Bauxite preparation |
| 2. | Wet-grinding ball mill | output 140 t/h | 2 | |
| 3. | Desilicating tanks | 1000 $cm^3$ | 6 | |
| 4. | High-pressure diaphragm pump | 240 $m^3/h$ | 4 | Digestion |
| 5. | Slurry preheater | 200 $m^2$ | 8 | |
| 6. | Digester vessel | 50 $m^3$ | 24 | |
| 7. | Flash tank | 30 $m^3$ | 18 | |
| 8. | Settling tank | 6000 $m^3$ | 5 | Settling, red mud handling |
| 9. | Drum filter for red mud | 50 $m^2$ | 12 | |
| 10. | Aluminate liquor control filtration unit | 150 $m^3/h$ | 6 | Aluminate liquor treatment |
| 11. | Plate heat exchanger | 400 $m^2$ | 8 | |
| 12. | Precipitation tank | 2000 $m^3$ | 24 | precipitation, hydrate filtration |
| 13. | Disk filter | 120 $m^2$ | 6 | |
| 14. | Drum filter for product hydrate | 60 $m^2$ | 4 | |
| 15. | Calcining kiln | 500 t/day | 2 | Calcination |
| 16. | Evaporating equipment | 120 t/h water | 1 | Evaporation |

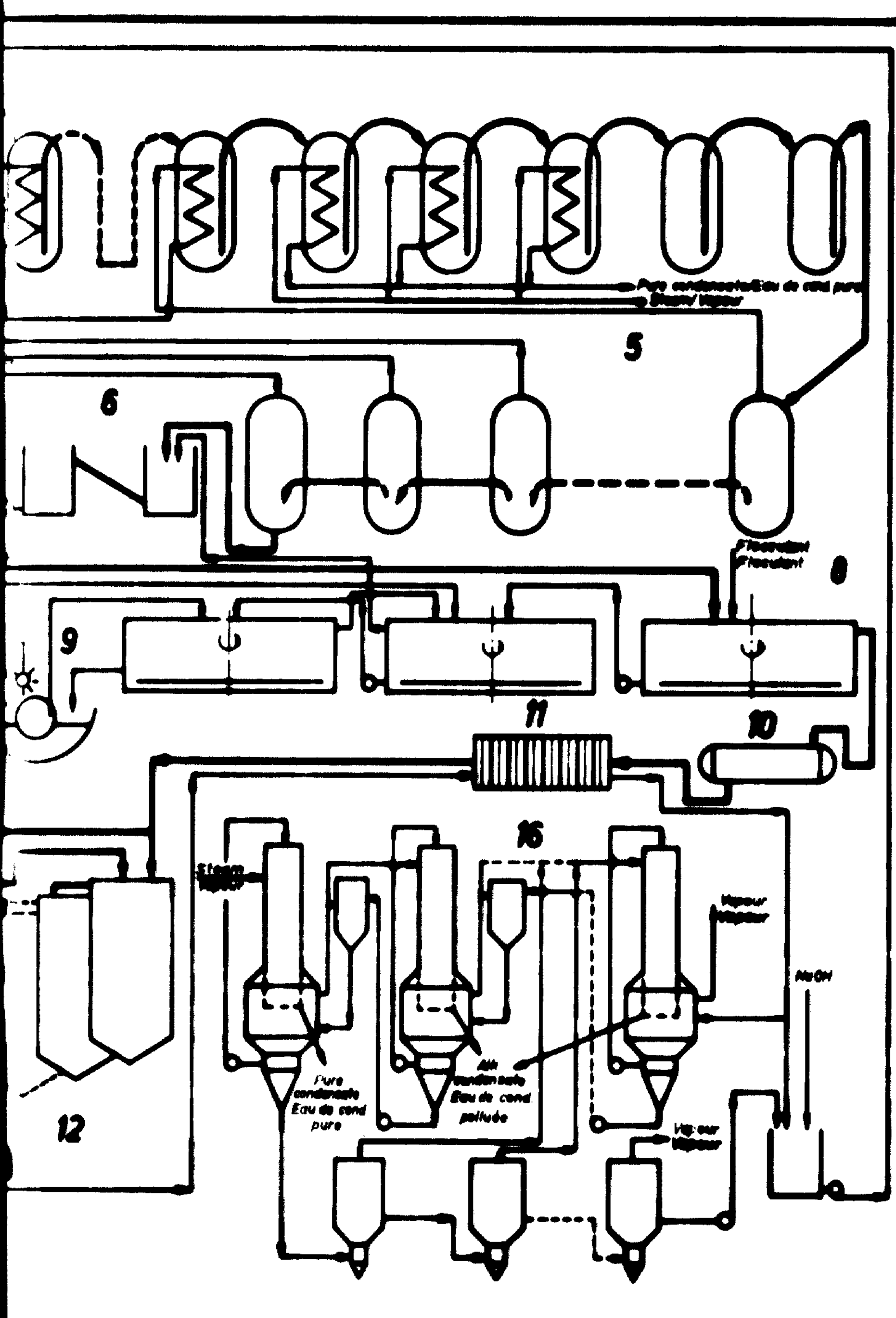
**Table 4**

contd.

| No | Designation | Technical data | No. of pieces | Plant unit |
|---|---|---|---|---|
| 17. | Fuel oil storage tank | 5000 $m^3$ | 2 | Storage |
| 18. | Liquid-caustic storage tank | 5000 $m^3$ | 1 | area |
| 19. | Centrifugal Compressor | 15.000 $m^3/h$ | 2 | Compressed |
| 20. | Turbo-vacuum pump | 400 $m^3/min$ | 2 | air<br>and vacuum<br>station |
| 21. | Steam boiler | 80 t/h | 3 | Steam |
| 22. | Steam turbine with generator | 15 MW | 1 | plant |


Alk condensate
Eau de cond polluée
1
2
3
4
6
7
Grit
Sable
9
Red mud
Boue rouge
11
Hydrate washwater
Eau de lavage pour hydrate
13
14
15
Fuel oil
Mazout
Alumina
Alumine
12
16
Steam
Vapeur
Pure condensate
Eau de cond pure
Alk condensate
Eau de cond polluée

SECTION 1



| | | |
|---|---|---|
| 16 | Evaporation | Evaporation |
| 15 | Calcining | Calcination |
| 14 | Hydrate storage | Stockage du hydrate |
| 13 | Hydrate filtration and washing | Filtration et lavage de l'hydrate |
| 12 | Precipitation | Décomposition |
| 11 | Aluminate liquor cooling | Refroidissement de la liqueur d'aluminate |
| 10 | Control filtration | Filtration de finissage |
| 9 | Red mud filtration | Filtration de la boue rouge |
| 8 | Red mud settling and washing | Décantation et lavage de la boue rouge |
| 7 | Degritting | Extraction de sable |
| 6 | Dilution | Dilution |
| 5 | Digestion and washing | Attaque et détente |
| 4 | Slurry storage and desilication | Stockage et désilification de la pulpe |
| 3 | Grinding | Broyage |
| 2 | Crushing | Concassage |
| 1 | Bauxite yard | Stockage de la bauxite |

ALUTERV
BUDAPEST
HUNGARY

MALI ALUMINA PLANT
TECHNOLOGICAL FLOWSHEET
USINE D'ALUMINE MALI
SCHEMA TECHNOLOGIQUE

# SECTION 2

## 4.2. Smelter

### 4.2.1 Smelter technology

All over the world, aluminium is smelted on an industrial scale exclusively by the Hall-Héroult electrometallurgical process. The melting point of alumina being higher than 2000°C, a flux of cryolite is employed to lower this temperature to about 1000°C. The melt is contained in a carbon-lined steel sheet cell ("pot") serving as the cathode. The anode, which consists of cokeified carbon, is hung from above into the melt. D. c. passed through the cell separates metallic aluminium at the cathode: oxygen separates at the anode and, combining with the anode carbon, escapes in the form of $CO_2$.

Molten metal on the cell bottom is sucked out once every or every other day. It is cast either into ingots - usual if the metal is to be sold on the market - or slabs and billets, for supply to semifabrication facilities. Part of the molten metal may be cast-rolled into sheet or wire, to serve as a pre-product for semifabrication.

a/ Cell types

The oxygen escaping on the electrolysis of $Al_2O_3$, combining with the carbon of the anode, will gradually consume the anode, thus, to sustain continuous cell operation, the anode must be made up at the same rate as it is consumed. There are two distinct ways of doing so, denoted by the terms "prebake" and "self-baking or Söderberg" operation.

In both cases, the anode is made of petroleum coke or coal-tar coke, and coal-tar pitch. All these materials must be very low in ash (less than 0,5 percent). After suitable granulation, these materials are mixed together into what is called the anode paste. This is an operation requiring specialized equipment and considerable care. Anode paste in its raw state is called green. Prior to its introduction into the electrolysis, it must be baked to make it electrically conductive and resistant to heat.

The fundamental difference between self-baking and prebake technology lies in the baking operation.

In a cell using self-baking anodes, the green paste is gradually fed on top of the gradually sinking anode mass. As it approaches the high heat of the cell, it gets gradually baked to the right consistency.

In a smelter using prebaked anodes, the green anode paste is pressed into blocks and then baked in a separate plant outside the smelter. Baking takes some 25 days. A number of such prebaked blocks are hung into the electrolysis cell, and gradually replaced as and when they are consumed by the electrolytic process.

There are further subtypes, not to be detailed here, within both fundamental types outlined above.

b/ Choice of cell type

In early aluminium smelter-history, pre-baking was the only process known. Self-baking soon after its invention displaced prebaking over most of the aluminium industry, but nowadays modern prebake anodes are preferred in newly established large smelters. Still, smelters using self-baking cells are also being built nowadays, and the world aluminium smelter capacity is using prebake and self-baking anodes approximately half-and-half. The advantages and drawbacks of the two types are as follows.

The prebake cell will sustain a heavier current density, that is, it will produce more aluminium per unit surface. This is a factor that tends to reduce first cost. The prebaking plant, on the other hand, requires a considerable investment in its own right. Also a prebake smelter building ("potroom") will cost slightly less.

In prebake potroooms, the atmosphere is contaminated exclusively by fluorine gases, whereas in self-baking potrooms, there is in addition a disagreeable coal-tar-pitch vapor. This type therefore requires more sophisticated and costly air purifying equipment and potroom design.

Prebake cells are easier to handle, but then, the prebaking operation itself is complicated enough to outweigh this advantage.

As regards the specific consumptions of materials and power, the overall conditions of the two smelter types are about identical. Detailed calculations have shown the first cost of a small self-bake smelter to be lower, primarily because the first cost of the prebaking plant can be dispensed with. For large smelters, the prebake solution will turn out to be more economical. The breakeven point between the two solutions is at about 100 000 tpy smelter capacity.

Since the aluminium smelting capacity envisaged for Mali in the present report would be 50 000 tpy in two stages, the self-baking type of cell design is to be recommended.

c/ Choice of cell size

The main parameter of cell size is the current that the cell will let pass. Increasing current will reduce first cost up to about 80 000 amps. Above this value, disturbances due to the strong magnetic fields generated by the heavy currents intervene and compensating these will cost more, so that first cost will increase above 80 000 amps. Today's modern 130 000- to 150 000-amp cells will prove economical in big smelters above 100 000 tpy capacity only. In view of the smelter size envisaged for Mali, 70 000-amp cells are recommended.
The rectifier equipment envisaged to supply the cells with d.c. is 72-KA, 750-V d.c. of 97 to 98 percent efficiency.

d/ Potrooms

In view of the hot climate and in order to provide satisfactory ventilation working, platforms shall be located at +4→5 m level. Potrooms with two row of cells in each are to be recommended. The 50 000 tpy capacity smelter would include two potlines, each comprising 160 cells, installed in four potrooms of 80 cells each.

### 4.2.2 Specific material consumptions

| | |
|---|---|
| Alumina | 1,92 ton per ton of aluminium |
| Cryolite | 0,03 " " " " |
| Al fluoride | 0,03 " " " " |
| Petroleum coke | 0,425 " " " " |
| Pitch | 0,17 " " " " |
| Power | 16 000 kWh a.c. per ton of aluminium |

The plantsite area required for the smelter is 20 to 25 hectares.

### 4.2.3 Main items of equipment and machinery for 50 000 tpy.

2x160 electrolysis cells, 70-KA

gas collecting and scrubbing equipment (fans, scrubbers, electrofilters smokestacks etc.)

12 pcs 25/5 ton electrically insulated travelling cranes
40 crust breaking rigs
stud cleaning equipment
compressor station
vacuum pump station
foundry to convert molten aluminium into ingots
and/or slabs and billets
8 holding furnaces
4 slab casting machines
anode paste plant equipment
power receiving station
2 rectifier sets - 72 kiloamp, 750-V d.c. silicon.

### 4.3. Alumina plant and smelter construction

When preparing the definitive feasibility study it will be necessary to carry out the engineering geological investigation of the most favored sites. However, even now we may state that in view of the sparse habitation of most of the sites selected, and of the general morphology and soil structure involved, it is extremely unlikely for the designer to run up against problems of foundation, soil bearing capacity, ground water, vegetation etc.

As regards the alumina plant, the only important thing to ensure in the way of protecting the environment is to prevent the liquid draining from red mud from entering watercourses: this is the more imperative, the larger the river (e.g. the Bafing at Manantali!)

As regards the smelter, the pitch vapour and fluorine content of the stack gases will gradually kill off vegetation down the dominant wind, within a distance of one to two kilometres. A comparatively expensive gas scrubbing equipment, to be installed on the potroom roof, would be needed to forestall this.

The alumina plantsite is to be of about 600 by 500 m size: for a 300 000 tpy plant this will hold in addition to the technological constructions also the auxiliary facilities and utilities, warehouses, workshops, office and social space, etc. It will further permit the doubling of the first, 300 000 tpy plant. The roads, the utility and technological piping layout must be designed to start with so as to permit such expansion.

The smelter site is to be of about 600 by 400 m size for 25 000 tpy output. This will accommodate, just as above, all auxiliary facilities etc. and will permit the doubling of smelter size.

The layout of the individual buildings and plant units depends partly on technological logistics and hookup, and partly on the hookup to external utilities (water, power, raw-materials inflow, product removal, sewage and waste water treatment, siting of red mud pond and smelter waste storage, etc.) The annexed typical layouts will have to be adapted to these conditions, in particular also if the alumina plant will be sited next to the smelter.

### Site levelling

In order to reduce site levelling volume, the individual plant sections and buildings may be located at different levels adapted to the terrain configuration so arranged as to let gravity assist materials flow in the plant. Of course, a level grade should underlie any one plant unit.

### In-plant road net

In-plant road net should have two accesses from the outside, one for heavy traffic and the other for light and pedestrian traffic. In-plant roads are one- or two-lane (4 and 6 m wide, respectively), and comprise a double-layer rock-chip or similar subgrade and a bituminous carpet. Layer thickness and width to depend on planned traffic.

### Sewage and industrial waste waters

Acid and alkaline wastes of the alumina plant are led to an industrial waste treatment plant.

In the smelter, the only industrial waste water of any consequence is generated in the foundry: this water is oily and must accordingly be led into an oil trap. Sewages are led into a sewage treatment unit. Rains running off the buildings and the paved outside areas should, in view of the heavy rains to be expected, be led off in open ditches.

### Red mud pond

Quantitywise red mud is the most important waste of alumina production. 300 000 tpy of alumina will give rise to 450 000 $m^3$ red mud. Accordingly, the correct layout of red-mud storage volumes may be provided by the comparatively simple expedient of damming off tributary valleys by comparatively small-volume dams. Red mud arrives at the pond as an aqueous slurry through a pipeline; most of the liquid released by the mud is collected in canal , and returned to the plant for repulping further quantities of mud. Care must be taken to prevent the rest of the liquor from contaminating the ground water and the nearby watercourses.

## Smelter waste

A separate waste tip for used cathode carbon and refractory-brick debris is to be provided. This debris contains cyanides which are liable to be washed into the ground by rains; proper care should be taken to forestall any hazard to man or his environment accruing out of this situation.

## Architectural and structural work

### /A/ Alumina plant technology buildings

Under the climate of the region envisaged, most plant units can be installed in the open, which reduces the number of buildings required; what remains in full volume is foundation, paving and structural work (steel or reinforced concrete). Technology buildings might be steel or r.c.c. or combined, depending on economy and other external factors. Roofs and cladding might be of asbestos cement or aluminium corrugated sheet, with steel- or aluminium-framed doors and windows. No thermal insulation is required, but roofs and claddings are to be designed so as to provide a strong natural ventilation.

### /B/ Smelter technology buildings

The most important smelter buildings are the potrooms, equipped with travelling cranes. These are to be r.c.c. structures except for the roof structures which should be of steel. In order to improve natural ventilation, the cells and the cell-handling [redacted] are to be installed above the ground floor on a so-called stage at sufficient height to permit van traffic under the cells. The air flowing in under the cladding of the potroom, open all around, may rise through floor grids in the cell-handling [redacted] flow around the cells, and escape through roof vents.

Wall cladding and roof to be designed so as to combine maximum protection from rain with maximum natural ventilation. The entire r.c.c. structure to be designed so as not to obstruct air flow. Potrooms are connected by passages at handling-platform level. Of the rest of the technology buildings, the foundry hall and the anode paste hall, both provided with travelling cranes, are the most important; these usually have r.c.c frames with steel or aluminium doors and windows, largely a.c. or aluminium vorrugated sheet cladding and roofing, and to a lesser extent masonry walls.

Each technology building in both the alumina plant and the smelter requires office and social (changeroom, lavatory) space, transformer cubicles etc., amounting to 10 to 15 percent of total floor space.

### Non-technology buildings

The office, social and welfare buildings, warehouses and storage areas, auxiliary facilities and utilities, transformer houses etc. are of conventional design, largely r.c.c (partly precast, partly made on-site), with wall cladding and roofing designed so as to provide sufficient protection from sunshine, heat and rains according to the local conditions.

### /C/ Corrosion protection and safety

Except for the usual protection of concrete from alkaline liquors, no particular corrosion protection is required in the alumina plant.

In the potrooms, electric shock protection is to be a prime consideration even in architectural design. No particular corrosion protection of buildings is required, but damage to underground metal piping by stray currents should be prevented.

### /D/ Buildings and constructions outside the plant fence

Regional planning concerning housing, social, welfare, educational, commercial etc. facilities, utilities and amenities, and also the hookup to the regional infrastructure, must be provided for the area affected by the construction and operation of the plant and/or smelter.

Let us point out that if the alumina plant is sited next door to the smelter a saving of about 3 to 5 percent on the construction costs of both may be achieved (e.g. by reducing storage capacity for alumina, workshop, office and laboratory floor space, etc.)

The tables below give typical data concerning the building and structural work needed to construct an alumina plant, and smelter, respectively.

Symbols are as follows:

| | |
|---|---|
| B | plant unit housed in building |
| 0 | plant unit in open air |
| S | steel structure |
| RCC | reinforced concrete structure |
| M | masonry wall cladding |
| AC | Corrugated sheet roofing and wall cladding. |

**Table 5**

Typical data of construction required for 300 000 tpy alumina plant

| S.No. | Denomination | | Building | | | | | | Open air arrangement | | Note |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Basic area m² | Number of stories | Air volume m³ | Crane | Structure | Roofing and wall cladding | Basic area /m²/ | Foundation and supporting structure | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1. | Bauxite storage and preparation | O | - | - | - | - | - | - | 1000[x] | RCC:250m³ | [x] Refers to paved-area |
| 2. | Bauxite crushing | B | 300 | 2 | 1600 | - | RCC | AC+M | - | - | |
| 3. | Bauxite grinding | O+B | 360 | 3 | 5600 | - | RCC | AC+M | 200 | RCC:900m³ | reinforced concrete grinding mill foundations |
| 4. | Slurry storage | O | - | - | - | - | - | - | 2900 | RCC:700m³ | |
| 5. | High-pressure pump station | B | 1200 | 2 | 10000 | 5Mp | RCC+S | AC+M | - | - | |
| 6. | Digestion | O | - | - | - | - | - | - | 1680 | concrete:700m³ | |
| 7. | Red mud settling and washing | O | - | - | - | - | - | - | 10600 | RCC:600m³<br>concrete:300m³ | |
| 8. | Red mud filtration, Control filtration | B | 1800 | 2 | 29000 | 2x1Mp | S+RCC | AC+M | - | - | two-bay hall |
| 9. | Hydrate filtration, Hydrate storage | B+O | 2200 | 3 | 50000 | 2x1+ 3x2Mp | RCC+S | AC+M | 1200 | RCC:80m³<br>concrete:200m³ | |

| 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10. | Precipitation, makeup liquor storage | O | - | - | - | - | - | - | 3700 | RCC:5000m³<br>Concrete:1000m³ | |
| 11. | Calcination | O+B | 480<br>680 | 6<br>2 | 20000<br>11000 | -<br>3Mp | RCC | AC | 4000 | RCC:1300m³<br>Concrete:1000m³ | |
| 12. | Alumina silo | O+B | 2xØ 14m | - | 2x5000 | - | RCC | M | - | - | |
| 13. | Evaporation, Salt removal | O+B | 500 | 2 | 9000 | 2x3Mp | RCC+S | AC+M | 1800 | RCC:800m³<br>Concrete:700m³ | |
| 14. | Compressed-air supply | B | 980 | 2 | 13000 | 10/3Mp | RCC+S | M | | | |
| 15. | Caustic soda storage | | | | | | | | | | |
| 16. | Fuel oil storage | O | - | - | - | - | - | - | - | | Earth dam surrounding space for two 5000m³ tanks |
| 17. | Power receiving station and switchgear | O+B | 600 | 2 | 6800 | - | RCC | M | - | - | |
| 18. | Transformer station | O+B | - | - | - | - | RCC | M | - | - | Open-air transformers Covered switchgear |
| 19. | Cooling tower | O | - | - | - | - | - | - | 600 | - | |
| 20. | Water supply | O+B | - | - | - | - | RCC | M | 1800 | - | |
| 21. | Water treatmt. | O+B | - | - | - | - | RCC | M | 1800 | - | |
| 22. | Plant laboratory | B | 600 | 2 | 4200 | - | RCC | M | - | - | |
| 23. | Central laboratory | B | 1000 | 2 | 7800 | - | RCC | M | - | - | |
| 24. | Engineers' offices | B | 800 | 4 | 10800 | - | RCC | M | - | - | |

| 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 25. | Management , social space | B | 1500 | 4 | 21000 | - | RCC | M | - | - | |
| 26. | Technological materials store | B | 1200 | 1 | 6000 | - | RCC | M | - | - | |
| 27. | Central workshop | B | 1800 | 1 | 1500 | 5Mp | RCC | M | - | - | |
| 28. | Central warehouse | B | 1800 | 1 | 1200 | 5Mp | RCC | M | - | - | |
| 29. | Garage and repair shop | B | 940 | 1 | 4500 | 3Mp | RCC | M | - | - | |
| 30. | Gatekeeper's lodge at ligh traffic entry | B | 80 | 1 | 300 | - | RCC | M | - | - | |
| 31. | Gatekeeper's lodge at heavy traffic entry and weigh bridge | B+0 | 80 | 1 | 300 | - | RCC | M | - | - | |

Table 6.

### Typical data of construction for main plant units of a 90000 tpy aluminium smelter

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Central control | B | 1000 | 2 | 7000 | - | RCC | M | - | - | - |
| 2. | Rectification | B | 2x600 | 2 | 2x6000 | - | RCC | M | | | |
| 3. | Potrooms | B | 4x8400 | 2 | 4x126000 | - | RCC+S | AC | | | |
| 4. | Compressed-air supply | B | 400 | 2 | 5000 | 10/3 Mp | RCC | M | | | |
| 5. | Foundry | B | 5000 | 1 | 40000 | 10/3 Mp | | | | | |
| 6. | Auxiliary facilities | B | 4000 | 1 | 20000 | | | | | | |
| 7. | Silo | O | - | - | - | - | RCC | - | | | 2x7900 $m^3$ if alumina plant is not next door |
| 8. | Central warehouse | B | 4000 | 1 | 20000 | - | RCC+S | M | | | |
| 9. | Central workshop | B | 5000 | 1 | 50000 | 5 Mp | RCC+S | M | | | |
| 10. | Management, social space | B | 2000 | 4 | 28000 | - | RCC | M | | | |
| 11. | Engineers' offices | B | 800 | 3 | 8400 | - | RCC | M | | | |
| 12. | Central laboratory | B | 1000 | 2 | 7000 | - | RCC | M | | | |
| 13. | Anode paste plant | B+O | - | - | 80000 | 2x5 Mp | RCC | M | | | 2000 $m^2$ in open area arrangement |
| 14. | Garage and repair shop | B | 540 | 1 | 4500 | 3 Mp | RCC | M | | | |

## 4.4. Considerations concerning the establishment of a semis plant

Aluminium semis production is capital intensive and requires a comparatively large number of qualified personnel. The market is usually slow to recognize the merits of the new products. It is therefore indicated to set up and expand the semis industry in a slow gradual fashion.

On the basis of the above estimate of demand but with these introductory remarks in mind we have conceived the following outline project, viable in our opinion, of establishing a semis industry in Mali

### 4.4.1. First stage

One of the most verstile items of aluminium semifabricating equipment is the extrusion press, it may be used to produce rather a broad range of profiles, pipe, flats, and conductors (bus bars, cables and wires). This is why we recommend a press as the first stage of the semifabricating industry.

The press uses extrusion billets cast at the aluminium smelter. It's annual production program would be

| | |
|---|---|
| Profiles | 2500 tpy |
| scaffolding pipe | 500 " |
| Irrigation pipe up to 150 mm OD | 1000 " |
| Electric conductor /cable etc/ | 2000 " |
| Altogether | 6000 tpy |

(Let us point out that actually it is considered more up-to-date to produce wire and cable by cast-rolling molten metal at the smelter.)

Equipment for the extrusion plant would include

- one 2500 ton multipurpose press
- one 2500 ton rod press
- tempering and annealing furnaces, other treating and possibly drawing equipment.

| | |
|---|---|
| floor space required | 5000 $m^2$ |
| power consumption | 5 MW/1500 kWh/t |
| total weight of machinery and equipment | approx. 1000 t |
| construction period | 2-3 yrs |
| labor demand | 18-20 hrs/t |

Simultaneously with the press one would construct a wire drawing and cable making mill. .The starting material is Almelec rod (EAlMgSi 0,5) of about 8-9 mm dia. This alloy has that advantage over unalloyed metal that owing to its strength it will replace ACSR (Aluminium Cable Steel Reinforced).

Production program:

- 19- and 37-strand cables made of 1,8- to 3,0-mm dia wire or similar products

Equipment required:

2 pcs nine-reel wire drawing machines
3 pcs high-speed tubular cable machines

Tempering and annealing furnaces, drying ovens, other miscellaneous equipment

First cost of wire-cable mill:

The press and wire-cable mill could suitably be situated close to the most extensive market, possibly at Bamako.

### 4.4.2 Second stage

Sheet cast-rolling mill to satisfy the country's demand for aluminium sheet

Production program

10 000 to 12 000 tpy sheet, plate and band up to
1200 mm width

**Equipment required**

furnace row
cast-rolling machine
cold-rolling table
tempering, annealing, treating etc. equipment
cutting equipment
heat-treatment furnaces

The base material is molten aluminium, so that siting this mill next to the smelter is recommended.

A corrugating street is required to produce corrugatet sheet. The base material for this unit is sheet made at the cast-rolling mill. The corrugating mill should be sited next to the most extensive market, e.g. at Bamako.

Semifabrication should comprise a casting shop. Since the construction of such a foundry is now underway at Bamako, it would suffice to raise its capacity to the desired value. Let us point out that 1000 tpy of extruded irrigating pipe alone would require some 100 tpy cast couplings and other fittings.

## 5. Infrastructure; transportation

### 5.1. Infrastructure required for an alumina-aluminium industry and the conditions of its realization

Like all heavy-industry investments, an aluminium industry requires a great deal of infrastructure, and that even if the industry to be established is not fully integrated, but one or another of the links in a fully integrated chain are to be realized only. The aluminium industry requires lots of electric power, a fair-sized water supply, and the transportation of substantial quantities of raw and auxiliary materials and products.

By the term infrastructure we shall mean all the investments, conditions and circumstances external to the "plant fence" which have to be realized/ satisfied in order to permit the economical operation of the plant. Many of these conditions, and some additional ones besides, are to be satisfied also during plant construction. In the construction period, it is not so much the tonnage to be transported that may cause problems but the size of certain pieces of equipment (such as large digester vessels, to be transported in one piece; various pieces of calcining kilns; smelter cells etc.). The transportation of modern alumina-plant and smelter equipment may be a problem even on a 1435-mm gauge railway (the gauge is 1000-mm in Mali), and comparatively modern highways.

Clearly, transportation routes during both construction and production must be all-season, as the interruption of deliveries during the off season would require the provision of very large storage capacities for bauxite alumina, fuel, anode paste, caustic etc., with additional labor required for the operation and maintenance of these. A special problem in exploiting the bauxite resource of Mali is that some 650 kms of the natural evacuation route to the seashore pass through Senegalese territory (or along the Senegal-Mauritanian border), and alternative outlets towards Guinea or the Ivory Coast are not more favorable, either.

In summary, an alumina-aluminium industry in Mali will require considerable infrastructural investment. We shall outline the actual situation in

Section 3 and the volumes to be transported in the various cases envisaged in Section 2.

## 5.2. Volumes to be transported

(Raw and auxiliary materials plus products)

We shall first consider transport volumes for a 300 000 tpy alumina plant and a 50 000 tpy smelter, whilst pointing out that volumes vary linearly as plant capacity.

300 000 tpy alumina plant

Inputs:

| | | | | | |
|---|---|---|---|---|---|
| Bauxite (depending on grade) | 800 | to | 850 | thousand | tpy |
| Fuel oil (including consumption of power plant) | 105 | to | 120 | " | " |
| Caustic soda (solid) | 20 | to | 30 | " | " |
| Miscellaneous | 5 | | 5 | " | " |
| Total inputs | 930 | to | 1005 | thousand | tpy |

Output (alumina)

| | |
|---|---|
| Total output | 300 000 tpy |
| total inputs plus outputs of alumina plant | 1 300 000 tpy |

Bauxite would be procured from domestic sources, the rest of inputs would be imported practically in toto. Even though the transportation of bauxite predominates, the volume of raw and auxiliary materials to be imported still adds up to about 150 000 tpy.

50 000 tpy smelter

| | | |
|---|---|---|
| Inputs | Alumina | 100 000 tpy |
| | Anode paste, cathode materials | 30 000 tpy |
| | Fluorine salts | 3 200 tpy |
| | Miscellaneous | 2 300 tpy |
| Total inputs | | 135 500 tpy |
| | of which 35 000 tpy is imported | |
| Output | Metal | 50 000 tpy |
| Total inputs plus outputs of aluminium smelter | | 185 000 tpy |

The bauxite mine is not discussed separately because - bauxite being won open-cast - the inputs are negligible against those of the alumina plant and smelter.

Considering the total inputs and outputs of a 300 000 tpy alumina plant and 50 000 tpy smelter, there is need to transport, load, unload and partly transload a daily 4000 tons, assuming the flow of commodities to be uniform.

We may state in summary that, whichever siting variant shall be selected, the transportation volumes involved will represent a heavy load on transportation facilities.

## 5.3. Actual state of transportation facilities; expansion projects in hand

### 5.3.1 Road network

The entire road net of Mali today has an aggregate length of about 12 000 km; about 60 percent of this are all-weather roads.

From an engineering viewpoint, roads are subdivided in six classes, as follows.

I. asphalted roads, more than 5 m width
II. idem, less than 5 m width
III. laterite roads, more than 6 m width
IV. idem, less than 6 m width
V. improved tracks,
VI. tracks

The actual distribution of the above-stated 12 000km of road over these categories is as follows.

| | | countrywide | in the presumable alumina-aluminium industry area |
|---|---|---|---|
| I. | category | 800 km | - |
| II. | " | 500 | - |
| III. | " | 800 | 60 km |
| IV. | " | 400 | 10 |
| V. | " | 2700 | 1000 |
| VI. | " | 6800 | 2000 |
| | | 12000 km | 3070 km |

We feel that the above figures give a striking demonstration of the problems facing infrastructural development in connexion with an alumina-aluminium industry.

About the possible development of the road network in the presumable alumina-aluminium industry area the following information was available.

- the projects for a road of 13-ton axle load and 9-m width between Satadougou and Bafoulabé, sufficient for the purposes of the alumina-aluminium industry, have been prepared, but in lack of funds this road does not figure among the high-priority projects,
- a detailed project has been prepared for the modernization of the Bamako-Siguiri road, which is actually a laterite road maintained by motorgrader,
- the modernization of the Kayes-Bakel road is being planned,
- finally, in order to lighten the load on the railroad, the development of the track between Bamako and Kita is being planned; this project might be started in 1973, but no funds are available for the time being.

All in all, the roads required for the transportation connected with the alumina-aluminium industry, of sufficient width and load capacity, cannot be expected to be available in the foreseeable future.

As regards the ton-kilometre cost of trucking on existing roads we could acquire no unambiguous information, but tend to accept the value of 4¢per ton-kilometre figuring in an earlier study.

This figure notwithstanding, we have assumed in the present Report transportation over roads designed and built for the purpose, in a truck fleet owned and operated by the alumina-aluminium company, at a mean speed of 40 kmph, in units of 25 ton minimum size, to cost 2 ¢ per ton-kilometre; experience has shown this figure to be realistic in a well-organized and well-managed trucking operation.

In calculating infrastructural investment we have made use of the following figures.

First cost of road, with conventional small-size construction and conventional road bed

| | |
|---|---|
| Category I | $ 62.000 per km |
| Category II | $ 44.000 " " |

The other categories do not enter into consideration for reasons of size and load capacity.

### 5.3.2 Railroad

The Republic of Mali has a single railroad line of total length 1290 km between Dakar and Koulikoro, of which 645 km are on Malian territory; the rest runs through Senegal. After passing the Senegalese frontier, the railroad trace touches Kayes, Mahina, Kita and Bamako. Its Bamako-Koulikoro segment is just 30 km long.

This single-track railroad is of 1000-mm gauge, with 30,5 kg/metre weight rails.

The actual rolling stock of the railroad carries a yearly 325 000 tons of freight approx. By suitable maintenance of the existing track it is planned to augment traffic by 10 percent per year.

The median transport demand stated above would raise actual throughput by amounts, which could not be handled by the existing rolling stock and track unless a substantial modernization is carried out (lengthening station rails, installing more modern signalling equipment, laying heavier rails etc.) In an extreme case, laying another track might to be envisaged.

Further information regarding the railroad, of interest in the context of the present report, includes the following.

- maximum loading width permissible is 2910 mm, which - as referred to farther above - limits the size of heavy and bulky equipment (digester vessels, pieces of rotary kilns, electrolysis cells etc.) to be transported by rail. The logical alternative would be to ship these by barge up the Senegal to Kayes and by special truck from there to the plantsite.
- maximum gross train weight, 750 t
- maximum trainload, 500 t
- average freight-train speed, 30 kmph
- annual traffic non-uniform, seasonal
- existing locomotives are 1100- to 1200-HP
- the increase in throughput to be expected would require 1800-HP locomotives to be procured (of axle group 3BB or 4BB),
- from the Senegalese border to Bamako there are altogether 23 stations, 11 to 40 km apart,
- most of the stations are equipped with a bypass and a shunting track. Actual track length ranges from 176 to 70 m.

Railroad transport may be affected by circumstances other than just technical. The fact that half of the Dakar-Niger railroad is on Senegalese territory might put the Malian railroad company in a difficult position in certain situations.

As far as we have been informed about future plans, it is planned to augment actual throughput by some 50 percent in a first stage, by improving and modernizing the existing line. With a view to this, the following have been envisaged:

- increasing the load capacity of several bridges,
- replacing 30,5 kg/m weight rails by 45 kg/m ones,
- procurement of new rolling stock.

There exists a detailed project for a railroad through Bamako-Siguiri-Kouroussa, to join the Conakry-Kankan railroad of Guinea. We have not, however, seen this project.

We have read some news concerning the possible financing of this railroad from external sources. The building of this line would, of course, introduce into the frame of reference of the present subject an element which we could not, for the time being, take into consideration.

Let us finally give some approximative figures concerning the cost of railroad building and modernization.

| | |
|---|---|
| Modernization and reconstruction of existing line | $ 20,000 per km |
| Building of new line | $ 80,000 per km |
| 35-ton conventional freight cars | $ 18,000 a piece |
| 1800-HP Diesel locomotives | $ 534,000 a piece |

### 5.3.3 River transportation

Freight transportation on the two main waterways of Mali - the Niger and the Senegal - is minimal at present. The Niger, of no interest for the present Report, is navigable over a length of some 100 km, and even that only seasonally.

Transportating iron ore from Kayes to the sea in barges of very shallow draft (20 cm) has been predicted to cost 5 $/t. Projections are 2 $/t for 60-cm draft and 1,5 $/t for one-metre draft.

A number of studies, most of them under the auspices of the UNDP, have been prepared concerning the future of navigation on the Senegal. Most of these studies also discuss the benefits of raising and stabilizing the discharge of the Senegal to other sectors of the economy (irrigation) agriculture, power generation transportation of other mining products, etc.) As stated elsewhere in this report, it is the Manantali Project that seems - at least in the context of the present Report - to provide the greatest aggregate benefit to an alumina-aluminium industry, as it would provide a sustained year-round power output of 100 MW, and ensure a year-round minimum discharge of 300 $m^3$/sec for the Senegal at Kayes, permitting the use of vessels of one-metre draft.

Detailed study on the navigability of Senegal river put at our disposal concerning the establishment of the power plant at Manantali unequivocally mentions the section between the sea and Bakel only. In our study, however, this navigable section has been extended up to Kayes by keeping in mind, that there are none of such obstacles along the river reach between Bakel and Kayes hindering our suppositions.

We considered also the question of possible navigability between Kayes and Manantali, as the problem is motivated and evident. Our delegation went along the route between Kayes and Bafoulabé and came to the statement, that the making navigable of the section mentioned - taking also the Félou-falls into consideration - could be achieved, however, at considerable expanses. Still higher would be the investment costs of the section between Bafoulabé and Manantali.

According to our opinion the suitable establishment of the navigable trace would need excess expenses by 15-20% (about $ 13,8 m) as compared to that of the allocated for the public road (of about 230 km) between Kayes and Manantali. That is why the solution for the public road has been chosen between Manantali and Kayes, not to mention other utilization possibilities of the road in question.

# 6. Viability of the aluminium industry

## 6.1. Alumina Plants

### 6.1.1. Economic comparison of alumina plant siting variants

The eight variants considered have been listed in Section 3.1. Economic comparison of these was based on the following considerations.

- Bauxite grade will affect bauxite and caustic soda consumption and hence also the cost of these raw materials per ton of alumina produced.

- Power supply to the alumina plant depends on whether the plant can buy power from a grid, or whether power is to be generated in a plant-owned facility. In the variants where power can be bought, we have calculated with the price of bought power, whereas in the other variants we have taken into account the increased fuel oil consumption of the alumina plant's steam/power plant.

- Investment cost of the powerline in the first case and of the steam/power plant in the second depends on the power supply system chosen. The respective differences have been taken into account as affecting the first cost of the investment.

- The individual plant siting variants raise different demands concerning transportation as regards both the bringing together of raw and auxiliary materials and the removal of the product. These differences are reflected by differences in freight cost.

In our calculations we have made the following assumptions.

- Bauxite was costed at $ 1,50 per ton.

- Caustic and fuel oil were costed at world market prices, cif African seaport without customs, tariffs and taxes, at $ 70 for caustic and $ 18 for fuel oil.

- Price of bought power - assuming one-third of the Manantali Project's depreciation to be borne by the power price - has been estimated at 0,52 ¢/kWh.

- The first cost of a power line was assumed at 10 000 $/km; the increase in the steam plant's first cost required to equip it for power generation was assumed at $ 3 million. The annual debt servicing charges of these investments were assumed as 15 percent p.a. of first cost (or first-cost difference).

- In calculating freight costs we have assumed the Senegal River to be navigable downstream of Kayes. Freight cost of river transport was assumed at $ 3 per ton, including $ 1 for loading and unloading.

- For all variants located next to the Dakar-Niger railroad, transportation by railroad was assumed between the plant and Kayes. The railroad freight cost was calculated using the railroad tariff in force.

- Trucking has been costed at 2 ¢ per ton-kilometre, assuming haulage in 25-ton conventional (non-off-highway) units.

The results of our calculations are stated in the annexed Table. Clearly, the two variants most worthy of further detailed analysis are

- alumina plant at Moussala, treating bauxite from Sitadina.
- alumina plant at Manantali, treating bauxite from Baléa.

Construction of the alumina plant at Moussala is advocated primarily by the closeness of the bauxite deposit. The Manantali site is, in addition to the higher grade of the Baléa bauxite, also favored by a comparatively short bauxite haulage route.

Our calculations reveal further that all variants involving a longish leg of bauxite haulage, and or a considerable volume of railroading, are rather unfavorable owing to high freight costs. This is why the exploitation of the Bamako-Ouest deposits seems altogether unjustified under the present conditions.

Let us point out further that - although this has not been taken into account in our calculations - the Manantali site is to preferred to the Moussala site because Manantali is at a reasonable distance from the Sitadina deposit, too, so that this latter may serve as an alternative plant feed source in the more remote future and further because Manantali is the only reasonable location for an aluminium smelter, and siting the smelter next door to the alumina plant has a number of obvious technical and economic advantages.

Table 7.

## Comparison of siting-dependent operating costs of alumina plant siting variants

| Designation | Bauxite | Caustic | Fuel oil | Bought power | Freight cost | Debt servicing | Total |
|---|---|---|---|---|---|---|---|
| | dollars per ton of alumina | | | | | | |
| I. Sitadina | | | | | | | |
| I/1 Kayes | 3,90 | 7,00 | 6,30 | 1,56 | 23,73 | 1,25 | 43,74 |
| I/2 Mahina | 3,90 | 7,00 | 6,30 | 1,56 | 19,70 | 0,60 | 39,06 |
| I/3 Moussala | 3,90 | 7,00 | 7,20 | - | 13,96 | 1,50 | 33,56 |
| I/4 Manantali | 3,90 | 7,00 | 6,30 | 1,56 | 19,55 | - | 38,31 |
| II. Baléa | | | | | | | |
| II/1 Manantali | 4,20 | 4,20 | 6,30 | 1,56 | 17,30 | - | 33,56 |
| II/2 Boulouli | 4,20 | 4,20 | 7,20 | - | 20,26 | 1,50 | 37,36 |
| III. Bamako Ouest | | | | | | | |
| III/1 Bamako | 3,90 | 6,30 | 6,30 | 1,56 | 30,51 | 0,40 | 48,97 |
| III/2 Baoulé | 3,90 | 6,30 | 7,20 | - | 24,91 | 1,50 | 43,81 |

### 6.1.2 Production cost and net profit of the alumina plant:

As a sequel to the siting analysis described above, we shall examine in detail just two possibilities, notably

alumina plant at Moussala,
alumina plant at Manantali.

Since the bauxite resource available does not limit alumina plant size, we could, in our analysis of the relationship between plant size and profitability, consider four different plant sizes at both sites chosen: 300, 600, 900 and 1200 thousand tpy. The first cost and operating capital requirements of the individual variants are listed in Table 8.

Total investment cost + infrastructural cost are tabulated in Table 9.

Operating costs have been calculated for a 20-year period after start-up, as follows.

Bauxite cost was calculated as a function of the specific consumptions referred to above, at mining costs decreasing from $ 1,50 to 1,38 as plant size increases.

The costs of caustic, fuel oil and electric power have been calculated from the specific consumptions and prices stated above.

Miscellaneous materials have been costed at $ 6 per ton of alumina, independently of plant size.

Freight costs have been calculated farther above.

Customs duties have been calculated from the sixth year of operation onward, after caustic and fuel oil, at a rate of 30 percent. Let us point out that this item is a very heavy load on alumina-plant finance, especially in the larger-size plants, and no alumina plant will be capable to support customs duties higher than this.

Repair and maintenance cost has been uniformly assumed as 1,5 percent of first cost in each variant.

In estimating the payroll we have started from the assumption that in the initial phases of operation it will presumably be impossible to operate the plant with exclusively Malian personnel, and that it will be necessary to employ expatriate personnel, who would be phased out in about ten years.

Hiring expatriate personnel would require salaries much higher than those current in Mali, as follows:

| Designation | Salary of local employee, $ per year | Salary of expatriate employee, $ py |
|---|---|---|
| 1. Top management | 2000 | 17000 |
| 2. Middle management | 1000 | 13500 |
| 3. Qualified personnel | 800 | 10000 |
| 4. General labor | 250 | - |

Assuming modern technologies and equipment, the number of employees for the individual plant sizes would be as follows:

| | |
|---|---|
| 300 000 tpy | 730 employes |
| 600 000 " | 920 " |
| 900 000 " | 1130 " |
| 1200 000 " | 1290 " |

For overheads and administrative expenses we have assumed in addition to the payroll and materials cost mentioned above, $ 1 per ton for the 300 000 tpy plant, and progressively lower figures for the large-sizes plants.

Depreciation periods envisaged were 20 years for civil engineering and constructions and 10 years for machinery and equipment.

Table 10 shows the net cost of alumina production per ton of alumina produced and the depreciation for the first and tenth year of operation considered as characteristic.

In this table interests of credit to be raised in connection with the establishment of the alumina plant reasonably cannot figure among the net production costs as it is the function of an unknown credit and a financial form. Whe shall come back to the questions relating to the interest of the credit to be raised later on.

Production costs have been broken up in the table also conforming to the forms of financing indicating herewith the distrubition of payments as to which has to be covered by local currency and which by convertible currency. We would remark that customs duties comprise figures of the local customs.

The above-outlined considerations give the following rough estimates for the average net alumina production costs:

| | |
|---|---|
| 300 000 tpy | $ 50 per ton of alumina |
| 600 000 " | 48 " " " " |
| 900 000 " | 47 " " " " |
| 1200 000 " | 46 " " " " |

In our calculation of the net alumina-plant income we have considered three sales prices fob African seaport: $ 60, 70 and 80 per ton. Let us point out that, price trends being what they are, even $ 80 per ton is not unrealistic over the 20 years time span considered.

Net income was calculated as sales price less production cost plus depreciation, with 50 percent income tax subtracted from the sixth year of operation onward. The net income thus found plus the depreciation was considered as the net profit of alumina production.

In the knowledge of the net profits as defined above we have raised the question as to what would be the payout potential of an alumina plant in the first ten years of operation, that is, what would be its creditworthiness? Raising of this question is motivated firstly by the condition that in the present phase of making this study there is no information about the capital sources, respectively the very question is as to whether the relization of alumina plant is a realistic idea of a profitable capital investment possibility. Under such conditions in our investigation just by applying the concept of creditworthiness we tried to scan about the expectable profitability of the planned alumina plant. In this context, we have calculated the amount of credit that the profit generated by an alumina plant over the first ten years of operation could pay back, assuming interest rates of 3 and 6 percent. Calculation was performed by the discounted cash flow method taking into account also the debt servicing of other credits possibly to be raised during the payback period. This calculation reveals in essence the possible debt - to - equity ratios of alumina-plant financing.

The results of these calculations are summed up in Table 11, which states the income generated available for debt servicing in the first ten years of operation, and the credit that may be raised on this basis. These sums have been stated also in terms of percentages on first, cost, that is it has been stated what percentage the raisable credit of the first cost of the alumina plant (within the fences) is. We have to note, however, that data given in Table 11, cannot be directly deducted from Table 10, as in the course of determination of the calculation base of creditworthiness a 50 per cent income-tax has also been considered. It should be mentioned that in the course of investigation of creditworthiness the income retained in the alumina plant has not been taken into account, accordingly the net profit remaining after payment of taxes has entirely been used up for debt servicing of credits and interest payment. In case of demend for retainable income a percentage decrease of creditworthiness has to be expected. According to the above neither non of interest payment obligation due to own capital invested for the establishment of the alumina plant has been presumed.

What has to be kept in mind in the evaluation of these results in Table 11. that a 70 : 30 debt: equity ratio is an usual financing structure in alumina plants, and that creditors may well expect the investor to raise 30 percent at least of first cost in the form of equity. Hence, 70 percent creditworthiness may be considered as the limit of alumina-plant profitability.

Our calculations reveal that an alumina price of $ 60 per ton fob African seaport - which would mean a cif cost of about $ 70 in a European port - does not satisfy the condition of profitability. At a fob price of $ 70 per ton, profitability is marginal, depending on the interest rate, for plant sizes of 600 000 to 1 million tpy whereas at a fob price of $ 80 the larger-size alumina plants could bring a considerable profit.

In order to facilitate insight into the data thus provided we have plotted in Fig. 1. creditworthiness vs. plant capacity, alumina price and interest rate. For completeness, we have plotted also the case of zero percent interest. The figure is based on the data for the Manantali site.

For the investigation of financing possibility of investments connected with an infrastructure the creditworthiness also for the total investment (within the fences) plus infrastructure has been calculated. In Table 12 the percentual development of creditworthiness is shown in case from the credits going to be raised not only the investment of the alumina plant but those of the infrastructure have to be financed and no other financial source for debt servicing of credits but the attainable net profit by alumina production is available. (Hence enlisting of investments connected with the infrastructure and possible profit those of has not been considered in our calculation as for the time being there is no information neither on the measure of its utilizing possibilities available.)

Creditworthiness calculations on the total investment cost plus infrastructure indicate that the taking into consideration of the investments of the infrastructure worsens the creditworthiness by 10 per cent in the range investigated and thus the lower limit of alumina plant's capacity value which could be regarded as profitable would increase by 150 to 250 thousand tons.

Fig.2.indicates the creditworthiness values resulting from the total (investment + infrastructural) costs at various capacities, alumina price and interest rates.

A further characteristic of alumina-plant profitability is the aggregate net profit over the 20 years of operation considered, if all credit has been repaid over the first ten years. The relevant figures are listed in Table 13

Table 8.

## Investment costs of various size alumina plants at two selected localities

(within the fence)

| Designation | First cost | Operating capital | Total investment |
|---|---|---|---|
| | in million dollars | | |
| **Alumina plant at Moussala** | | | |
| capacity: 300 000 tpy | 89,6 | 6,6 | 96,2 |
| 600 000 tpy | 149,4 | 9,2 | 158,6 |
| 900 000 tpy | 201,8 | 11,2 | 213,0 |
| 1200 000 tpy | 250,3 | 13,3 | 263,6 |
| **Alumina plant at Manantali** | | | |
| capacity: 300 000 tpy | 86,3 | 6,6 | 92,9 |
| 600 000 tpy | 144,0 | 9,2 | 153,2 |
| 900 000 tpy | 194,4 | 11,2 | 205,6 |
| 1200 000 tpy | 241,2 | 13,3 | 254,5 |

Remark. Investment cost includes debt servicing prior to start-up.

Distributions of first cost of the Moussala alumina plant (e. g.)

| Capacity | Equipment and machinery m$ | Installation m$ | Civil eng. constr. m$ | Miscellaneous m$ | Interest. m$ | Total first cost $ |
|---|---|---|---|---|---|---|
| 300 000 tpy | 48,2 | 10,0 | 18,4 | 6,3 | 6,7 | 89,6 |
| 600 000 " | 80,3 | 16,7 | 30,7 | 10,5 | 11,2 | 149,4 |
| 900 000 " | 108,6 | 22,5 | 41,4 | 14,2 | 15,1 | 201,8 |
| 1200 000 " | 134,7 | 27,9 | 51,4 | 17,6 | 18,7 | 250,3 |

Table 9.

## Total /investment + infrastructure/ costs of various size alumina plants at two selected localities

| Denomination | | Total investment m$ | Infrastructure m$ | Total investment plus infra-structure m$ |
|---|---|---|---|---|
| **Alumina plant at Moussala** | | | | |
| capacity : | 300 000 tpy | 96,2 | 24,0 | 120,2 |
| | 600 000 tpy | 158,6 | 24,0 | 182,6 |
| | 900 000 tpy | 213,0 | 24,0 | 237,0 |
| | 1200 000 tpy | 263,6 | 24,0 | 287,6 |
| **Alumina plant at Manantali** | | | | |
| capacity: | 300 000 tpy | 92,9 | 25,5 | 118,4 |
| | 600 000 tpy | 153,2 | 25,5 | 178,7 |
| | 900 000 tpy | 205,6 | 25,5 | 231,1 |
| | 1200 000 tpy | 254,5 | 25,5 | 280,0 |

Table 10.

## Production costs of various size alumina plants at two selected localities in thousand dollars per year

| | Designation | Moussala alumina plant | | | | | | | | Manantali alumina plant | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 300000 tpy | | 600000 tpy | | 900000 tpy | | 1200000 tpy | | 300000 tpy | | 600000 tpy | | 900000 tpy | | 1200000 tpy | |
| | | 1. year | 10. year | 1. year | 10. year | 1. year | 10. year | 1. year | 10.year | 1. year | 10.year | 1. year | 10.year | 1. year | 10.year | 1.year | 10.year |
| 1. | Bauxite | 1.170 | 1.170 | 2.231 | 2.231 | 3.276 | 3.276 | 4.306 | 4.306 | 1.260 | 1.260 | 2.402 | 2.402 | 3.528 | 3.528 | 4.637 | 4.637 |
| 2. | Caustic | 2.100 | 2.100 | 4.200 | 4.200 | 6.300 | 6.300 | 8.400 | 8.400 | 1.260 | 1.260 | 2.520 | 2.520 | 3.780 | 3.780 | 5.040 | 5.040 |
| 3. | Fuel oil | 2.160 | 2.160 | 4.320 | 4.320 | 6.480 | 6.480 | 8.640 | 8.640 | 1.890 | 1.890 | 3.780 | 3.780 | 5.670 | 5.670 | 7.560 | 7.560 |
| 4. | Bought power | - | - | - | - | - | - | - | - | 468 | 468 | 936 | 936 | 1.404 | 1.404 | 1.872 | 1.872 |
| 5. | Miscellaneous materials | 1.800 | 1.800 | 3.600 | 3.600 | 5.400 | 5.400 | 7.200 | 7.200 | 1.800 | 1.800 | 3.600 | 3.600 | 5.400 | 5.400 | 7.200 | 7.200 |
| 6. | Freight cost | 4.088 | 4.088 | 8.376 | 8.376 | 12.564 | 12.564 | 16.752 | 16.752 | 5.190 | 5.190 | 10.380 | 10.380 | 15.570 | 15.570 | 20.760 | 20.760 |
| 7. | Customs duties | - | 1.278 | - | 2.556 | - | 3.834 | - | 5.112 | - | 945 | - | 1.890 | - | 2.835 | - | 3.780 |
| 8. | Repairs and maintenance | 1.344 | 1.344 | 2.073 | 2.073 | 2.800 | 2.800 | 3.474 | 3.474 | 1.198 | 1.198 | 1.998 | 1.998 | 2.698 | 2.698 | 3.348 | 3.348 |
| 9. | Payroll and social charges | 2.124 | 748 | 2.822 | 994 | 3.287 | 1.158 | 3.753 | 1.322 | 2.124 | 748 | 2.822 | 994 | 3.287 | 1.158 | 3.753 | 1.322 |
| 10. | Overheads and administrative | 300 | 300 | 450 | 450 | 600 | 600 | 750 | 750 | 300 | 300 | 450 | 450 | 600 | 600 | 750 | 750 |
| 11. | Net production cost | 15.086 | 14.988 | 28.072 | 28.800 | 40.707 | 42.412 | 53.275 | 55.956 | 15.490 | 15.059 | 28.888 | 28.950 | 41.937 | 42.643 | 54.920 | 56.269 |
| 12. | Depreciation: | | | | | | | | | | | | | | | | |
| | civil engineering construction | 1.070 | 1.070 | 1.795 | 1.795 | 2.420 | 2.420 | 3.005 | 3.005 | 1.080 | 1.080 | 1.800 | 1.800 | 2.430 | 2.430 | 3.015 | 3.015 |
| | machinery and equipment | 6.820 | 6.820 | 11.350 | 11.350 | 15.340 | 15.340 | 19.020 | 19.020 | 6.470 | 6.470 | 10.800 | 10.800 | 14.580 | 14.580 | 18.090 | 18.090 |
| 13. | Net cost plus depreciation | 22.976 | 22.878 | 41.217 | 41.945 | 58.467 | 60.172 | 75.300 | 77.981 | 23.040 | 22.609 | 41.488 | 41.550 | 58.947 | 59.653 | 76.025 | 77.374 |
| 14. | To be covered from net production cost: | | | | | | | | | | | | | | | | |
| | by convertible currency | 7.121 | 5.820 | 12.906 | 11.190 | 18.457 | 16.460 | 23.967 | 21.688 | 5.994 | 4.703 | 10.686 | 8.970 | 15.135 | 13.138 | 19.546 | 17.267 |
| | by local currency | 7.965 | 9.168 | 15.166 | 17.610 | 22.250 | 25.952 | 29.308 | 34.268 | 9.496 | 10.356 | 18.202 | 19.980 | 26.802 | 29.505 | 35.374 | 39.002 |

Table 11.

### Creditworthiness of various size alumina plants at two selected localities

(Figures in thousand dollars)

| Designation | [illegible] plantsite | | | | | [illegible] plantsite | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Income available for debt servicing | Credit that can be raised at | | Idem, in percent of investment | | Income available for debt servicing | Credit that can be raised at | | Idem, in percent of investment | |
| | | 3 % interest | 6 % | 3 % interest | 6 % | | 3 % interest | 6 % | 3 % interest | 6 % |
| **300000 tpy capacity** | | | | | | | | | | |
| fob alumina price $ 60 | 29561 | 23960 | 20768 | 24,91 | 21,57 | 27166 | 22034 | 19080 | 23,72 | 20,54 |
| fob alumina price $ 70 | 59561 | 46893 | 41819 | 50,20 | 43,47 | 57166 | 46367 | 40151 | 49,91 | 43,22 |
| fob alumina price $ 80 | 87691 | 70963 | 61480 | 73,77 | 63,88 | 84,443 | 68491 | 58309 | 73,72 | 63,84 |
| **600000 tpy capacity** | | | | | | | | | | |
| fob alumina price $ 60 | 75821 | 61284 | 53043 | 38,62 | 33,44 | 70691 | 57337 | 49650 | 37,43 | 32,41 |
| fob alumina price $ 70 | 136404 | 109898 | 95166 | 69,29 | 60,00 | 130318 | 105700 | 91530 | 68,99 | 59,74 |
| fob alumina price $ 80 | 181380 | 147086 | 127379 | 92,75 | 80,31 | 175570 | 142603 | 123313 | 92,95 | 80,49 |
| **900000 tpy capacity** | | | | | | | | | | |
| fob alumina price $ 60 | 124366 | 100791 | 87279 | 47,32 | 40,98 | 116961 | 94846 | 82148 | 44,14 | 38,96 |
| fob alumina price $ 70 | 208366 | 169003 | 146347 | 79,34 | 68,71 | 199761 | 162024 | 140304 | 78,80 | 68,24 |
| fob alumina price $ 80 | 275866 | 223751 | 193756 | 105,05 | 90,96 | 267261 | 216773 | 187713 | 105,43 | 91,30 |
| **1200000 tpy capacity** | | | | | | | | | | |
| fob alumina price $ 60 | 173691 | 140879 | 121983 | 53,44 | 46,28 | 163901 | 132936 | 115117 | 52,23 | 45,23 |
| fob alumina price $ 70 | 279976 | 227086 | 196643 | 86,34 | 74,60 | 268666 | 217915 | 188702 | 85,62 | 74,15 |
| fob alumina price $ 80 | 369976 | 300086 | 259856 | 114,10 | 98,58 | 358669 | 290913 | 251914 | 114,31 | 98,98 |

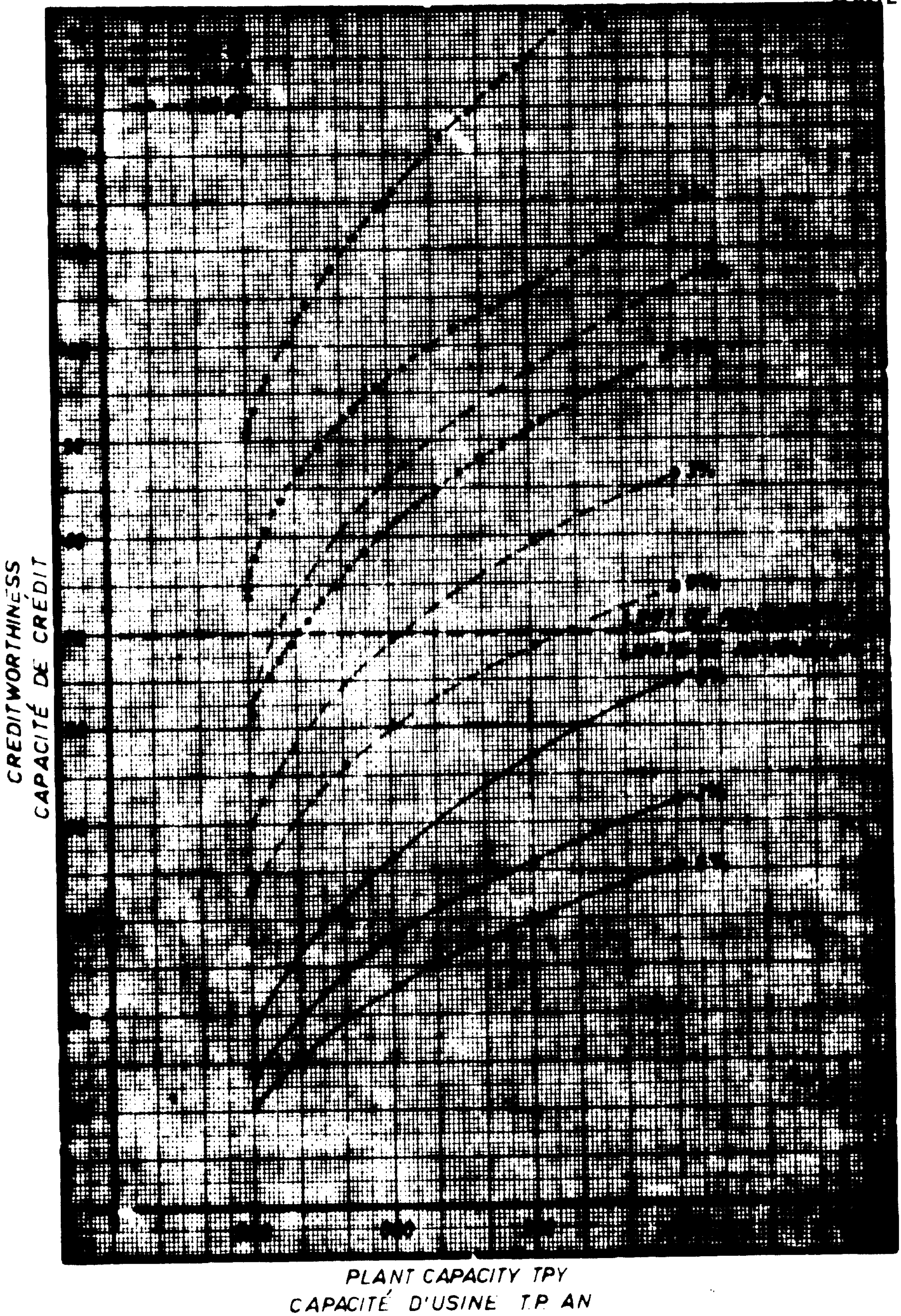
Table 12.

## Creditworthiness of various size alumina plants at two localities calculated on base of total investment plus infrastructural cost.

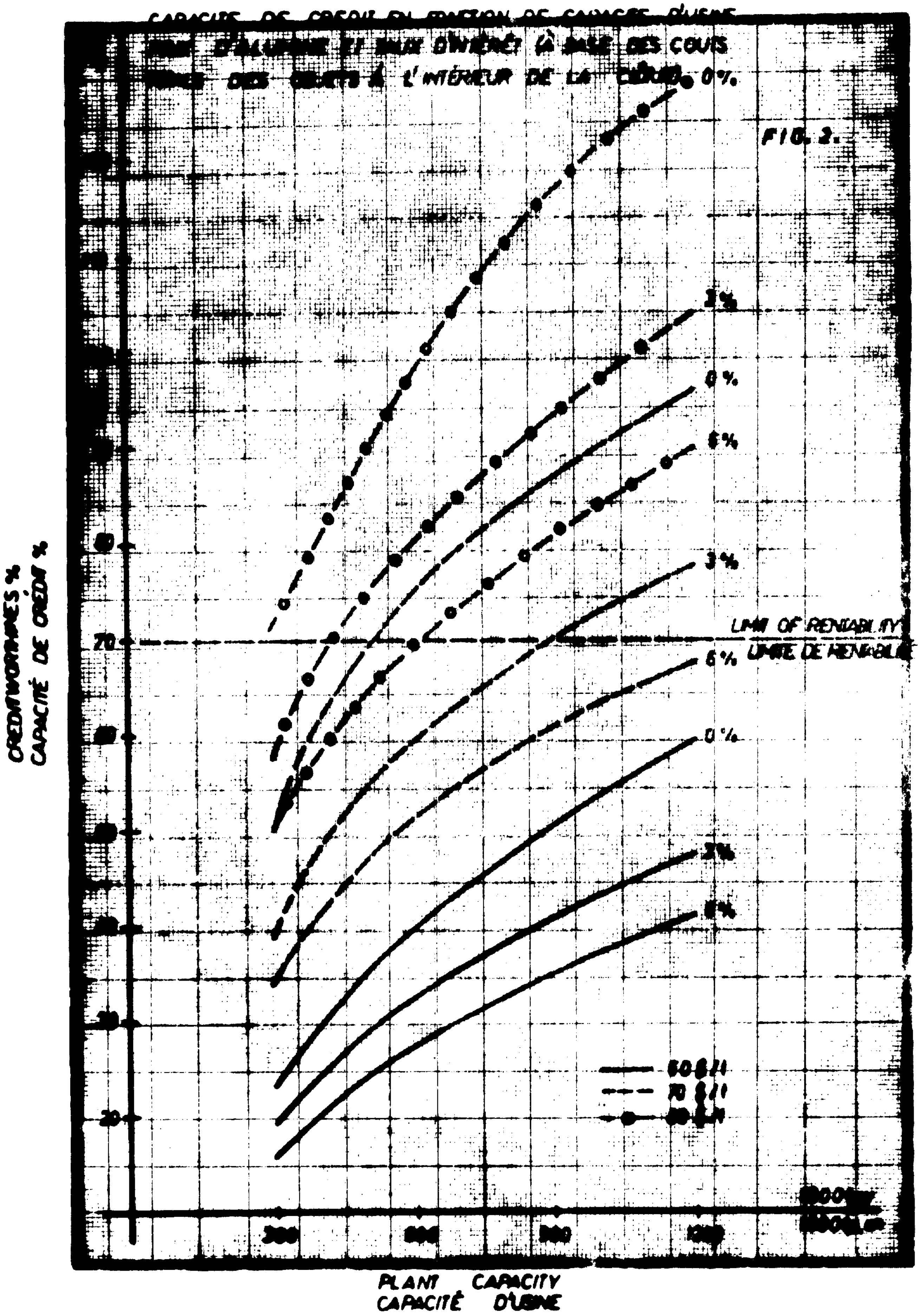
(Figures in thousand dollars)

| Designation | Income available for debt servicing | Mousenia plant site | | | | Income available for debt servicing | Manantali plant site | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Credit that can be raised at | | Idem, in percent of total inv. + infrstr. | | | Credit that can be raised at | | Idem, in percent of total inv. + infrstr. | |
| | | 3 % | 6 % | 3 % | 6 % | | 3 % | 6 % | 3 % | 6 % |
| | | interest | | interest | | | interest | | interest | |
| **300 000 tpy capacity** | | | | | | | | | | |
| fob alumina price $ 60 | 29.541 | 23.960 | 20.748 | 19,93 | 17,26 | 27.166 | 22.034 | 19.080 | 18,61 | 16,11 |
| fob alumina price $ 70 | 59.541 | 48.293 | 41.819 | 40,18 | 34,79 | 57,166 | 46.367 | 40.151 | 39,16 | 33,91 |
| fob alumina price $ 80 | 87.491 | 70.963 | 61.450 | 59,04 | 51,12 | 84.443 | 68.491 | 59.309 | 57,85 | 50,09 |
| **600 000 tpy capacity** | | | | | | | | | | |
| fob alumina price $ 60 | 75.521 | 61.254 | 53.043 | 33,54 | 29,05 | 70.691 | 57.337 | 49.650 | 32,08 | 27,78 |
| fob alumina price $ 70 | 135.494 | 109.898 | 95.165 | 60,18 | 52,12 | 130.318 | 105.700 | 91.530 | 59,15 | 51,22 |
| fob alumina price $ 80 | 181.359 | 147.098 | 127.379 | 80,56 | 69,76 | 175.570 | 142.403 | 123.313 | 79,69 | 69,00 |
| **900 000 tpy capacity** | | | | | | | | | | |
| fob alumina price $ 60 | 124.266 | 100.791 | 87.279 | 42,53 | 36,83 | 116.961 | 94.866 | 82.148 | 41,05 | 35,55 |
| fob alumina price $ 70 | 208.365 | 169.003 | 146.347 | 71,31 | 61,75 | 199.761 | 162.024 | 140.304 | 70,11 | 60,71 |
| fob alumina price $ 80 | 275.865 | 223.751 | 193.756 | 94,41 | 81,75 | 267.261 | 216.773 | 187.713 | 93,80 | 81,22 |
| **1200 000 tpy capacity** | | | | | | | | | | |
| fob alumina price $ 60 | 173.691 | 140.879 | 121.993 | 48,98 | 42,42 | 163.901 | 132.938 | 115.117 | 47,48 | 41,11 |
| fob alumina price $ 70 | 279.976 | 227.086 | 196.643 | 78,96 | 68,37 | 268.669 | 217.915 | 188.702 | 77,83 | 67,39 |
| fob alumina price $ 80 | 369.976 | 300.084 | 259.856 | 104,34 | 90,35 | 358.669 | 290.913 | 251.914 | 103,90 | 89,97 |

CREDITWORTHINESS VS. ALUMINA PLANT CAPACITY, ALUMINA PRICE AND INTERESTRATE
CAPACITE DE CREDIT EN FONCTION DE CAPACITE D'USINE, PRIX D'ALUMINE ET TAUX D'INTÉRÊT



CREDITWORTHINESS VS. ALUMINA PLANT CAPACITY ALUMINA PRICE AND INTEREST RATE
(BASED ON TOTAL INVESTMENT + INFRASTRUCTURAL COSTS)



CAPACITE DE CREDIT EN FONCTION DE CAPACITE D'USINE [illegible] D'ALUMINE ET TAUX D'INTERET (A BASE DES COUTS [illegible] DES OBJETS A L'INTERIEUR DE LA CLOTURE)

FIG. 2.

Table 13.

Financial variaties of various size alumina plants at two selected localities on a 20 years time horizon (in thousand dollars)

| Plant capacity | Moussala alumina plant | | | Manantali alumina plant | | |
|---|---|---|---|---|---|---|
| | at fob alumina price of | | | | | |
| | 60 $/t | 70 $/t | 80 $/t | 60 $/t | 70 $/t | 80 $/t |
| 300 000 tpy | 21330 | 36340 | 51330 | 21030 | 36030 | 51030 |
| 600 000 tpy | 46210 | 76210 | 106210 | 45490 | 75490 | 105490 |
| 900 000 tpy | 71480 | 116470 | 161480 | 70370 | 115370 | 160370 |
| 1200 000 tpy | 96880 | 156880 | 216880 | 95370 | 155370 | 215370 |

## 6.2. Production cost and net profit of aluminium smelting

As far as the siting of the aluminium smelter is concerned, the only variant we shall investigate is Manantali, as siting the smelter anywhere else would clearly entail a substantial excess cost for the transmission of power. Despite the above outlined two options for alumina-plant siting, we have examined smelter profitability regardless of whether alumina is to come from Manantali or Moussala. This simplification affects the cost of primary aluminium only inas-much as the transportation cost of alumina from Moussala to Manantali will add itself to the cost of aluminium if alumina is taken from Moussala. This excess cost would be $ 6,35 per ton of alumina.

Two aluminium smelter capacities at Manantali have been envisaged, notably (a) 25 000 tpy (b) 50 000 tpy. The first cost and operating capital required for both cases are listed in Table 14. First cost includes a plant unit producing anode paste in sufficient quantity to supply the smelter. Total investment costs plus infrastructural costs are shown in Table 15. Operation costs have been estimated for a period of 20 yrs after the coming onstream of the facility, as shall be explained below.

Cost of alumina to the smelter has been calculated on the basis of the specific consumption already discussed. The price of alumina to be used in the smelter has been determined under the assumption that the alumina plant would be willing to supply alumina to the smelter at a price equal to the fob price at a seaport less the cost of delivering the alumina to said seaport.

Our calculations have shown this to reduce alumina price by 8 $/t against the price discussed above ; accordingly, we have assumed in our calculations alumina prices of 52, 62 and 72 $/t.

The cost of coke, pitch, fluorine salts and power have been calculated on the basis of the specific consumptions referred to above, and of the following world market prices :

| | | |
|---|---|---|
| coke | 66 $/t | f.o.b. Atlantic port |
| pitch | 36 $/t | f.o.b. Atlantic port |
| fluorine salts | 356 $/t | f.o.b. Atlantic port |
| power | 0,0052 $/kWh | f.o.b. Atlantic port |

In the unit prices freight cost up to an African port is also included.

Miscellaneous materials have been calculated at $ 15 per ton of alumina, regardless of smelter size.

The cost of bringing together these materials at the smelter site have been calculated, assuming river transport up to Kayes and trucking from there on, to be $ 13,30 for the smaller and $ 13,23 for the larger smelter size, per ton of aluminium produced.

Customs duties have been assumed at 30 percent of the price of coke, pitch and fluorine salts, starting in the sixth year of smelter operation.

Costs of repairs and maintenance have been estimated for both variants at 1,5 percent of first cost.

In calculating the cost of labor we have kept in mind - just as in the case of the alumina plant - that the periods of startup and run-in of the smelter will require the employment of expatriate personnel, to be phased out over a period of some ten years.

The salaries of the expatriate personnel, significantly higher than those of the local ones, have been taken into account at the following levels:

| Designation | Salary of local employee, $ per year | Salary of expatriate employee, $ per year |
|---|---|---|
| 1. Top management | 2000 | 17000 |
| 2. Middle management | 1000 | 13500 |
| 3. Qualified personnel | 800 | 10000 |
| 4. General labor | 250 | - |

The total numbers of employees for the two capacity variants have been assumed as follows:

25000 tpy - 900 employees
50000 tpy - 1270 employees

For overheads and administrative expenses we have calculated, in addition to the payroll and cost of materials already mentioned, $ 20 for the smaller smelter and $ 15 for the larger one, per ton of aluminium produced.

Depreciation periods of the investment have been assumed as 20 years for civil engineering constructions and 10 years for equipment.

Table 16. states the net cost of producing aluminium plus the depreciation (for the above three prices of alumina ) for the first and tenth year of operation, millions of dollars supposing the location of the alumina plant in Manantali.

In Table 16. interest of credit to be raised in connection with the establishment of the aluminium smelter are of course not figuring as it is a function of an unknown credit sum and financing form.

In Table 16. production costs have been broken up also as regards the financing forms, respectively indicated the distribution of production costs to be expectedly covered by convertible currency and with local currency. We note that alumina for the smelter had been entirely ranged among the costs to be covered by local currency.

The net production cost per ton of aluminium, derived as a rough estimate from the above considerations, will be

for a 25000 tpy capacity smelter

| | | | | |
|---|---|---|---|---|
| at an alumina | price | of $ 52 | $ 355 |
| " | " | 62 | 375 |
| " | " | 72 | 390 |

For a 50000 tpy capacity smelter,

| | | | |
|---|---|---|---|
| at an alumina | price | of $ 52 | $ 335 |
| " | " | 62 | 355 |
| " | " | 72 | 370 |

Cost data surveyed herewith relate to the case when the alumina plant is established in Manantali. If the alumina plant were established the net production costs would be higher by an amount of 6 $/t - as mentioned above - due to the freight cost requirement of alumina.

In calculating the net profit of smelting we have assumed three prices of aluminium :

$ 450 per ton
$ 490 per ton
$ 530 per ton

These prices are based on actual world market prices ; we have assigned the lowest alumina price to the lowest aluminium price , and so forth, assuming the two prices to fluctuate more or less in parallel on the world market. Thus finally every aluminium price one single aluminium prime cost belongs to.

Net income was calculated as the sales price of aluminium less production cost plus depreciation, with 50 percent income tax subtracted from the sixth year of operation onward. The net income thus calculated plus the depreciation is the net profit of smelting.

Starting from the net-profit figures of the various smelter-capacity and aluminium price variants, we have performed an examination of profitability just as in the case of the alumina plant and under identical assumptions. Again in connection with the establishment of the aluminium smelter we wanted to get an answer as to how creditworthiness of the smelter during its first ten year of operation looks like. Calculation in our case would mean the investigation of debt servicing capability by the net income accumulated during the first ten years operation of the supposed alumina plant and furthermore whether the credit which could be raised would be able at all or to what extent to cover the expenses of establishment of the aluminium smelter.

Calculation of creditworthiness has been made at two possible ( 3 % and 6 % ) interest rates to demonstrate creditworthiness is effected

depending on being capable of raising credit at 3 % or 6 % interest rate. For the reimbursement of credits going to be raised an annual repayment has been presumed taking also the interest of other credits going to possibly be raised in the course of debt servicing.
Result of our calculations are tabulated in Table 17. separately treating the cases when the smelter would purchase alumina from an alumina plant going to be established in Moussala and that when the alumina plant would also be erected in Manantali. In Table 17 the sums going to get accumulated for debt servicing within 10 years are enlisted indicating what percentage of the first cost they represent. For the limit of profitability, similarly to the method in case of the alumina plant, 70 per cent of the creditworthiness has been chosen that is to say it was required to achieve incurring at least a 70 %: 30 % debt: equity ratio from the expenses of the establishment of the aluminium smelter. It is to be noted that data enlisted in Table 17. cannot be directly deducted from those of Table 16. as when stating the calculation base of creditworthiness a 50 per cent income-tax has also been taken into account. Again it is to be noted, that in the course of investigation of creditworthiness the income retained at the smelter has not been calculated, that is the net profit remaining after payment of taxes has entirely been used up for debt servicing of credits and interests. In case of requirement for retainable profit the percentual grade of creditworthiness has to be changed. As a sequence of the abovesaid neither any interest duty on own (equity) capital invested in the establishment of the aluminium smelter has been presumed.

The calculations presented reveal that an aluminium smelter of 25000 tpy capacity will not be economically viable under the actual conditions and that a 50000 tpy capacity smelter will be marginally profitable. Moreover, even the 50000 tpy smelter will not be profitable unless favorable sales conditions exist, which shows that prior to the decision to establish a smelter, the existing market situation and its foreseeable trends of development, and the sales price to be expected for the aluminium produced in Mali will have to be analyzed with great care.

In order to facilitate insight into the situation we have plotted in Fig. 16.

creditworthiness vs. smelter capacity, price of aluminium and interest rate. The figure also shows values for zero percent interest. The figure has been plotted by the assumption of locating both the alumina plant and the smelter in Manantali.

Creditworthiness for the investigation of financing possibility of investments connected with the infrastructure has also been calculated on the total investment cost plus infrastructural cost. In Table 18 the development of percentual creditworthiness is presented in case from credits going to be raised not only the investments of the smelter but those of the infrastructure have to be financed and for debt servicing of credits raised no other financial source than the net profit of the aluminium smelting is at disposal. (Accordingly the description of investments connected with the infrastructure and possible profit that of has not been taken into consideration in our calculation as for the time being there is neither any information on the measure of its accumulation nor its utilization possibilities).

The creditworthiness calculations made on base of the total investment cost plus infrastructural cost lay emphasis on earlier statements upon the profitability of establishment of the aluminium smelter. Though due to other considerations (primarily owing to the restricted amount of electric power available) in the first stage only the realization of a 25000 tpy aluminium smelter seems to be expedient, in order to secure an economic aluminium production it is carefully to be analized the expectable requirements for aluminium respectively consumption both of the Republic of Mali and the neighbouring countries and above all the attainable aluminium prices. The creditworthiness of the 25000 tpy cpacity smelter especially when related to the total investment cost plus infrastructural cost is not so unequivocally favourable such as to permit the lack of thorough knowledge in the period of realization.

In Fig. 4. creditworthiness values on base of the total investment cost plus infrastructural cost are presented at various production capacities, aluminium prices, and credit interest rates.

To further analyse the creditworthiness of aluminium production those net profit sums have also been demonstrated which remain as a balance during the investigated 20 years of operation after debt servicing of credit and interest.

Thus those sums are free from different credit debts and remaining after payment of taxes appear entirely as the profit of the aluminium production. Aggregate sums for 10 years of the profit defined according to the above stated are presented in thousand dollars in Table 19.

Table: 14.

Investment cost of Manantali smelter capacity variants

| Designation | First cost[x] | Operating capital | Investment cost |
|---|---|---|---|
| | million dollars | | |
| 25 000 tpy capacity | 38,4 | 7,0 | 45,4 |
| 50 000 tpy capacity | 68,5 | 12,5 | 81,0 |

[x] Remark: The investment cost includes debt servicing charges up to start up.

Distribution of first cost of the smelter

| Capacity | Equipment and machiney m$ | Installation m$ | Civil eng. constr. m$ | Miscellaneous m$ | Interest m$ | Total first cost m$ |
|---|---|---|---|---|---|---|
| 25 000 tpy | 21,0 | 3,0 | 9,0 | 2,0 | 3,4 | 38,4 |
| 50 000 tpy | 38,0 | 5,0 | 16,0 | 3,5 | 6,0 | 68,5 |

Table 15.

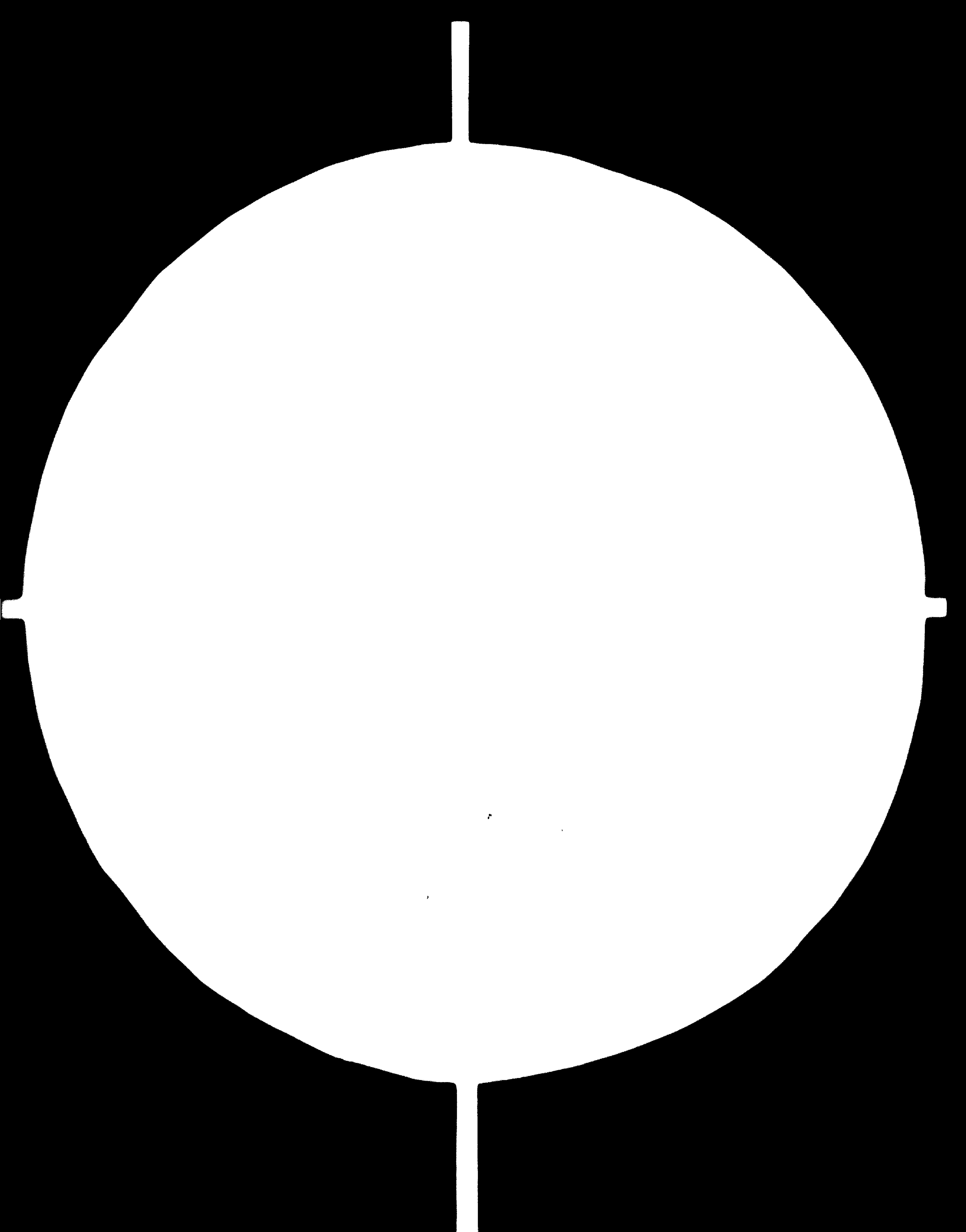
## Total investment cost plus infrastructural cost for the capacity variants of Manantali smelter

| Denomination | Investmentcost | Infrastructural cost | Investment cost plus infrastructural cost |
|---|---|---|---|
| | in million dollars | | |
| **25000 tpy capacity** | | | |
| Alumina from Moussala | 45,4 | 26,8 | 72,2 |
| Alumina from Manantali | 45,4 | 13,8 | 59,2 |
| **50000 tpy capacity** | | | |
| Alumina from Moussala | 81,0 | 26,8 | 107,8 |
| Alumina from Manantali | 81,0 | 13,8 | 94,8 |

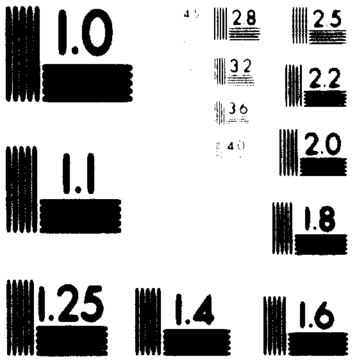
B-571

→

84.11.28
AD.86.07
ILL4.0+10



2 OF 2



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

24x
F

Table 16.

Production cost vs. alumina price for various smelter sizes at Manantali

| Designation | 25 000 tpy capacity | | | | | | 50 000 tpy capacity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | at plantgate alumina price of $ 52 | | at plantgate alumina price of $ 62 | | at plantgate alumina price of $ 72 | | at plantgate alumina price of $ 52 | | at plantgate alumina price of $ 62 | | at plantgate alumina price of $ 72 | |
| | 1. year | 10.years | 1.year | 10.years | 1. year | 10.years | 1. year | 10.years | 1. year | 10.years | 1. year | 10.years |
| 1. Alumina | 2.496 | 2.496 | 2.976 | 2.976 | 3.456 | 3.456 | 4.992 | 4.992 | 5.952 | 5.952 | 6.912 | 6.912 |
| 2. Coke | 701 | 701 | 701 | 701 | 701 | 701 | 1.402 | 1.402 | 1.402 | 1.402 | 1.402 | 1.402 |
| 3. Pitch | 153 | 153 | 153 | 153 | 153 | 153 | 306 | 306 | 306 | 306 | 306 | 306 |
| 4. Fluorine salts | 578 | 578 | 578 | 578 | 578 | 578 | 1.157 | 1.157 | 1.157 | 1.157 | 1.157 | 1.157 |
| 5. Power | 2.145 | 2.145 | 2.145 | 2.145 | 2.145 | 2.145 | 4.290 | 4.290 | 4.290 | 4.290 | 4.290 | 4.290 |
| 6. Miscellaneous | 375 | 375 | 375 | 375 | 375 | 375 | 750 | 750 | 750 | 750 | 750 | 750 |
| 7. Freight cost | 334 | 334 | 334 | 334 | 334 | 334 | 662 | 662 | 662 | 662 | 662 | 662 |
| 8. Customs duties | - | 430 | - | 430 | - | 430 | - | 860 | - | 860 | - | 860 |
| 9. Repairs and maintenance | 525 | 525 | 525 | 525 | 525 | 525 | 938 | 938 | 938 | 938 | 938 | 938 |
| 10. Payroll and social charges | 1.174 | 507 | 1.174 | 507 | 1.174 | 507 | 1.645 | 727 | 1.645 | 727 | 1.645 | 727 |
| 11. Overheads and administrative | 500 | 500 | 500 | 500 | 500 | 500 | 750 | 750 | 750 | 750 | 750 | 750 |
| 12. Net produvtion cost | 8.981 | 8.744 | 9.461 | 9.224 | 9.941 | 9.704 | 16.892 | 16.834 | 17.852 | 17.794 | 18.812 | 18.754 |
| 13. Depreciation: | | | | | | | | | | | | |
| civil engineering construction | 525 | 525 | 525 | 525 | 525 | 525 | 925 | 925 | 925 | 925 | 925 | 925 |
| machinery and equipment | 2.800 | 2.800 | 2.800 | 2.800 | 2.800 | 2.800 | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 |
| 14. Production cost increased by depreciation | 12.306 | 12.069 | 12.786 | 12.549 | 12.266 | 13.029 | 22.817 | 22.759 | 23.777 | 23.719 | 24.737 | 24.679 |
| 15. To be covered from net production cost: | | | | | | | | | | | | |
| by convertible currency | 2.560 | 1.933 | 2.560 | 1.933 | 3.560 | 1.933 | 4.609 | 3.743 | 4.609 | 3.743 | 4.609 | 3.743 |
| by local currency | 6.421 | 6.811 | 6.901 | 7.291 | 7.381 | 7.771 | 12.283 | 13.091 | 13.243 | 14.051 | 14.203 | 15.011 |

Table 17.

## Creditworthiness of various size smelters at Manantali depending on alumina purchased from different plants calculated on base of investment cost (Figures in thousand dollars)

| Denomination | Income available for debt servicing | When purchased Manantali alumina |  |  |  | Income available for debt servicing | When purchased Moussala alumina |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Credit that can be raised at |  | Idem, in percent of total investment plus infrastructural cost at |  |  | Credit that can be raised at |  | Idem, in percent of total investment plus infrastructural cost at |  |
|  |  | 3% | 6% | 3% | 6% |  | 3% | 6% | 3% | 6% |
| **25000 tpy aluminium production** |  |  |  |  |  |  |  |  |  |  |
| Metal price $ 450 | 23.964 | 19,437 | 16.831 | 42,81 | 37,07 | 22.334 | 18.115 | 15,686 | 39,90 | 34,55 |
| " " $ 490 | 29.164 | 23.655 | 20.484 | 52,10 | 45,12 | 27.534 | 22.332 | 19.339 | 49,19 | 42,60 |
| " " $ 530 | 34.120 | 27,674 | 23.964 | 60,96 | 52,78 | 32.705 | 26.527 | 22.971 | 58,43 | 50,6 |
| **50000 tpy aluminium production** |  |  |  |  |  |  |  |  |  |  |
| Metal price $ 450 | 56.515 | 45.839 | 39.694 | 56,59 | 49,00 | 53.255 | 43.194 | 37.404 | 53,32 | 46,18 |
| " " $ 490 | 65.409 | 53.052 | 45.940 | 65,50 | 56,72 | 62.964 | 51.069 | 44.223 | 63.05 | 54,60 |
| " " $ 530 | 73,209 | 59,379 | 51.419 | 73,31 | 63,48 | 70.764 | 57.396 | 49.702 | 70,86 | 61,36 |

Table: 18.

## Creditworthiness of various size smelters at Manantali depending on alumina purchased from different plants calculated on base of total investment plus infrastructural cost

(Figures in thousand dollars)

| Denomination | Income available for debt servicing | When purchased Manantali alumina | | | | Income available for debt servicing | When purchased Mousseala alumina | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Credit that can be raised at | | Idem, in percent of total investment plus infrastructural cost at | | | Credit that can be raised at | | Idem, in percent of total investment plus infrastructural cost at | |
| | | 3% | 6% | 3% | 6% | | 3% | 6% | 3% | 6% |
| **25000 tpy aluminium production** | | | | | | | | | | |
| Metal price $ 450 | 23,964 | 19,437 | 16381 | 32,83 | 28,43 | 22.334 | 18,115 | 15,686 | 25,09 | 21,72 |
| " " $ 490 | 29,164 | 23,655 | 20,484 | 39,96 | 34,60 | 27.534 | 22.332 | 19,339 | 30,93 | 26,78 |
| " " $ 530 | 34,120 | 27,674 | 23,964 | 46,75 | 40,48 | 32,705 | 26,527 | 22,971 | 36,74 | 31,82 |
| **50000 tpy aluminium production** | | | | | | | | | | |
| Metal price $ 450 | 56,515 | 45,839 | 39,694 | 48,35 | 41,87 | 53,255 | 43,194 | 37.404 | 40,07 | 34,70 |
| " " $ 490 | 65,409 | 53,082 | 45,940 | 55,96 | 48,46 | 62.964 | 51,069 | 44,223 | 47,37 | 41,02 |
| " " $ 530 | 73,209 | 59,379 | 51,419 | 62,64 | 54,24 | 70.764 | 57.396 | 49,702 | 53,24 | 46,11 |

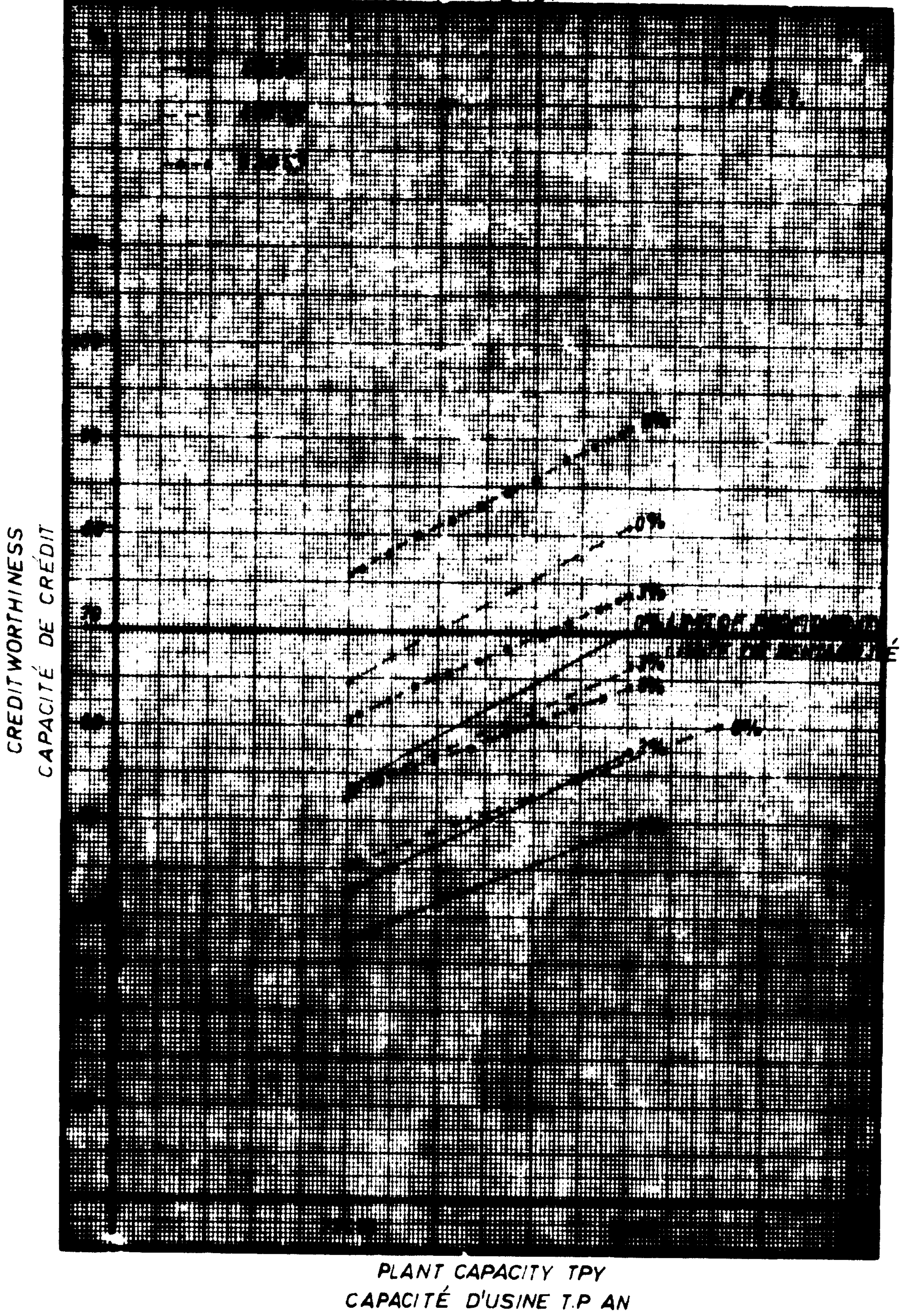
Table: 14.

## Financial balance of capacity varieties at Manantali smelter at 20 year time horizon

(In thousand dollars)

| Smelter capacity | When purchasing | |
|---|---|---|
| | Manantali alumina | Moussala alumina |
| 25000 tpy capacity | | |
| at $ 450 | 15,580 | 14.760 |
| at $ 490 | 18,180 | 17.360 |
| at $ 530 | 20,780 | 19.960 |
| 50000 tpy capacity | | |
| at $ 450 | 33,630 | 32.000 |
| at $ 490 | 38,830 | 37.200 |
| at $ 530 | 44,030 | 42.400 |

CREDITWORTHINESS VS. SMELTER CAPACITY, ALUMINIUM PRICE AND INTEREST RATE
CAPACITÉ DE CRÉDIT EN FONCTION DE CAPACITÉ D'USINE, DE PRIX D'ALUMINIUM
ET DU TAUX D'INTÉRÊT



## CREDITWORTHINESS VS. SMELTER CAPACITY, BILLET PRICE AND INTEREST RATE (BASED ON TOTAL INVESTMENT + INFRASTRUCTURAL COSTS)

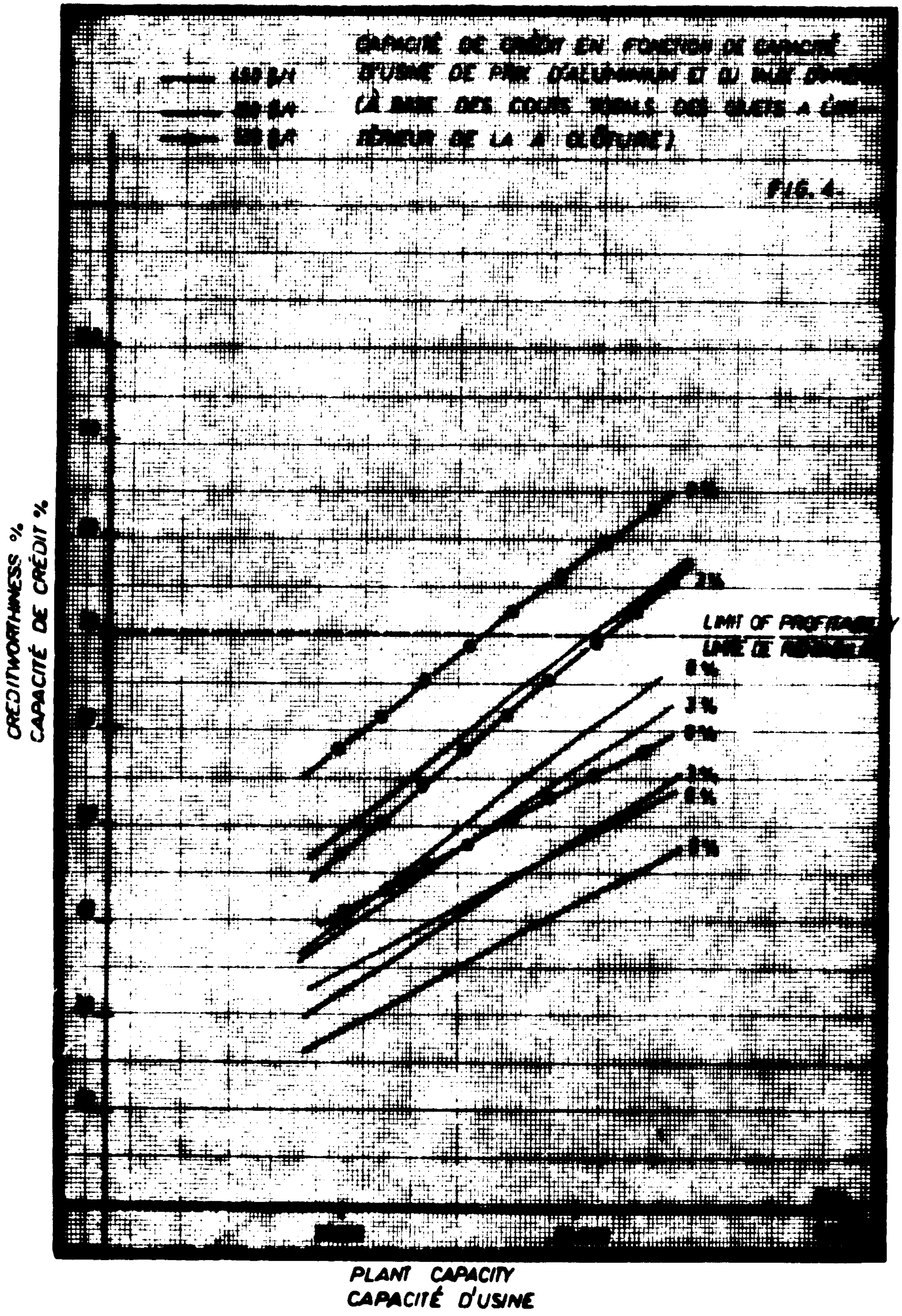


FIG. 4

### 6.3. Investment cost of semis plants

As it has been stated under para 3.3.2 the temporary development of the amount of semiproducts can not be established as it highly depends on the momentarily unknown and just after start-up developing demands. Thus detailed economy calculations relating to semis production can not be made. For informative purposes, however, there are the investment costs concerning equipment enlisted in para 4.4., which could be realized according to the momentary financial circumstances of the country after having started metal production.

| First cost of extrusion press: | 6000 tpy capacity | |
|---|---|---|
| Complete press mill | $ 6,6 to | 7,6 million |
| of which construction | 2,3 | 2,7 |
| machinery, equipment | 2,8 | 3,1 |
| installation | 0,8 | 1,0 |
| miscellaneous | 0,7 | 0,9 |

| First cost of 2000 tpy complete wire-drawing and cable mill | |
|---|---|
| | $ 1,3-1,5 million |
| of which, construction | 0,5-0,6 |
| machinery, equipment | 0,6-0,7 |
| installation | 0,2 |
| miscellaneous | 0,1 |

First cost of sheet and plate mill of 10 to 12 thousand tpy capacity

| | |
|---|---|
| First cost of complete mill | $ 13-15 million |
| of which construction | 1,3-2,2 |
| machinery, and equipment | 8,0-9,0 |
| installation | 1,7-2,5 |
| miscellaneous | 2,0-3,0 |

First cost of a plate corrugationg street is approx $ 2 m.

## 6.4. Principal items of infrastructural investment required by the individual alumina-plant and smelter siting variants.

### 6.4.1 Road and railroad

Road traces are shown and numbered on a 1 000 000 scale map.

I. Bauxite mine at Sitadina

1/1. Alumina plant at Kayes.

Bauxite haulage road

| | | |
|---|---|---|
| Trace 1. Sitadina-Faléa-Keniéba-Sadiola-Kayes | 380 km | $ 24,7 million |

New trace between Diatisan and Kayes.
About 70 structures (culverts, small bridges to be built.

| | | |
|---|---|---|
| Trace 2. Sitadina-Satadougou-Kéniéba-Mahina-Kayes | 400 km | $ 24,0 " |

Detailed project for Satadougou-Mahina-Bafoulabé section exists
Transportation of alumina by barge.

1/2. Alumina plant at Mahina.

a/ Bauxite haulage road

| | | |
|---|---|---|
| Trace 2. Sitadina-Satadougou-Kéniéba-Mahina | 270 km | |
| Alumina transport road | 130 km | |
| | 400 km | $ 24,0 million |
| b/ Bauxite haulage road as above | 270 km | $ 16,0 " |
| Alumina transport by rail (Mahina-Kayes of Table 1) | 130 km | $ 8,7 " |
| | 400 km | 24,7 " |

Further transportation of alumina by barge.

| | | |
|---|---|---|
| 1/3. Alumina plant at Moussala | | |
| Bauxite haulage road | | |
| Trace 2. Sitadina-Moussala | 70 km | |
| Alumina transport road | | |
| Trace 2. Moussala-Mahina-Kayes | 330 km | |
| | 400 km | $ 24,0 million |
| 1/4. Alumina plant at Manantali | | |
| Bauxite haulage road | | |
| Trace 3. Sitadina-Manantali new trace over 90 percent of total length | 200 km | $ 13,0 million |
| Alumina transport road: | | |
| Trace 4. Manantali-Mahina-Bafoulabé-Kayes | 230 km | $ 13,8 million |
| | 430 km | $ 26,8 million |
| II. Bauxite mine at Baléa | | |
| II/1. Alumina plant at Manantali | | |
| Bauxite haulage road: | | |
| Trace 5. Baléa-Koumakiré-Manantali numerous constructions required | 180 km | $ 11,7 million |
| Alumina transport road | | |
| Trace 4. Manantali-Mahina-Kayes | 230 km | $ 13,8 million |
| | 410 km | $ 25,5 million |
| II/2. Alumina plant at Boulouli | | |
| Bauxite haulage road | | |
| Trace 6. Baléa-Tanbaga-Boulouli (numerous constructions required) | 170 km | $ 11,0 million |
| alternative trace: No. 7 through Kita: same length | | |
| Alumina transport by rail: Boulouli-Kayes cf. Table 1. | | |
| | 300 km | $ 14,8 million |
| | 470 km | $ 25,8 million |

## III. Bauxite mine in Bamako-Ouest group of deposits

### III/1. Alumina plant in Bamako

| | | |
|---|---|---|
| Bauxite haulage route: Trace 8, Sakorodaba-Siby-Bamako | 130 km | $ 7,8 million |
| Alumina transportation by rail (Bamako-Kayes cf. table 1.) | 510 km | $ 20,8 million |
| | 640 km | $ 28,6 million |

### III/2. Alumina plant at Baoulé

| | | |
|---|---|---|
| Bauxite haulage route: <br>Trace 9, difficult terrain <br>Sakorodaba-Baoulé | 85 km | $ 6,0 million |
| Alumina transportation by rail (Baoulé-Kayes, cf. Table 1.) | 430 km | $ 18,8 million |
| | 515 km | $ 24,8 million |

**Remarks:**

a/ Depending on terrain conditions, building one km of road has been estimated to cost between 60 000 and 70 000 $.

b/ The cost of road transport also is incorporated in the production cost of alumina.

Table

## Railroad investment costs

| Route designation | Distance km | Cost of reconstruction | Station trade, km | Cost | 1800-HP diesel locomotives @ $534 000 | | 400-HP shunt diesel locos @ $150 000 | | special alumina wagons four-axle @ $36 700 | | fuel-oil tank wagons @ $14 000 | | four-axle mixed-good wagons @ $18 000 | | Wagon rotation days | Total cost |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | pcs | cost | pcs | cost | pcs | cost | pcs | cost | pcs | cost | | |
| I/2/b Mahina-Kayes | 130 | 2600 | 6 | 480 | 4 | 2136 | 2 | 300 | 72 | 2642 | 30 | 420 | 8 | 144 | 3 | 8722 |
| II/2 Boulouli-Kayes | 300 | 6000 | 14 | 1120 | 6 | 3204 | 2 | 300 | 92 | 3376 | 41 | 574 | 12 | 216 | 4 | 14790 |
| III/1 Bamako-Kayes | 510 | 10200 | 24 | 1920 | 6 | 3204 | 2 | 300 | 115 | 4220 | 48 | 672 | 14 | 252 | 5 | 20768 |
| III/2 Baoulé-Kayes | 430 | 8600 | 20 | 1600 | 6 | 3204 | 2 | 300 | 115 | 4220 | 48 | 672 | 14 | 252 | 5 | 18848 |

Costs are in thousand-dollar units

### 6.4.2 Railroad

Estimates are given in Table 1. They tie in to the corresponding items above and are numbered accordingly.

### 6.4.3. River transportation: power plant

As stated above, we expect the solution of river transportation on the Senegal River of the realization of the Manantali Project.

Manantali lies on the Bafing river, the largest tributary of the Senegal, at a distance of about 80 km from Bafoulabé, as the crow flies. Siting the project is based on a thorough study by Senegal-Consult. The dam would permit the storage of about 10 thousand million $m^3$ of water.

The power generating group would include eight vertical Francis turbines and eight vertical generators of 22,5 MVA output each, with a water throughput of 345 $m^3$/sec at minimum and 560 $m^3$/sec at maximum level difference. The installed power generating capacity of 150 MW would ensure a sustained year-round output of 100 MW. The transformer station would deliver power at 220 kV.

As and when the output of the power plant attains the full rated capacity the discharge of the Senegal at Kayes will attain 300 $m^3$/sec as a year-round minimum.
This discharge permits navigation from Kayes to the estuary of the Senegal in barges of one-metre draft.

Senegal-Consult estimated the Manantali Project to cost $ 115,4 million at 1970 prices. Of this, the dam and accessory facilities would cost $ 90,8 million, while the power generating facility as such would cost the remaining $ 24,6 million.

## 6.5. Economy of exporting high grade Malian bauxite.

Economy calculations on exportation possibility of high grade Malian ore have been made. Aim of our calculation was revealing the condition whether the high transportation costs debiting the Malian bauxite can be compensated by the diminished production costs attainable in the course of processing same in Eureopean alumina plants.
According to our knowledge in case of processing bauxite of the composition of 48 % $Al_2O_3$ and 6 % $SiO_2$ in Europe the emerging costs dependent on the ore (i.e. bauxite and caustic soda consumption with their freight cost included ) could come to 30-35 $/t within the production cost, out of which 18-20 $/t are figuring for bauxite consumption cost and 12-15 $/t for that of caustic soda.

Considering the above composition of ore these figures may result as a consequence of the following raw material consumption: bauxite 2.6 t/t and caustic 0,190 t/t.

Under such conditions if high grade bauxite from the Sitadina ore were processed a saving of about 50 % would be achieved decreasing caustic soda cost to 6-7 $/t in the production cost. Making use of this bauxite cost may go up to 24-27 $/t in the production cost of alumina which by considering 2.6 t/t bauxite consumption permits a purchase price of 9-11 $/t for bauxite. As a consequence according to this calculation exportation of Malian bauxite would be economic for the European alumina plants if the exported bauxite were at a price of 9-11 $/t at the site of the alumina plant at disposal.

Bauxite resulting from the Sitadina area, however, is debited by the following expenses :

| | | | |
|---|---|---|---|
| exploitation costs (with wages) | 2 | $/t | bauxite |
| trucking to Kayes (400 km ; 0.02 $/t km) | 8 | " | " |
| delivery by barge to St.Louis | 3 | " | " |
| sea transport to Europe | 6-8 | " | " |
| reloading at European port | 1 | " | " |
| inland transportation in Europe | 4-6 | " | " |
| total cost debiting bauxite: | 24-28 | $/t | bauxite |

Accordingly the cost debiting Sitadina bauxite exceeds by far those advantages European alumina plants could make use of. In the calculation profit has not been taken into account though it would have been motivated in favour of reinbursement of investments necessary for the starting of exploitation of bauxite. Another calculation quite similar to the former may be made for the exportation of Baléa area bauxite.

In case of processing Baléa bauxite considerable saving (approx. 70 %) in caustic consumption may be achieved, bauxite consumption, in turn will slightly increase related to the bauxite of the composition of 48 % $Al_2O_3$ and 6 % $SiO_2$. By making use of the advantage of low caustic consumption the permissible cost for bauxite may go up to 26-30 $/t in the production cost of alumina which will come at a specific bauxite consumption of 2.8 t/t for Baléa bauxite to the same permissible purchase price of 9-11 $/t at the plant site of the consumer the figure being in agreement with that for the Sitadina bauxite.

As the drawing and freight costs releting to Baléa bauxite are similar to those stated for Sitadina bauxite we are bound to hold a poor opinion also of the exportation possibility of Baléa bauxite.

According to the statement and economy calculation, as compared with the average quality bauxite going to be processed in Europe the exportation of the undoubtedly high grade Malean bauxite does not offer such economic advantages as to compensate for the very high freight cost debiting the ore.

One will come to the same conclusion if the affect of ore quality is examined on base of the price the so-called "base price". According to the established practice bauxite price will be determined at the shipping ation in the function of $Al_2O_3$ and $SiO_2$ content by the following formula

$$( Al_2O_3\% - 2 \times SiO_2\% / \times B / \$/t ),$$

where B represents the so-called "base price".

The average value for this in the European practice would be about 0.15 $/t.

With a certain bauxite of composition regarded as a base for investigation the formula would result in a price :

$$/\ 48 - 2 \times 6\ /\ \times 0.15 = \underline{5{,}40\ \$/t}$$

the same with Sitadina bauxite

$$/\ 46.5 - 2 \times 3\ /\ \times 0.15 = \underline{6{,}07\ \$/t}$$

and with Baléa bauxite

$$/\ 42.1 - 2 \times 1.23\ /\ \times 0.15 = \underline{5{,}95\ \$/t}$$

The difference in price ( 0.5 - 0.7 $/t ) is obviously unable to compensate the very high inland freight cost ( up to an African port ).

## 6.6. Summarized cost assessment for the establishment of an integrated aluminium plant

In the foregoing chapters of this study the possibilities of establishing an integrated aluminium plant (bauxite, mine, alumina plant, aluminium smelter, semis plant) based on the bauxite available in the Republic of Mali have been investigated. In the investigation of the establishment of alumina plants of capacities in the range 300.000 to 1.200.000 tons has been presumed, furthermore concerning the smelter and semis plant 25.000 tpy capacity units have been suggested, first of all taking present potentialities of the country into consideration.

In our study investment cost assessments have been given both for the establishments of the individual plants within the fence and for the infrastructure in connection with operation (roads, railroads). The latter would serve the fulfilment of transportation purposes of the corresponding plants and could additionally perform other tasks, too.

Based on detailed cost assessments one may find tabulated the estimated investment costs of the individual establishments broken up regards the investment costs of alumina production capacity variants, furthermore direct aluminium industry undertaking and that of the infrastructure. The summarized cost assessment will also consider the alumina plant locating variants in Moussala or Manantali. (Table 21.)

**Investment cost assessment of an integrated aluminium plant** Table: 21.

| Denomination | 300.000 tpy alumina plant | | | 600.000 tpy alumina plant | | | 900.000 tpy alumina plant | | | 1.200.00 tpy alumina plant | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Investment | Infra-structure | Total | Investment | Infra-structure | Total | Investment | Infra-structure | Total | Investment | Infra-structure | Total |
| Alumina plan in Mouasala | 96,2 | 24,0 | 120,2 | 158,6 | 24,0 | 182,6 | 213,0 | 24,0 | 237,0 | 263,6 | 24,0 | 287,6 |
| 25.000 tpy aluminium smelter | 45,4 | 26,8 | 72,2 | 45,4 | 26,8 | 72,2 | 45,4 | 26,8 | 72,2 | 45,4 | 26,8 | 72,2 |
| 25.000 tpy semis plant | 24,5 | - | 24,5 | 24,5 | - | 24,5 | 24,5 | - | 24,5 | 24,5 | - | 24,5 |
| Total investment cost | 166,1 | 50,8 | 219,6 | 228,5 | 50,8 | 279,3 | 282,9 | 50,8 | 333,7 | 333,5 | 50,8 | 384,3 |
| Alumina plant in Manantali | 92,9 | 25,5 | 118,4 | 153,2 | 25,5 | 178,7 | 205,6 | 25,5 | 231,1 | 245,5 | 25,5 | 280,0 |
| 25.000 tpy aluminium smelter | 45,4 | 13,8 | 59,2 | 45,4 | 13,8 | 59,2 | 45,4 | 13,8 | 59,2 | 45,4 | 13,8 | 59,2 |
| 25.000 tpy semis plant | 24,5 | - | 24,5 | 24,5 | - | 24,5 | 24,5 | - | 24,5 | 24,5 | - | 24,5 |
| Total investment cost | 162,8 | 39,3 | 202,1 | 223,1 | 39,3 | 262,4 | 275,5 | 39,3 | 314,8 | 324,4 | 39,3 | 363,7 |

## 7. Conclusions and recommendations

The investigations detailed above show that it is indeed worth while to study the realization of an alumina-aluminium industry in Mali. The principal reason for doing so is the quality and quantity of the Malian bauxite resource. It must not, however, be dissimulated that the realization of said industry is fraught with a number of difficulties. It is of the utmost importance to recognize that no alumina-aluminium industry will be able to overcome these difficulties on its own. Consequently a very close gearing together of the entire future economic development of Mali, and of the investment projects involved in it, will be required in order that an alumina-aluminium industry- and the infrastructural investments required by it - may come into existence.

It was our aim from the beginning to concentrate on the feasibility rather than the unfeasibility of an alumina-aluminium industry in Mali, and we have accordingly made a number of assumptions, without the realization of which the establishing of such an industry seems hopeless to start with. These are as follows.

- Supplying the industry with raw materials, and removal of its products is to be to a large extent by water (on the Senegal River): that is, we have assumed the Senegal River to be rendered navigable in due time.

- The navigability of the Senegal presupposes the existence of some discharge-regulating installation. We have assumed this installation to be the Manantali Project which, in addition to regulating the discharge, would produce sufficient power also to supply the aluminium smelter capacity envisaged.

- We have finally assumed that the road network required to supply the alumina plant and smelter and miscellaneous other lower-cost infrastructural investments will be realized in due time.

As regards the alumina plant the principal outcome of our economic considerations is that - in the present situation - a plant of at least 600000 t/y capacity would be required to produce alumina at a profit, and even that only if the finance required for the investment is available (e.g. from the World Bank) at an interest rate of 3 percent at most, and alumina can be sold on the world market - e.g. under a long-term sales agreement - at a minimum price of $ 70 per ton f.o.b. African seaport.

Aluminium smelting has been shown by our calculations to be unprofitable in any case if the smelter is to compete on the world market at either the actual or the previsible future prices. Its establishment is, however, justified if it is considered as an import-substituting industry, to compete not against world market prices at Kaolack or another seaport, but against the rather high price of aluminium and aluminium semis imported to Mali. Import substitution does, however, necessitate the installation of an aluminium semifabricating capacity. We have not gone on to examine problems of producing finished products as we deem that to be largely a problem of the private sector of industry.

## Recommendations

The present Pre-Feasibility Study is not, by the nature of things, based on fully satisfactory data; nor may its conclusions be considered definitive. Prior to any definitive decision, investigations in considerably more detail will have to be performed into the following.

1. Prospection of the bauxite deposits in a detail permitting technico-economical calculations at preliminary project report level.
2. Laboratory testing of the samples taken in the course of the above/mentioned prospection, likewise at preliminary project report level.
3. Engineering geological investigation of the most favorable sites.
4. Exploration of financing options and potentials, possibly by preliminary negotiations with international institutions such as the World Bank and/or sources in the technically developed countries.
5. Market research concerning semifabricated products, both in Mali and the neighbouring regions.

The above enumeration is in the logical order of, subjects but not in the order of urgency. The subjects to be given top priority are, in our opinion, as follows.

1. The saleability of alumina, if possible under a long-term agreement that may serve as security for the financing of the project.

2. A more detailed analysis of finance structure and at the same time a tentative exploration of sources of finance.

3. Harmonising of the above-enumerated largely interdependent investment projects at the level of Mali's Economic Plan.

4. A more detailed investigation into the market for aluminium and aluminium products, treated somewhat cursorily on the basis of scanty data in the present Report.

The above enumeration reveals that the next step forward in examining the feasibility of an alumina-aluminium industry will largely depend on a certain number of decisions to be made at Mali Government level. We feel that the Mali Government should in these decisions be assisted by a consultative organisation well versed in problems of the aluminium industry.

As the frame of reference of the above-enumerated activities we propose the preparation of a Preliminary Project Report.

## Appendix

### Laboratory testing of Mali bauxites

Laboratory testing was performed at **FÉMKUT** ( the Non-Ferrous Metals Research Institute of the Hungarian Aluminium Corporation )under a program supplied by **ALUTERV**. The purpose of testing was the determination of the chemical and mineralogical compositions of certain selected samples, and the testing of their digestion and settling behaviour.

Of a total number of 23 bauxite samples taken in the field from the Bamako-Ouest and Sitadina deposits, ten were selected on the basis of geological deocumentation about these deposits. These samples were assumed to characterize sufficiently the mean bauxite grades of the recalculated reserves stated in the geology section.

Table 1.

Chemical composition of bauxites

| Sample designation | $Al_2O_3$ % | $Fe_2O_3$ % | $SiO_2$ % | $TiO_2$ % | L.O.I. % | Module |
|---|---|---|---|---|---|---|
| Ouro Néna<br>7-8 +1,6 mm | 49,11 | 23,70 | 0,58 | 5,65 | 20,55 | 84,65 |
| Ouro Néna<br>7-8 -1,6 mm | 43,57 | 29,03 | 2,02 | 6,07 | 18,53 | 21,65 |
| Sitadina<br>15-16 +1,6 mm<br>(Tech. 1.) | 53,64 | 17,39 | 3,59 | 1,93 | 22,50 | 14,95 |
| Sitadina<br>15-16 -1,6 mm | 56,04 | 13,91 | 5,65 | 2,38 | 21,17 | 9,91 |
| Tech 2. | 45,13 | 26,49 | 2,06 | 5,54 | 19,73 | 21,90 |
| Tech 3. | 45,87 | 21,84 | 3,77 | 3,78 | 23,24 | 12,16 |
| Tech 4. | 50,50 | 17,15 | 2,90 | 2,29 | 26,14 | 17,11 |
| Tech 5. | 52,94 | 16,67 | 2,52 | 4,35 | 21,99 | 21,00 |
| Tech 6. | 37,25 | 39,70 | 1,32 | 2,34 | 16,08 | 28,22 |
| Lump sample | 53,63 | 15,13 | 2,33 | 3,48 | 24,19 | 23,05 |

We have separately analyzed the +1,6 and -1,6 mm fractions of the samples Ouro-Néna 7-8 and Sitadina 15-16 in order to confirm the information furnished by rapid analysis as to the beneficiation potential of these samples. Just as pointed out in the geological section, the fine-grained fractions are consistently worse than the coarse-grained ones.

The technological tests were performed on six samples, considered representative of the deposits. These samples were composed as follows:

Tech 1. : Sitadina 15-16, +1,6
Tech 2. : 6 parts Ouro-Néna 7-8, -1,6 mm and 1 part Lump Sample
Tech 3. : Koumassi Puits Donnot 5-6
Tech 4. : Sitadina 13-14
Tech 5. : Ouro Néna 5-6
Tech 6. : Sandambakourou 9-10-12

Table 2.

Mineralogical composition of bauxites

| | Ouro Néna 7-8 | | Sitadina 15-16 | | T E C H | | | | | Lump |
|---|---|---|---|---|---|---|---|---|---|---|
| | +1,6 | -1,6 | +1,6=Tech 1/ | -1,6 | 2 | 3 | 4 | 5 | 6 | |
| $Al_2O_3$ | | | | | | | | | | |
| in kaolin | tr | 0,7 | 1,7 | 2,6 | 0,7 | 2,0 | 1,3 | 1,0 | 0,4 | 0,8 |
| in diaspore | 0,3 | 0,3 | 1,0 | 1,2 | 0,3 | 0,3 | 0,5 | tr | 1,0 | 0,3 |
| in gibbsite | 29,3 | 25,0 | 31,8 | 25,9 | 26,6 | 36,2 | 44,1 | 31,3 | 21,0 | 36,0 |
| in boehmite | 16,6 | 14,8 | 10,0 | 25,0 | 14,6 | 5,5 | 3,0 | 19,5 | 11,7 | 13,8 |
| in goethite | 2,1 | 2,1 | 0,7 | 1,0 | 2,4 | 1,0 | 1,1 | 0,6 | 2,2 | 2,5 |
| in haematite | 0,8 | 0,7 | 0,4 | 0,3 | 0,5 | 0,8 | 0,5 | 0,5 | 1,0 | 0,2 |
| $Fe_2O_3$ | | | | | | | | | | |
| in goethite | 11,3 | 13,0 | 7,7 | 6,9 | 12,5 | 6,5 | 6,5 | 7,0 | 15,5 | 11,2 |
| in haematite | 11,3 | 15,2 | 8,7 | 5,6 | 13,2 | 14,3 | 9,6 | 9,2 | 22,0 | 2,9 |
| in maghemite | 1,1 | 0,8 | 1,0 | 1,4 | 0,8 | 1,0 | 1,0 | 0,5 | 2,2 | 1,0 |
| $SiO_2$ | | | | | | | | | | |
| in quartz | 0,55 | 1,2 | 1,6 | 2,6 | 1,15 | 1,5 | 1,4 | 1,3 | 0,9 | 1,3 |
| in kaolin | tr | 0,8 | 2,0 | 3,0 | 0,85 | 2,3 | 1,5 | 1,2 | 0,5 | 1,0 |
| $TiO_2$ | | | | | | | | | | |
| in anatase | 4,1 | 4,0 | 1,0 | 1,5 | 3,7 | 2,9 | 1,8 | 2,9 | 2,3 | 2,4 |
| in rutile | 1,5 | 2,0 | 0,9 | 0,9 | 1,8 | 0,9 | 0,5 | 1,5 | tr | 1,1 |
| CaO | | | | | | | | | | |
| in kalcite | 0,2 | tr | tr | tr | tr | ∅ | ∅ | ∅ | ∅ | tr |
| in dolomite | tr | tr | tr | tr | tr | 0,2 | 0,4 | tr | ∅ | tr |

Mineralogical analysis was performed by means of a Müller Mikro 1011 vacuum X-ray spectrometer. The results stated above justify the following conclusions.

In each sample, a significant amount of alumina is tied down in boehmite. None of the samples could, therefore, be digested at a low temperature about 140°C unless a rather low recovery could be tolerated.

Alumina built into iron minerals (goethite, hematite) is also significant, and these will not fully decompose even at a digestion temperature of 240°C.

Part of the silica in each sample is in the form of quartz which would be non-reactive at a low digestion temperature, but more or less reactive at the optimal temperature of alumina digestion, notably at 240°C.

Most of the iron is in the form of hematite which presages well for red-mud settling characteristics.

## Digestion tests

Digestion tests were performed in bench-scale digestion apparatus. Digestion parameters were as follows :

| | |
|---|---|
| $Na_2O$ concentration in digestion liquor | 170 gpl |
| Molar ratio in digestion liquor | 4,11 |
| Duration of digestion | 1 h |
| Digestion temperatures | 140 and 240°C |

In the tables below, IMR = input molar ratio ; EMR = effective molar ratio.

Table 3.

**Sample:** Tech 1.

Digestion temperature: 140°C

Liquor

| IMR | gpl $Na_2O_c$ | gpl $Al_2O_3$ | EMR |
|---|---|---|---|
| 1,30 | 150,1 | 139,0 | 1,78 |
| 1,45 | 150,6 | 127,7 | 1,94 |
| 1,55 | 152,8 | 125,5 | 2,00 |
| 1,65 | 155,1 | 118,3 | 2,16 |
| 1,75 | 157,1 | 115,5 | 2,24 |
| 1,95 | 156,1 | 106,5 | 2,41 |

Red mud

| IMR | $Fe_2O_3$ | $Al_2O_3$ | $SiO_2$ | $Na_2O$ | $TiO_2$ | L.O.I. | Recovery | $\frac{Na_2O}{SiO_2}$ |
|---|---|---|---|---|---|---|---|---|
| | % | % | % | % | % | % | % | kg/kg |
| 1,30 | 29,45 | 43,09 | 6,40 | 5,04 | 3,40 | 11,79 | 52,6 | 0,788 |
| 1,45 | 29,50 | 43,14 | 6,77 | 5,30 | 3,51 | 11,61 | 52,5 | 0,783 |
| 1,55 | 29,27 | 42,93 | 6,57 | 5,23 | 3,27 | 11,59 | 52,5 | 0,796 |
| 1,65 | 29,54 | 42,90 | 6,40 | 5,11 | 3,35 | 11,45 | 53,0 | 0,798 |
| 1,75 | 30,28 | 42,40 | 6,28 | 5,25 | 3,68 | 11,46 | 54,5 | 0,836 |
| 1,95 | 30,90 | 40,78 | 6,76 | 5,39 | 3,40 | 11,25 | 57,3 | 0,797 |

Table 4.

Sample Tech 2.

Digestion temperature: 140°C

**Liquor**

| IMR | gpl $Na_2O_c$ | gpl $Al_2O_3$ | EMR |
|---|---|---|---|
| 1,30 | 151,6 | 135,0 | 1,85 |
| 1,45 | 153,6 | 129,0 | 1,96 |
| 1,55 | 155,6 | 123,0 | 2,08 |
| 1,65 | 157,2 | 117,0 | 2,21 |
| 1,75 | 158,6 | 113,0 | 2,31 |
| 1,95 | 160,8 | 108,6 | 2,44 |

**Red mud**

| IMR | $Fe_2O_3$ % | $Al_2O_3$ % | $SiO_2$ % | $Na_2O$ % | $TiO_2$ % | L.O.I. % | Recovery % | $\frac{Na_2O}{SiO_2}$ kg/kg |
|---|---|---|---|---|---|---|---|---|
| 1,30 | 40,49 | 34,21 | 3,03 | 2,03 | 8,04 | 10,79 | 50,3 | 0,670 |
| 1,45 | 40,53 | 34,08 | 3,10 | 1,94 | 8,00 | 10,72 | 50,6 | 0,626 |
| 1,55 | 40,62 | 33,91 | 3,29 | 1,94 | 7,94 | 10,72 | 50,9 | 0,590 |
| 1,65 | 42,05 | 32,40 | 3,01 | 1,99 | 8,47 | 10,47 | 54,8 | 0,661 |
| 1,75 | 43,73 | 30,10 | 3,39 | 2,01 | 8,84 | 10,10 | 59,5 | 0,593 |
| 1,95 | 46,85 | 26,86 | 3,36 | 2,06 | 9,26 | 9,58 | 66,2 | 0,613 |

Table 5.

**Sample:** Tech 1

Digestion temperature: 240°C

Liquor

| IMR | gpl $Na_2O_c$ | gpl $Al_2O_3$ | EMR |
|---|---|---|---|
| 1,20 | 146,8 | 178,9 | 1,35 |
| 1,30 | 148,1 | 180,4 | 1,35 |
| 1,40 | 150,1 | 174,0 | 1,42 |
| 1,45 | 146,8 | 169,5 | 1,42 |
| 1,50 | 152,1 | 163,5 | 1,53 |
| 1,70 | 155,6 | 147,1 | 1,74 |
| 1,90 | 160,1 | 133,0 | 1,98 |

Red mud

| IMR | $Fe_2O_3$ % | $Al_2O_3$ % | $SiO_2$ % | $Na_2O$ % | $TiO_2$ % | L.O.I. % | Recovery % | $\frac{Na_2O}{SiO_2}$ kg/kg |
|---|---|---|---|---|---|---|---|---|
| 1,20 | 38,19 | 31,45 | 8,05 | 6,69 | 4,36 | 9,41 | 73,3 | 0,831 |
| 1,30 | 46,97 | 21,09 | 9,53 | 7,85 | 5,03 | 7,66 | 85,4 | 0,824 |
| 1,40 | 51,09 | 14,45 | 11,01 | 8,88 | 5,56 | 6,92 | 90,8 | 0,807 |
| 1,45 | 50,98 | 14,46 | 11,05 | 8,67 | 5,87 | 7,56 | 90,8 | 0,785 |
| 1,50 | 51,71 | 13,95 | 10,65 | 8,95 | 5,71 | 6,89 | 91,3 | 0,840 |
| 1,70 | 52,52 | 13,71 | 10,60 | 9,17 | 5,33 | 6,72 | 91,6 | 0,865 |
| 1,90 | 51,77 | 13,65 | 11,05 | 9,23 | 5,61 | 6,77 | 91,5 | 0,835 |

**Table 6.**

**Sample**: Tech 2.

**Digestion temperature**: 240°C

**Liquor**

| IMR | gpl<br>$Na_2O_c$ | gpl<br>$Al_2O_3$ | EMR |
|---|---|---|---|
| 1,20 | 147,1 | 179,1 | 1,35 |
| 1,30 | 145,1 | 177,2 | 1,35 |
| 1,40 | 147,1 | 173,5 | 1,39 |
| 1,45 | 145,8 | 167,5 | 1,43 |
| 1,50 | 147,5 | 162,3 | 1,49 |
| 1,70 | 153,8 | 149,5 | 1,69 |
| 1,90 | 153,6 | 131,0 | 1,93 |

**Red mud**

| IMR | $Fe_2O_3$ | $Al_2O_3$ | $SiO_2$ | $Na_2O$ | $TiO_2$ | L.O.I. | Recovery | $\frac{Na_2O}{SiO_2}$ |
|---|---|---|---|---|---|---|---|---|
| | % | % | % | % | % | % | % | kg/kg |
| 1,20 | 49,29 | 22,54 | 3,62 | 4,09 | 10,19 | 8,52 | 73,2 | 1,130 |
| 1,30 | 54,58 | 16,14 | 4,01 | 4,52 | 11,06 | 7,78 | 82,7 | 1,127 |
| 1,40 | 58,00 | 11,01 | 4,30 | 4,60 | 11,97 | 7,15 | 80,9 | 1,070 |
| 1,45 | 59,54 | 10,64 | 4,27 | 4,56 | 11,91 | 7,38 | 89,5 | 1,070 |
| 1,50 | 58,22 | 10,55 | 4,58 | 5,16 | 12,59 | 7,02 | 89,4 | 1,127 |
| 1,70 | 58,73 | 10,51 | 4,58 | 5,41 | 12,16 | 6,97 | 89,5 | 1,181 |
| 1,90 | 58,87 | 10,10 | 4,20 | 5,60 | 12,14 | 7,09 | 90,0 | 1,310 |

Table 7.

Digestion temperatures . 240°C

Input molar ratios : 1,45

Liquor

| IMR | gpl $Na_2O_c$ | gpl $Al_2O_3$ | EMR |
|---|---|---|---|
| Tech 3. | 146,8 | 166,0 | 1,45 |
| Tech 4. | 147,8 | 165,5 | 1,47 |
| Tech 5. | 150,2 | 165,0 | 1,50 |
| Tech 6. | 149,1 | 157,5 | 1,56 |

Red mud

| IMR | $Fe_2O_3$ | $Al_2O_3$ | $SiO_2$ | $Na_2O$ | $TiO_2$ | L.O.I. | Recovery | $\frac{Na_2O}{SiO_2}$ |
|---|---|---|---|---|---|---|---|---|
| | % | % | % | % | % | % | % | kg/kg |
| Tech 3. | 54,55 | 12,12 | 8,86 | 9,27 | 8,71 | 6,43 | 89,4 | 1,046 |
| Tech 4. | 53,53 | 14,80 | 8,54 | 7,47 | 7,30 | 7,08 | 90,6 | 0,875 |
| Tech 5. | 48,00 | 16,93 | 7,10 | 6,60 | 11,69 | 7,10 | 88,9 | 0,930 |
| Tech 6. | 69,81 | 10,05 | 2,05 | 2,64 | 4,02 | 7,62 | 84,7 | 1,288 |

The above tables reveal, as expected, that these samples will not give satisfactory digestion recoveries at 140°C, whereas all the samples are digested reasonably well at 240°C. The $Na_2O/SiO_2$ weight ratios in the red mud phases are close to unity, although they should be about 0,85 in an average case. This is due to some of the $TiO_2$ also reacting with the digestion liquor, forming certain sodium titanates.

The digestion diagrams of the samples Tech 1. and 2. respectively, are shown as Figs. 1. to 4. The figures reveal that, under bench scale digestion conditions, the optimal input molar ratio for these samples is a uniform 1,45. It was for this molar ratio that digestion recovery for the four samples listed in Table 7. was determined.

### X-ray analysis of red muds

The red muds formed on the digestion of samples Tech 1. and 2. at 140 and 240°C, respectively, were subjected to X-ray diffractometry. Results are summarized in Tables 8 and 9.

Table 8.
Sample: Tech 1.

| Component percent | Digestion temperature | | | |
|---|---|---|---|---|
| | 240°C | 240°C | 140°C | 140°C |
| | IMR | | | |
| | 1,40 | 1,45 | 1,30 | 1,95 |
| $Al_2O_3$ in | | | | |
| sodalite | 8,6 | 8,8 | 4.4 | 4.9 |
| cancrinite | 0.5 | 0.2 | – | - |
| goethite | 1.6 | 1.7 | 1,2 | 1.2 |
| hematite | 1,4 | 1.4 | 1,1 | 0.7 |
| boehmite | 0,7 | 0,2 | 30,5 | 32.0 |
| gibbsite | - | - | 3,9 | – |
| diaspore | 1,7 | 1,7 | 1,9 | 1,8 |
| $Fe_2O_3$ in | | | | |
| goethite | 17,3 | 18,0 | 10,5 | 10,5 |
| hematite | 31,3 | 31,5 | 17,4 | 18,6 |
| maghemite | 2,5 | 2,5 | 1,6 | 1,8 |
| $SiO_2$ in | | | | |
| quartz | 1,0 | 1,1 | 1,6 | 1,4 |
| sodalite | 0,5 | 9,7 | 4,8 | 5,4 |
| cancrinite | 0,5 | 0,2 | tr | tr |
| $TiO_2$ in | | | | |
| anatase | 0,5 | 0,5 | 0,8 | 1,0 |
| rutile | 1,5 | 1,4 | 1,4 | 1,3 |
| Na-titanate | 3,6 | 4,0 | 1,0 | 1,1 |

Table 9.

**Sample**: Tech 2.

| | Digestion temperature | | | |
|---|---|---|---|---|
| | 240°C | 240°C | 140°C | 140°C |
| | IMR | | | |
| | 1,40 | 1,45 | 1,30 | 1,95 |
| $Al_2O_3$ in | | | | |
| sodalite | 2,7 | 2,8 | 1,2 | 1,3 |
| cancrinite | 1,0 | 0,9 | - | - |
| goethite | 4,4 | 4,4 | 3,1 | 3,6 |
| hematite | 1,4 | 1,5 | 0,9 | 1,0 |
| boehmite | 0,8 | 0,2 | 22,2 | 20,5 |
| gibbsite | - | - | 6,3 | - |
| diaspore | 0,5 | 0,7 | 0,5 | 0,5 |
| $Fe_2O_3$ in | | | | |
| goethite | 22,8 | 23,0 | 16,5 | 19,0 |
| hematite | 33,2 | 34,0 | 22,0 | 25,8 |
| maghemite | 2,0 | 2,5 | 2,0 | 2,0 |
| $SiO_2$ in | | | | |
| quartz | 0,3 | 0,3 | 1,7 | 2,0 |
| sodalite | 3,0 | 3,1 | 1,3 | 1,4 |
| cancrinite | 1,0 | 0,9 | - | - |
| $TiO_2$ in | | | | |
| anatase | 0,4 | 0,3 | 1,0 | 1,0 |
| rutile | 0,5 | 0,6 | 1,3 | 1,0 |
| Na-titanate | 11,1 | 11,0 | 5,7 | 7,2 |

These results permit to state the following.

- At 140°C, boehmite remains effectively undigested.
- Most of diaspore and the alumina in the iron minerals' lattices remain undigested at both 140 and 240°C.

- At 140°C, even part of gibbsite remains undigested at the lower molar ratio of 1,30.
- At 140°C, quartz is non-reactive, whereas at 240°C, the quartz content of Tech 2. was digested in its entirety; that of Tech 1. was digested less completely.
- Digestion dissolved 5 percent of $TiO_2$ in Tech 2, and 65 percent in Tech 1., giving rise to Na-titanates in the red mud.

With a view to reducing the NaOH loss in red mud and to furthering the digestion of the significant amount of alumina tied down in the iron minerals, we have made a digestion test with lime added in an amount of 3 percent on the bauxite digested.

Table 10.
Input molar ratio: 1,45
Digestion temperature: 240°C

Liquor

| Sample | gpl $Na_2O_c$ | gpl $Al_2O_3$ | EMR |
|---|---|---|---|
| Tech 1. | 149,1 | 168,0 | 1,46 |
| Tech 2. | 148,6 | 168,2 | 1,45 |

Red mud

| Sample | $Fe_2O_3$ | $Al_2O_3$ | $SiO_2$ | $Na_2O$ | $TiO_2$ | L.O.I. | Recovery | $\frac{Na_2O}{SiO_2}$ |
|---|---|---|---|---|---|---|---|---|
| | % | % | % | % | % | % | % | kg/kg |
| Tech 1. | 48,08 | 12,29 | 10,82 | 7,12 | 5,66 | 6,40 | 92,0 | 0,658 |
| Tech 2. | 55,84 | 9,87 | 4,20 | 4,34 | 11,78 | 7,51 | 89,6 | 1,033 |

These data reveal that the addition of lime improves the digestion of Tech 1., augmenting alumina recovery by 1,6 percent and decreasing the $Na_2O/SiO_2$ ratio in the red mud. No such improvement was observed in the limy digestion of Tech 2. In order to illustrate the effects of lime addition, we list in the following table X-ray diffractomery of red mud after the addition of lime .

Table 11.

| Component percent | Tech 1. | Tech 2. |
|---|---|---|
| $Al_2O_3$ in sodalite | 6,0 | 2,6 |
| cancrinite | 2,7 | 0,9 |
| goethite | tr | 3,6 |
| hematite | 1,[illegible] | 1,3 |
| boehmite | tr | 0,2 |
| diaspore | 1,7 | 0,3 |
| Ca-Al-silicate | 0,9 | 0,9 |
| $Fe_2O_3$ in goethite | 1,5 | 19,0 |
| hematite | 46,5 | 31,8 |
| maghemite | tr | 5,0 |
| $SiO_2$ in quartz | 1,0 | 0,3 |
| sodalite | 6,7 | 2,8 |
| cancrinite | 2,7 | 0,9 |
| Ca-Al-silicate | 0,4 | 0,2 |
| $TiO_2$ in anatase | tr | tr |
| rutile | tr | tr |
| Na-titanate | tr | 5,3 |
| $CaTiO_3$ | 5,7 | - |
| Ca-titanate | - | 6,5 |
| CaO in Ca-Al-silicate | 1,4 | 1,4 |
| calcite | 2,0 | - |

X-ray testing confirms the findings of chemical analysis. Alumina in goethite is fully digested in Tech 1., whereas in Tech 2 the alumina content of goethite was not appreciably affected. The optimum digestion of this sample would probably require the addition of more lime than 3 percent.

In the red mud of the Tech 1. sample, $Fe_2O_3$ in the form of goethite was converted practically totally into hematite, which is an advantage as regards the settling of red mud.

The Na-titanate in the red mud of Tech 1. was fully converted into $CaTiO_3$ by the addition of lime, whereas in the case of Tech 2. the conversion is partial only. This is why the $Na_2O/SiO_2$ ratio in the red muds was improved by the addition of lime in the case of Tech 1 and less so in Tech 2.

We may state in summary that the addition of lime in optimal quantities (whose establishing would require further laboratory testing) would improve both digestion efficiency and red-mud-bound $Na_2O$ loss.

## Settling behaviour

Red mud resulting from the digestion of Tech 1. and Tech 2. at the optimum molar ratios was settled in bench-scale settling tubes. The parameters of the settling tests were as follows :

**Testing for behavior in thickener**

| | | |
|---|---|---|
| $Na_2O$ concentration in liquor | 140 | gpl |
| Molar ratio of liquor | 1,7 | |
| Solids content of slurry | 65 | gpl |
| Flocculant (flour) : 2 kg per ton of dry red mud | | |
| Settling temperature | 95 °C | |

**Testing for behaviour in first washer**

| | | |
|---|---|---|
| $Na_2O$ concentration in liquor | 80 | gpl |
| Molar ratio of liquor | 2,0 | |

Solids content of slurry 100 gpl
Flocculant (flour): 2 kg per ton of dry red mud
Settling temperature 80°C

These tests reveal both red muds to exhibit excellent settling properties. Settling curves are shown as Figs. 5 (for the thickener) and 6 (for the first washer).

Table 12,

| Settling time min. | Height of clear zone | | | |
|---|---|---|---|---|
| | Thickener | | First washer | |
| | Tech 1. | Tech 2. | Tech 1. | Tech 2. |
| 0 | 0 | 0 | 0 | 0 |
| 5 | 13,5 | 4,9 | 15,3 | 10,3 |
| 10 | 23,0 | 15,6 | 19.8 | 18,7 |
| 15 | 23,6 | 20,0 | 21,1 | 20,5 |
| 20 | 24,1 | 22,4 | 21,7 | 21,3 |
| 25 | 24,5 | 23,1 | 22,2 | 21,8 |
| 30 | 24,8 | 23,5 | 22,5 | 22,1 |
| 35 | 25,0 | 23,9 | 22,8 | 22,4 |
| 40 | 25,2 | 24,1 | 23,0 | 22,6 |
| 45 | 25,3 | 24,3 | 23,2 | 22,8 |
| 50 | 25,4 | 24,4 | 23,3 | 23,0 |
| 55 | 25,5 | 24,5 | 23,5 | 23,2 |
| 60 | 25,6 | 24,6 | 23,6 | 23,3 |
| Solids content of compacted slurry gpl | 440 | 440 | 550 | 555 |

Fig.1

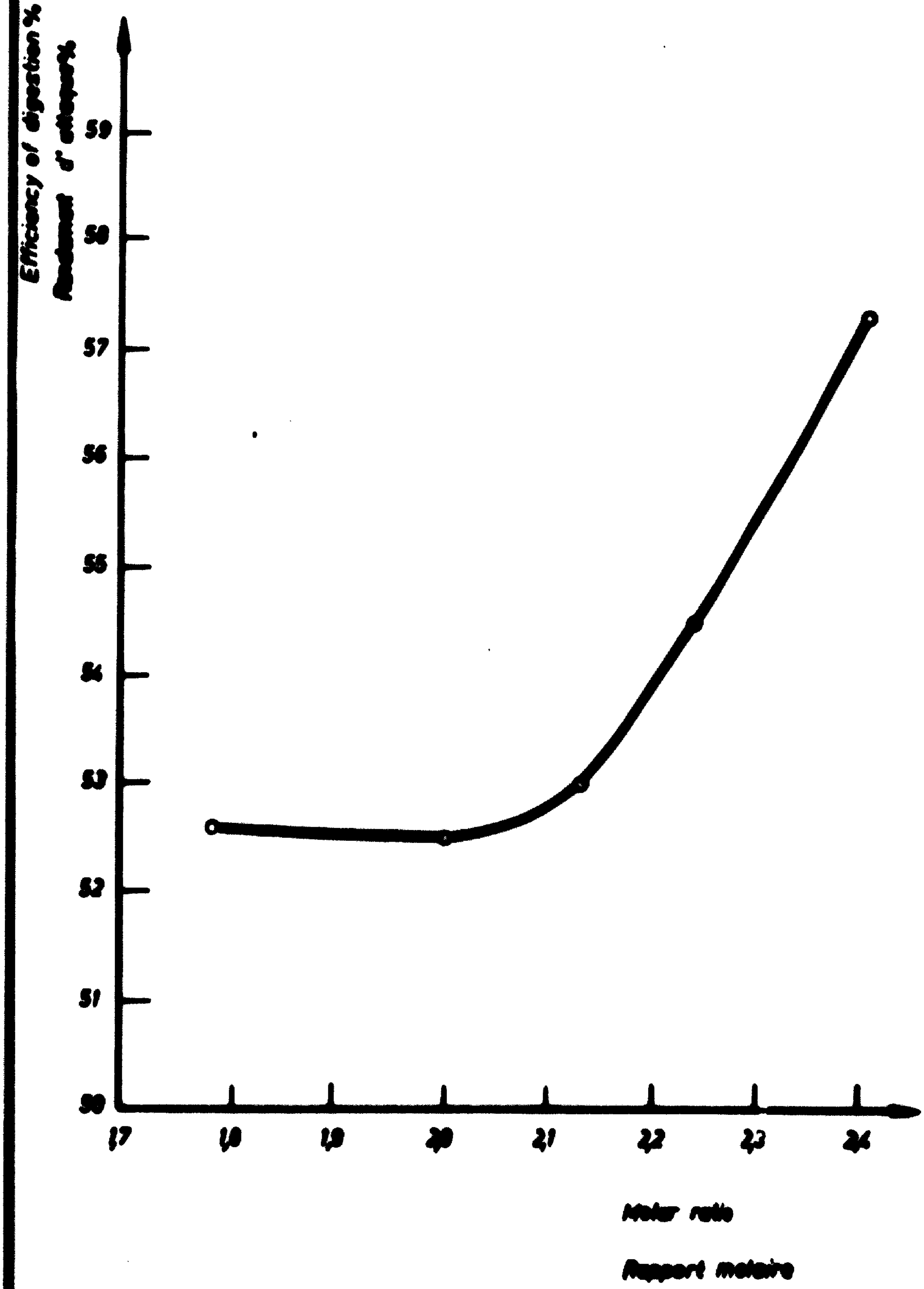

Efficiency of digestion %
Rendement d' attaque%
59
58
57
56
55
54
53
52
51
50
1,7
1,8
1,9
2,0
2,1
2,2
2,3
2,4
Molar ratio
Rapport molaire

Fig.2

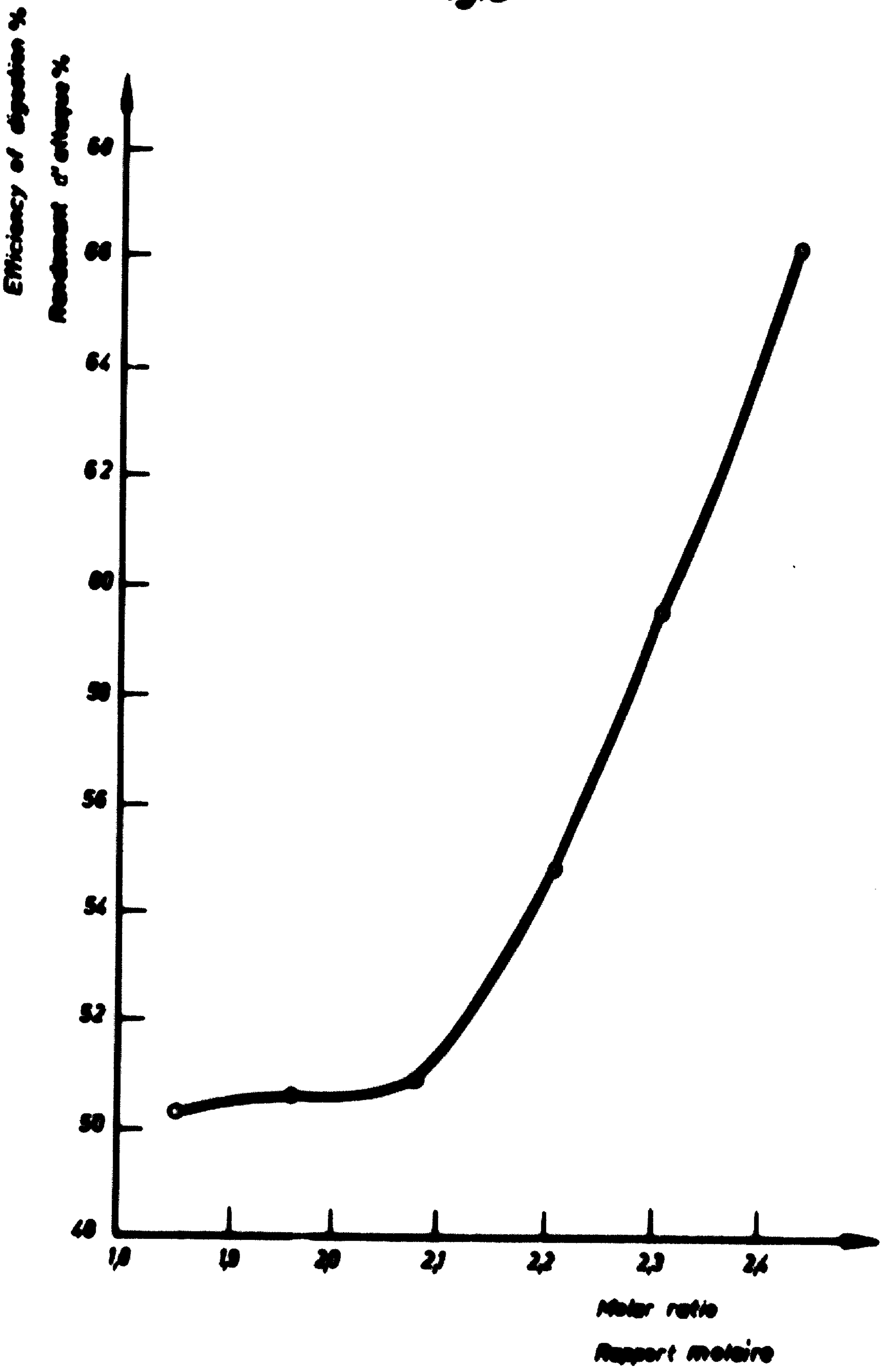

Efficiency of digestion %
Rendement d'attaque %
68
66
64
62
60
58
56
54
52
50
48
1,8
1,9
2,0
2,1
2,2
2,3
2,4
Molar ratio
Rapport molaire

Fig.3

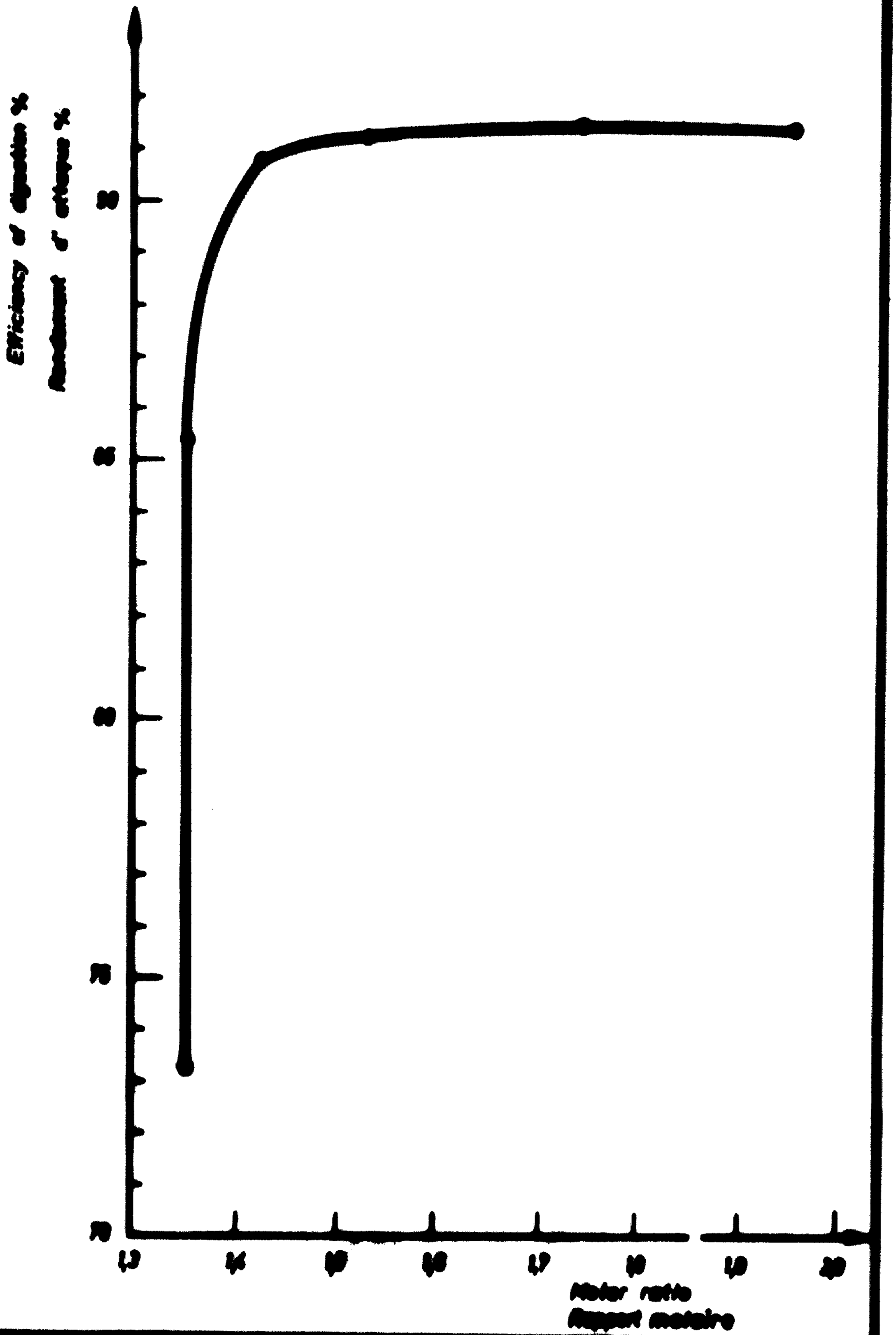

Efficiency of digestion %
Rendement d' attaque %
90
85
80
75
70
1,3
1,4
1,5
1,6
1,7
1,8
1,9
2,0
Molar ratio
Rapport molaire

Fig.6

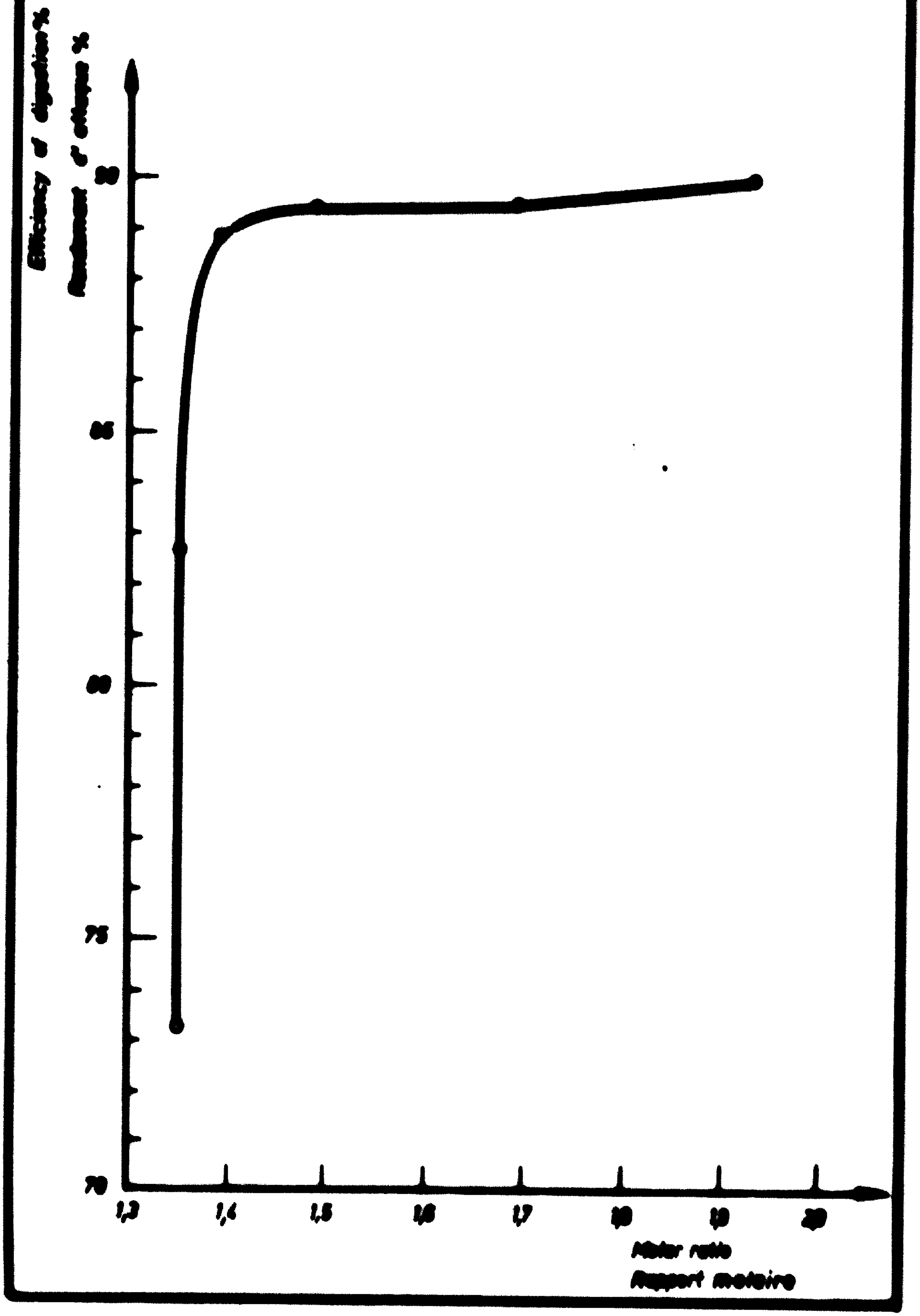

Efficiency of digestion %
Rendement d'attaque %
90
85
80
75
70
1,3
1,4
1,5
1,6
1,7
1,8
1,9
2,0
Molar ratio
Rapport molaire

Fig. 5

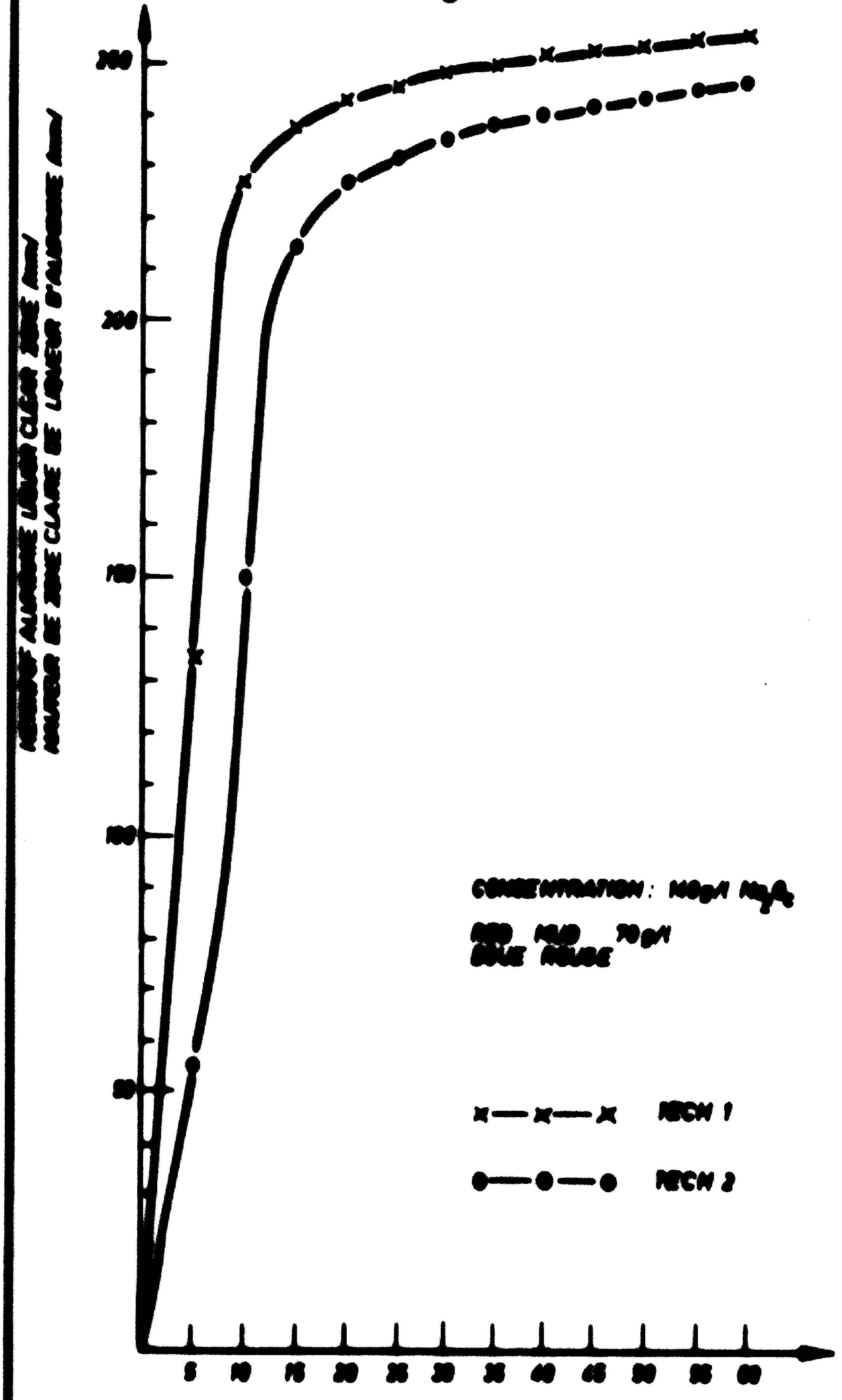
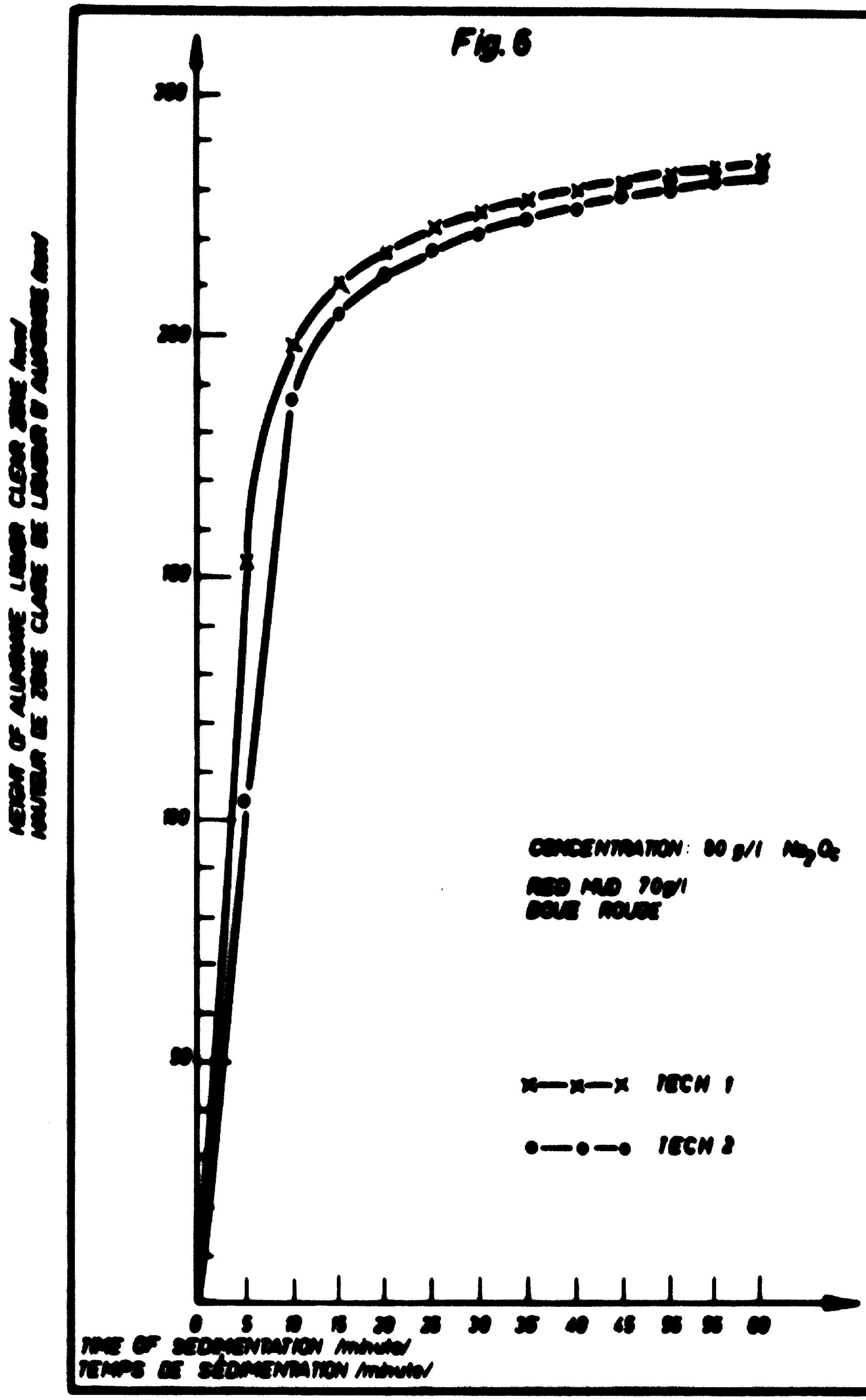

HEIGHT ALUMINATE LIQUOR CLEAR ZONE (mm)
HAUTEUR DE ZONE CLAIRE DE LIQUEUR D'ALUMINATE (mm)
250
200
150
100
50
5
10
15
20
25
30
35
40
45
50
55
60
CONCENTRATION : 140g/l $Na_2O_c$
RED MUD 70 g/l
BOUE ROUGE
RECH 1
RECH 2

Fig. 6


HEIGHT OF ALUMINATE LIQUOR CLEAR ZONE (mm)
HAUTEUR DE ZONE CLAIRE DE LIQUEUR D'ALUMINATE (mm)
250
200
150
100
50
0
5
10
15
20
25
30
35
40
45
50
55
60
TIME OF SEDIMENTATION /minute/
TEMPS DE SÉDIMENTATION /minute/
CONCENTRATION: 80 g/l $Na_2O_c$
RED MUD 70g/l
BOUE ROUGE
x—x—x TECH 1
●—●—● TECH 2

SOME FIGURES
OF THIS DOCUMENT
ARE TOO LARGE
FOR MICROFICHING
AND WILL NOT
BE PHOTOGRAPHED.

B-571

▽

84.11.28
AD.86.07
ILL4.0+10