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

FAIR USE POLICY

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

20693

FINAL REPORT

RED MUD DISPOSAL AT CVG INTERALUMINA

UNIDO PROJECT No. SI/VEN/93/801/11

CONTENTS

1. Introduction 1

2. Process Description 2

3. Water Balance 5

4. Assessment of Red Mud Treatment and Disposal Technology 8

5. Suggested Improvements to the Process and Housekeeping Procedures 9

6. Effects of Dewatering 11

7. Disposal Systems 13

8. Evaluation of the Possible Red Mud Thickening and Filtration Processes 15

9. Economic Comparison of the Possible Red Mud Thickening and Filtration Processes 26

10. Ecology 30

11. Recommendation 32

FINAL REPORT

RED MUD DISPOSAL AT CVG INTERALUMINA

UNIDO PROJECT No. SI/VEN/93/801/11

1. INTRODUCTION

CVG INTERALUMINA is an alumina refinery in Puerto Ordaz (Ciudad Guyana), Venezuela, that has a current capacity of 2.0 million metric tons per year (the largest in the world outside of Australia). Present production rate is about 1.5 MMTPY. The technological process involves the disposal of the mud content of the bauxite to settling lagoons. This red mud (containing approximately 10-20 grams per liter of caustic soda in its liquor phase) is pumped to the red mud lagoons located on the banks of the river Orinoco that flows into the Atlantic Ocean. These lagoons are near to their saturation (they enable the plant to operate for only two to three years with its present disposal system) and may force the refinery to shut down its operation, if a long term solution to the problem of environmentally sustainable red mud disposal can not be found. Since there is no more area available for a conventional, lagoon-type red mud disposal, some of the so-called "thickened tailings disposal" or "dry stacking" methods will have to be adapted. The present report compares four possible methods, thickened tailings disposal via superthickener or deep thickeners and dry stacking via vacuum or hyperbaric filtration.

The aim of the UNIDO project is to assist CVG INTERALUMINA in the assessment of the new processes and in the selection of the most favourable one.

The team selected to carry out the project was composed originally of the following four experts:

- Dr. John L. Chandler, Ph.D., Consultant Chemical Engineer, retired Senior Technical Consultant of Alcan Jamaica Company (Subsidiary of Aluminium Company of Canada). Presently independent Consultant Chemical Engineer, based in St Augustine, Florida, USA.
- Ronald F. Nunn, M.Sc., Chem.E., has worked 27 years in the alumina industry for Kaiser Aluminium and currently Kaiser Engineers, in process design and process operations, in recent years concentrating more on the environmental aspects of alumina plant operation.
- Dr Péter P. Siklósi, Ph.D., Chem.E., retired Chief Technical Adviser of Aluterv-FKI (Research, Development and Engineering Centre of the Hungarian Aluminium Corporation). Presently independent Consultant Chemical Engineer for the alumina industry, based in Budapest, Hungary.
- János Steiner, M.Sc., Mech.E., retired Head of Department of Aluterv-FKI (see above). Presently independent Consultant Mechanical Engineer for the alumina industry, based in Budapest, Hungary.

At a later stage UNIDO commissioned a fifth expert:

- Nils Oeberg, dipl.ing.chem.ETH, retired from Swiss Aluminium (Alusuisse-Lonza), with large experience in process design, basic engineering and project management. Presently he provides specific assistance to industry and related suppliers as consultant, based in Zürich, Switzerland).

2. PROCESS DESCRIPTION

This process description is intended to briefly describe the main process flows and their treatment in the plant.

2.1. Bauxite Handling, Grinding, Slurry Heating and Slurry Pre-desilication

In the past INTERALUMINA processed various foreign bauxites from Brazil, Guinea, Guyana, Australia, etc. Its present and future operation is based on the domestic bauxite deposit of Los Pijiguaos, upstream on the Orinoco river. Because of the seasonal changes of the river flow, for an average of four to five months per year (December to April, the dry season) the transportation of the bauxite is interrupted. Therefore, a large stockpile of bauxite has to be kept at the plant site. This involves large unloading, conveying, stacking and reclaiming facilities.

The typical bauxite factor for Los Pijiguaos bauxite is 2.2. tons per ton of alumina (dry basis), i.e. 4.4 million metric tons per year will have to be handled when fully exploiting the existing capacity and 6.6 MMTPY, if the plant gets expanded to the capacity of 3.0 MMTPY.

The bauxite is ground to a fine particle size using open circuit wet grinding in ball mills. Hot spent liquor is added to the mills to give 950-1000 gpl solids in the slurry discharged from the mill. Dry lime is added to the mills.

Slurry from bauxite grinding is heated by direct injection slurry heaters. The slurry is then held for about 8 hours at 100 °C in pre-desilicator tanks. Most of the reactive silica is converted to desilication product (DSP) under these conditions. Each tank is agitated and equipped with recirculation pumps.

2.2. Digestion

The bauxite slurry from pre-desilication is pumped to the first of 5 digester vessels (4 operating, 1 spare) connected in series, where it is combined with the spent liquor. The spent liquor is pumped to the first digester vessel through two series of indirect steam heaters. The first series of heaters (3 stages) are heated by flash steam from the 3 flash tanks in series used to depressure the slurry leaving the digestors. The second series of heaters heat the spent liquor, using live steam, up to 160 °C before entering the first digester. Sufficient time is allowed in the digestors to permit efficient extraction of more than 97 % of the extractable alumina. Flash steam is also used to partially heat the bauxite slurry being fed to the pre-desilication tanks. From the last flash tank the slurry is piped to the blow-off tank which is operated at atmospheric pressure. Good condensate, primarily from the live steam heaters, and contaminated condensate are segregated in 2 separate systems.

2.3. Sand Separation

The Pijiguaos bauxite used has a high sand content (about 11 % of the dry bauxite) which must be removed from the slurry leaving digestion before entering the mud settlers. The sand separation system consists of a series of cyclones and sand classifiers. This system is designed to separate the sand and wash it free of caustic soda before pumping the sand to disposal at 75 % solids An annual amount of about 0.5 MMTPY dry sand has to be separated at the 2 MMTPY production level; the quantity of wet sand to be disposed of amounts to 0.6-0.7 MMTPY. According to the present disposal process this sand is put into lagoon 1.

2.4. Red Mud Separation, Washing, and Filtration

Digestion slurry from sand separation enters the settlers and is thickened to about 400-450 gpl solids using synthetic flocculants to enhance thickening.

The underflow from the settlers is pumped to a multi-stage countercurrent decantation mud washing system using thickeners operating at about 400 gpl solids underflow. The mud from the last washer is pumped to the red mud disposal area (presently lagoons 2 and 3).

Hot wash water is added at the last mud washers in order to recover most of the caustic soda from the red mud before disposal.

The typical mud factor is 0.24 t dry red mud per t of dry bauxite, i.e. some 1.05 MMTPY of dry red mud has to be disposed of (with a 93 % operating factor some 128-130 t/h).

2.5. Security Filtration

Filter aid is added to the settler overflow in order to facilitate this filtration. The pregnant liquor is filtered through pressure leaf filters and pumped to precipitation via the flash cooling facility.

2.6. Flash Cooling

The pregnant liquor is cooled in several flash stages in series to the required temperature for precipitation. The flashed steam from these flash stages is used for heating the spent liquor from precipitaton in a series of heat exchangers connected to the flash stages.

2.7. Precipitation

A modern, continuous, high yield, precipitation process is used.

The basic process adds hydrate seed to the pregnant liquor from flash cooling and holds the resulting slurry for sufficient time and under the correct conditions to produce a sandy alumina product with more than 80 gpl alumina yield. The total plant pregnant liquor flow is split between two, continuous, lines of precipitators.

Interstage cooling capacity is provided to control the temperature in the precipitators.

2.8. Hydrate Classification and Filtration

The hydrate classification system uses a series of hydrocyclones and thickeners to classify the slurry leaving the last precipitators into a sandy product hydrate, a coarse seed hydrate and a fine seed hydrate.

Both the coarse and fine seed hydrate are filtered before recycle to the precipitator tanks. In addition the fine seed is washed with hot water in order to dissolve the oxalate from the seed surface.

2.9. Product Filtration and Calcination

The product hydrate produced by the hydrate classification system is fed to a system of horizontal pan filters, where the hydrate is filtered and washed practically free of caustic soda before being fed to the calciners. The calciners convert the product hydrate into product alumina which is transferred to alumina storage.

2.10. Evaporation

The spent liquor leaving precipitation must be concentrated before being fed to digestion. A multi-stage flash evaporation unit with a high steam economy is used.

The concentrated spent liquor after evaporation, is stored in a concentrated digestion feed liquor tank. The liquor is metered out of this tank to the Digestion process.

3. WATER BALANCE

3.1. Plant

The plant water balance is a very complex system, and for the purposes of this study will not be examined in complete detail. What will be examined is the effect on the water balance for each of the alternative mud dewatering and disposal systems under consideration.

The major effect will be on the amount of free-standing, caustic soda contaminated water in the lagoons.

In February 1994. lagoons 2 and 3 contain about 5 million cubic meters of contaminated water. This water is a major problem, and the plant's goal is to return all of this water to the plant for re-use as soon as possible.

Changing the technology used for dewatering/thickening the mud prior to disposal will greatly assist the removal of the water from the lagoons.

The installation of a superthickener, deep thickeners, pressure filtration or vacuum filtration will allow the free-standing water in lagoons 2 and 3 to be removed in 3.5 years to 4.5 years, assuming a 50 m^3/h recycle to the plant. The corresponding time for 100 m^3/hr recycle would be 2.5 years to 3.5 years. This assumes efficient control of all aspects of the water balance, and that no water other than that with the mud will be pumped to the lagoons.

Table 1 shows the water balance for the plant for the Base Case and the alternative technologies under consideration.

Case 0 -	base case using the existing equipment.
Case 1 -	using a superthickener or deep thickeners.
Case 2 -	using vacuum filtration.
Case 3 -	using pressure filtration.

Substituting the base case (0) with one of the approaches (case 1-3) herein discussed will modify the actual water balance of INTERALUMINA. The below given comparison summarizes the impact only on those items directly affected by such changes.

Table 1. Abstract of Water Balance in T H20/HR/STR.

ITEM	DESCRIPTION	CASE 0	CASE 1	CASE 2	CASE 3
OUT (1)	Mud Water to Pond	145	84	52	21
IN (1)	Miscellaneous Water to Areas	141	141	123	122
IN (2)	Pond Return to 7th Washer	43	0	0	0
IN (3)	Mud Wash Water (Cond.)	130	116	95	65
IN (4)	Injected Steam to areas	60	56	63	63
IN (5)	Subtotal	374	313	281	250
DIFF.	Required Evaporation	229	229	229	229

Note: The t/h numbers above include a 93 % operating factor; All data for Base Case were provided by INTERALUMINA

In other terms, the restricted waterbalance shows that the overall evaporation capacity will not be affected. Further comments will be included in Chapter 8 when evaluating the different alternatives (cases 1-3).

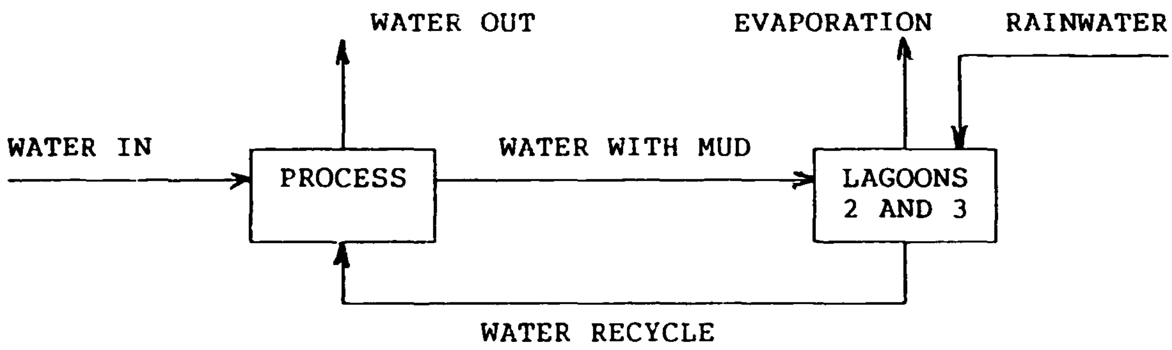
The above figures are based on the complete water balances supplied by INTERALUMINA for the four cases, using the following densities and water consumptions for red mud:

	Solids %	t H20/t Mud
CASE 0	31 %	2.0
CASE 1	44 %	1.8
CASE 2	55 %	1.5
CASE 3	75 %	1.0

3.2. Lagoons

Figure 1 shows the factors affecting the water balance in lagoons 2 and 3.

Fig. 1. INTERALUMINA water balace - schematic drawing



Currently the sand is being pumped to Lagoon Number 1; however, it may be pumped to Lagoons 2 and 3 at some future date.

The balance considers lagoons 2 and 3 only. INTERALUMINA has separate plans for Lagoon 1.

Although a considerable amount of condensate has been dumped to the lagoons in the past, INTERALUMINA indicates that control systems will be installed which should reduce this flow to zero.

Rainfall averages about 90 mm per month, most of which falls during the rainy season (June-October). This rain water can find its way into the lagoons by surface run-off or by percolating through the surface of the forested hillside above the lagoons and from there traveling below the land surface into the lagoons. Drainage channels have been recently cut to carry most of the run-off water away from the lagoons. However, INTERALUMINA does not have an accurate estimate of the rain water that enters the lagoons. A rough estimate is 0.5 to 1 million cubic meters per year.

Evaporation from the lagoons will contribute significantly to the removal of water. The average net evaporation rate is 80 mm of water per month. On this basis the net evaporation will be about 1.5 million m^3 the first year, about 1.0 m^3 the second year, about 800,000 m^3 the third year, and 600,000 m^3 in year four (proportional to the shrinking surface area of free water).

The combination of reducing the water with the mud to the lagoons and evaporation from the lagoon surface will allow the free standing water in Lagoons 2 and 3 to be completely removed in 3.5 years - 4.5 years assuming 50 m^3/h lagoon water recycle to the plant and 2.5 to 3.5 years for a 100 m^3/h recycle. If, in addition, the plant institutes more programs to use more lagoon water, eg. for purge water, and substitute for fresh water, then the lagoons may be emptied of water in less time.

The free-standing water in the lagoons contains about 30 gpl (as Na_2O) of sodium carbonate (Na_2CO_3) and caustic soda (NaOH) with a ratio of 1:1. This water may also contain other impurities detrimental to the plant performance, e.g., sulfates, organic materials, etc., which should be checked for. In any event, the recycled lagoon water must be causticized in a reactor with milk of lime ($Ca(OH)_2$) in order to convert the sodium carbonate content to caustic soda. Otherwise, the sodium carbonate from the lagoon will reduce the yield in precipitation and the plant's production rate. However, the caustic soda and sodium carbonate returned to the plant have significant value. At 30 gpl (Na_2O) the total recoverable, useful caustic soda value is approximately $25 million, assuming a value of $150/T, 100 % NaOH, and $40/T burnt lime, for causticization. Equipment has been recently added to causticize the lagoon water. The major cost of causticization will be the slaked lime requirements. The estimated cost for slaked lime is $30/T of NaOH produced by causticization.

The control of the rain water entering the lagoons has a significant effect on the lagoon water balance. Although channels have been cut in the hillside to divert some of the rain water, it may be beneficial to re-examine the situation to see if more work would be justified for diverting more of the rain water.

If some of the lagoon water is returned to the plant and used as mud wash water in substitution of condensate, then the caustic concentration in the mud washing and filtering system (if used) can be expected to increase, which will increase the soda loss with the mud. This additional loss is expected to be small, and could be compensated by a better management of unaccounted water entering the process (see later).

The environmental risk will be reduced by removal of the free-standing lagoon water. Although the probability is relatively small, a break in the dam could release a large spill of contaminated water into the Orinoco River. Beside this, some quantities of this contaminated water may find their way through the subsoil into the river (see also Section 4.2).

4. ASSESSMENT OF RED MUD TREATMENT AND DISPOSAL TECHNOLOGY

4.1. Red Mud Washers

The washers in this plant experience a number of difficulties in their operation. Firstly, the use of Pijiguaos bauxite presents its own particular problems.

The Pijiguaos bauxite has a high sand content. This results in a high sand load in Area 34 - Sand Separation, but also creates problems in the mud washers. INTERALUMINA has experienced piles of fine (53 μ - 106 μ) sand in the washers which the rakes cannot move - resulting in washer shutdown. This problem is made worse by the design of the washers, which are flat-bottom, outward raking type.

The mud washing system has 7 stages of washers for efficient washing of the mud. However, the plant has experienced difficulty in operating all 7 stages and consequently has only been operating 4 or 5 stages, with an increase in soda losses to the lagoons 2 and 3.

Since the efficient operation of the mud washing circuit is critical to the production and efficiency of the plant we suggest that emphasis be placed on efficient flocculation, and efficient process control of settling rates, mud levels, and the inventory of mud in the washers.

Part of the problem of the mud washers is the large amount of process dilution water which finds its way into the washers via the hosing up of spills in the red area. As mentioned elsewhere, reduction in the number of spills would allow more wash water to be added to the last wash stage and thus reduce the soda losses to the lagoons.

4.2. Mud Disposal

Currently the mud is pumped to lagoons 2 and 3 , at about 380 gpl solids, using centrifugal pumps. This system works reasonably well.

The problem arises from the fact that in the past a large amount of additional water has been pumped from the plant to the lagoons, particularly bad condensate. This extra water plus roughly 2 million m^3/yr of rain water, about half of which was recently diverted from the lagoons, resulted in the 5.3 million m^3 of free-standing water in lagoons 2 and 3, today.

This free-standing water, containing about 30 gpl Na_2O constitutes a significant environmental hazard; especially in light of the fact that the dikes are located on sand in some areas, and the bottom of lagoons 2 and 3 are based on river silt and consequently probably permeable. All of which increases the risk of the loss of caustic soda to the Orinoco River.

5. SUGGESTED IMPROVEMENTS TO THE PROCESS AND HOUSEKEEPING PROCEDURES

This section of the report suggests improvements in the water balance which will allow recycle to the plant of the free-standing water in lagoons 2 and 3 and the commensurate $25 million caustic soda recovery.

5.1. Base Case

The Base Case (Case 0 in Table 1) uses the existing 7 washer stages to wash the mud and send a mud slurry at about 400 gpl solids to lagoons 2 and 3.

5.2. Suggested Improvements

1. Institute programs to reduce the number of spills onto the slab in Area 34 - Sand Separation, Area 31 - Predesilication, Area 32 - Bauxite Grinding, Area 33 - Digestion, and Area 35 - Red mud Separation and Washing. Spills of bauxite or red mud in these areas require hosing into a sump with water or dilute spent liquor - both of which add water to the process.

2. Institute a program to minimize the amount of purge water used in the plant. Minimize the use of purge water on pump glands. Replace pump glands requiring purge water with mechanical seals requiring no water, where feasible.

3. Maximize the use of barometric condensers and cooling towers for use on process liquor, where feasible. This will maximize the evaporation of water from the process.

4. Minimize the use of fresh water in the plant. The water balance for the base case indicates fresh water plus condensate entering the process at about 886 t/h.

The goal should be to replace this condensate and fresh water with recycled lagoon water wherever economic and feasible.

5. Maximize the generation and use of good condensate of a suitable quality for use as boiler feed water.

5.3. Suggested Lagoon Water Substitution Points

1. Substitute lagoon water for purge water wherever feasible.

2. Substitute lagoon water for condensate (36.5 t/h) in Area 34 - Sand Separation. Since the sand rejects from Area 34 are low in liquor (25 %), the increase in soda losses with the sand should be minimal.

3. Substitute lagoon water for wash water (44 t/h) in Area 38 - Security Filtration. Assuming this water is used to wash the mud from the filter leaves and transport the mud to the washers, the mud slurry could be fed into the washer stage with a similar caustic concentration, with a minimal increase in the soda loss with the mud. This soda loss should become even less with the use of any of the alternate new technologies proposed.

4. Substitute lagoon water for hose water in the red areas of the plant. Since the lagoon water contains about 30 gpl Na_2O, a strict safety program must be instituted (if not already in place) to enforce the use of protective clothing, including face masks.

5. Substitute lagoon water for all or part of the wash water added to the last stage of mud washing. This will increase the soda loss to the lagoons, but this increase should

not be excessive. An economic evaluation will be necessary to estimate how much of the mud wash water may be economically replaced with lagoon water.

The above indicates that it may be possible to substitute about 100-150 t/h of water entering the red side of the process with lagoon water. For this reason, the time required to recycle all of the water from lagoons 2 and 3 has been estimated for 50 m^3/h and 100 m^3/h conservative recycle rates.

5.4. Effect of Installing Filters, Superthickener or Deep Thickeners on the Recycle of Lagoon Water

The effect of reducing the amount of water accompanying the mud discharge due to installation of filters, superthickener or deep thickeners is to reduce the amount of mud wash water. This, in turn, will increase the concentration of the soda in the water associated with the mud to the lagoons. However, the effect of this concentration increase on the amount of soda discharged will be compensated for by the big reduction in the volume of water being discharged with the mud.

The effect of the concentration increase in the mud wash water will be to reduce somewhat the amount of lagoon water that can be economically used for mud washing. However, the other possible substitution points ıor lagoon water should still permit recycle of 50-100 t/h of lagoon water.

6. EFFECTS OF DEWATERING

6.1. Effect of Method of Dewatering on Process Parameters

It is important to recognize that the choice of equipment for dewatering will affect liquor composition in other parts of the mud washing circuit, and even, to a lesser extent, in other operations of the Bayer process.

To calculate the effect of the changed dewatering operation we should apply the computer programme of the mass balance for the plant, or at least the part of the programme (sub-routine) applying to the mud washing circuit.

In all mud circuit programmes a major input variable is the underflow solids concentrations for each of the washing stages, expressed as (gram per litre) or (percent solids).

In the sample attached (Fig. 2) the following values (supplied by INTERALUMINA) are shown for the solids concentrations in underflows of stages 1 to 7 respectively: 449.8, 423.7, 394.2, 398.5, 378.7, 379.6, 377.7 g/l. More recent figures indicate about 400 g/l for the last washers.

One alternative being studied by INTERALUMINA is to substantially increase the overall washing effect of the mud washing circuit by adding an 8th stage to the existing circuit and using for this 8th stage, equipment which provides underflow concentrations much higher than obtainable from conventional thickeners. It has been suggested, by INTERALUMINA, that this addition may improve the overall washing effect of the mud circuit to such an extent that it may prove economical to eliminate up to four of the existing stages. Savings envisaged from such a reduction are power, maintenance, labour and flocculant. These savings have to be balanced against the effect their elimination will have on the solutes concentration of the mud stream being discarded to mud pond (or mud stack).

To reach the right decision on which dewatering device to add to the mud circuit, and how many, if any, of the existing thickeners should be eliminated, it is important to generate mass balances for all the possible alternatives.

The alternative dewatering devices under consideration, together with the underflow solids concentrations expected from each, are as follows:

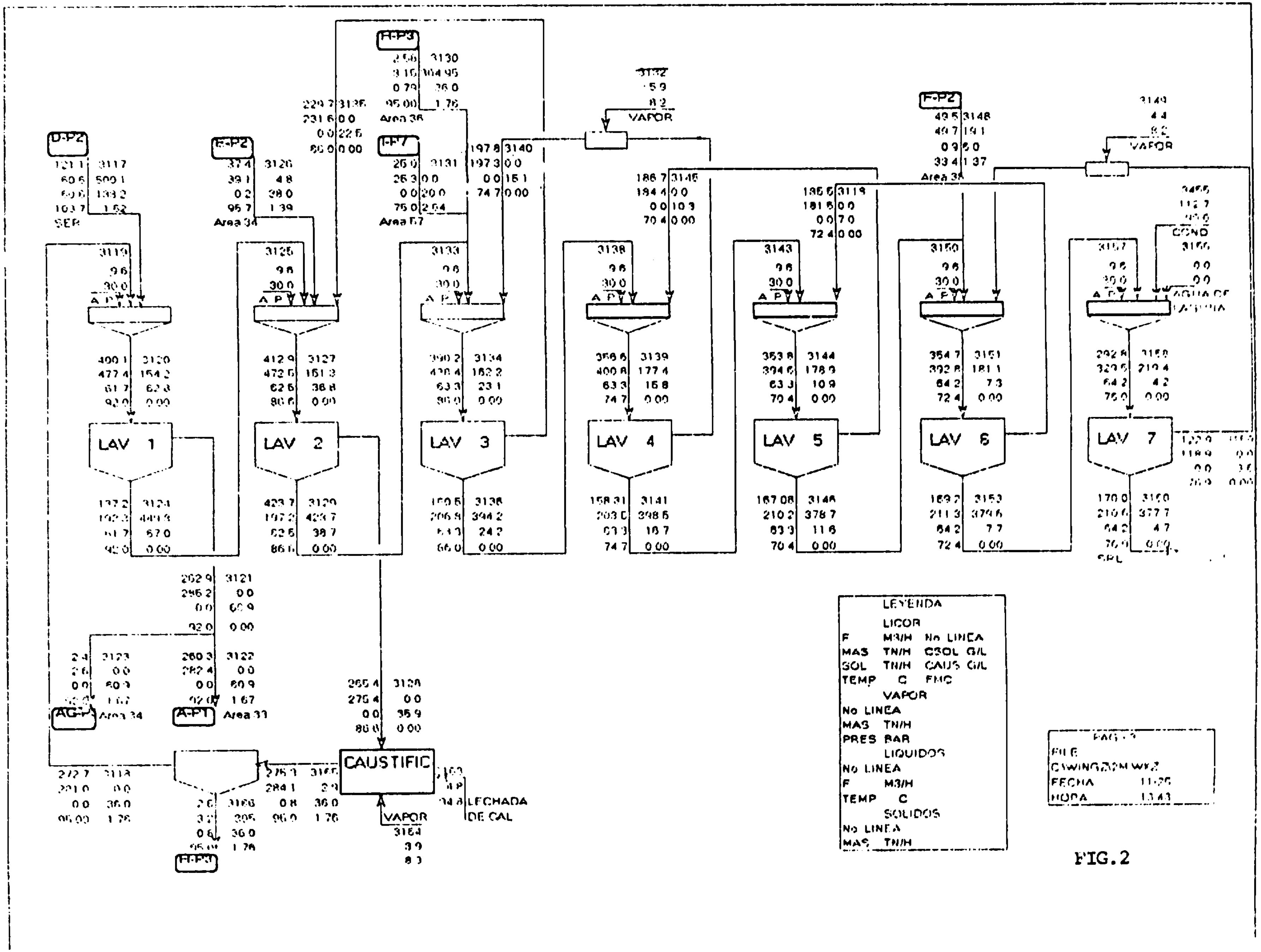
	Number of Units	Underflow Concentrations % Solids	g/l
Deep Thickener (ALCAN)	4	44	635
"Super Thickener" (EIMCO)	1	44	635
Vacuum Drum Filters	14	55	885
Hyperbaric Pressure Filters	4	75	1550

To obtain the mud circuit mass balances for the four dewatering devices under consideration, the computer programme was run for all number of stages "n" between 4 and 8 with (underflow solids concentration) in the nth stage of 635, 885 and 1550 g/l.

The balances so generated will give a calculation of the soda lost from the mud discharges of the four devices with water consumptions indicated in Chapter 3.1.

6.2. Effect of Dewatering Method on Choice of Disposal Technology

The basic rule is that the product from the dewatering device must match the disposal technology and vice versa. If the device produces a product which is too dense and/or too viscous for disposal, the product can be diluted (usually with water) to suit the



LAV 1
LAV 2
LAV 3
LAV 4
LAV 5
LAV 6
LAV 7
CAUSTIFIC
VAPOR
LECHADA
DE CAL
LEYENDA
LICOR
F M3/H No LINEA
MAS TN/H CSOL G/L
SOL TN/H CAUS G/L
TEMP C FMC
VAPOR
No LINEA
MAS TN/H
PRES BAR
LIQUIDOS
No LINEA
F M3/H
TEMP C
SOLIDOS
No LINEA
MAS TN/H

FIG.2

needs of the disposal area. With one exception the converse is not true - the product cannot be thickened to suit. The exception is solar evaporation, which, under suitable conditions in a suitable environment, can further thicken the product from any thickening device.

The major factor controlled by the "consistency" of the dewatered product is the angle at which the material will naturally come to rest on the land area selected for disposal of the product. This angle must be steep enough to fill the deposit area and volume by the end of the project, but must not be so steep that heavy rainfall on the slope causes erosion. Erosion causes heavy contamination of the run-off water and makes the land difficult to reclaim at the end of operations.

For red mud in general, there is no firm relationship between solids concentration (expressed as weight percent or grams per litre) and its angle of repose on a disposal stack. The relationship between these two variables varies from the country source of the bauxite, between mines within one country and even between different locations within one mine.

As an example, Fig. 3., produced by Eli Robinsky in laboratory work shows (for example) that mud with an angle of repose of 5 % will have a concentration of 46.7 % if it is from bauxite fed to the INTERALUMINA plant, whereas it will be 55.7 % if it originates from bauxite fed to the NALCO plant. To emphasize this problem a curve (dotted) has been added representing the characteristics of red mud originating from typical Jamaican bauxite. From this curve it can be seen that such Jamaican mud will set up a 5 % slope when its concentration reaches 35 %.

To summarize for a 5 % slope the following solids concentrations have to be reached:

Jamaican red mud	35 % solids
INTERALUMINA red mud	46.7 % solids
NALCO red mud	55.7 % solids

(According to experimental data by E. Robinsky.)

If we (erroneously) assume that a given dewatering device can dewater any bauxite to a solids concentration characteristic of that device we would be bound to conclude that, for example, a superthickener (46-49 % underflow) would thicken an INTERALUMINA mud adequately, but could not thicken a NALCO red mud to the necessary 55.7 %, and could grossly overthicken Jamaican red mud which only needs 35 %.

This situation is not the case, and reason is that each thickening device thickens to a "consistency" characteristic of that device and not to a unique solids concentration.

Device	Product % solids*	Typical thickened product
Conventional Thickeners	10-40 %	Slurry too "thin" to stack at more than 1 % slope, and subject to separation into liquid and thick-slurry layers. Easily pumpable.
Superthickeners Deep Thickeners	25-55 %	Slurry "thick" enough to stack at between 2 % and 6 % slope and resists separation into two layers. Pumpable.
Vacuum Filters	42-60 %	Cake "thick" enough to hold its slope, and too thick to pump without thinning by agitation and/or dispersants.
Hyperbaric Filters (5 bar)	50-80 %	Cake rigid enough to be broken in pieces. Too thick to be pumped without prior dilution. Can be conveyed.

* Depending on source of bauxite.

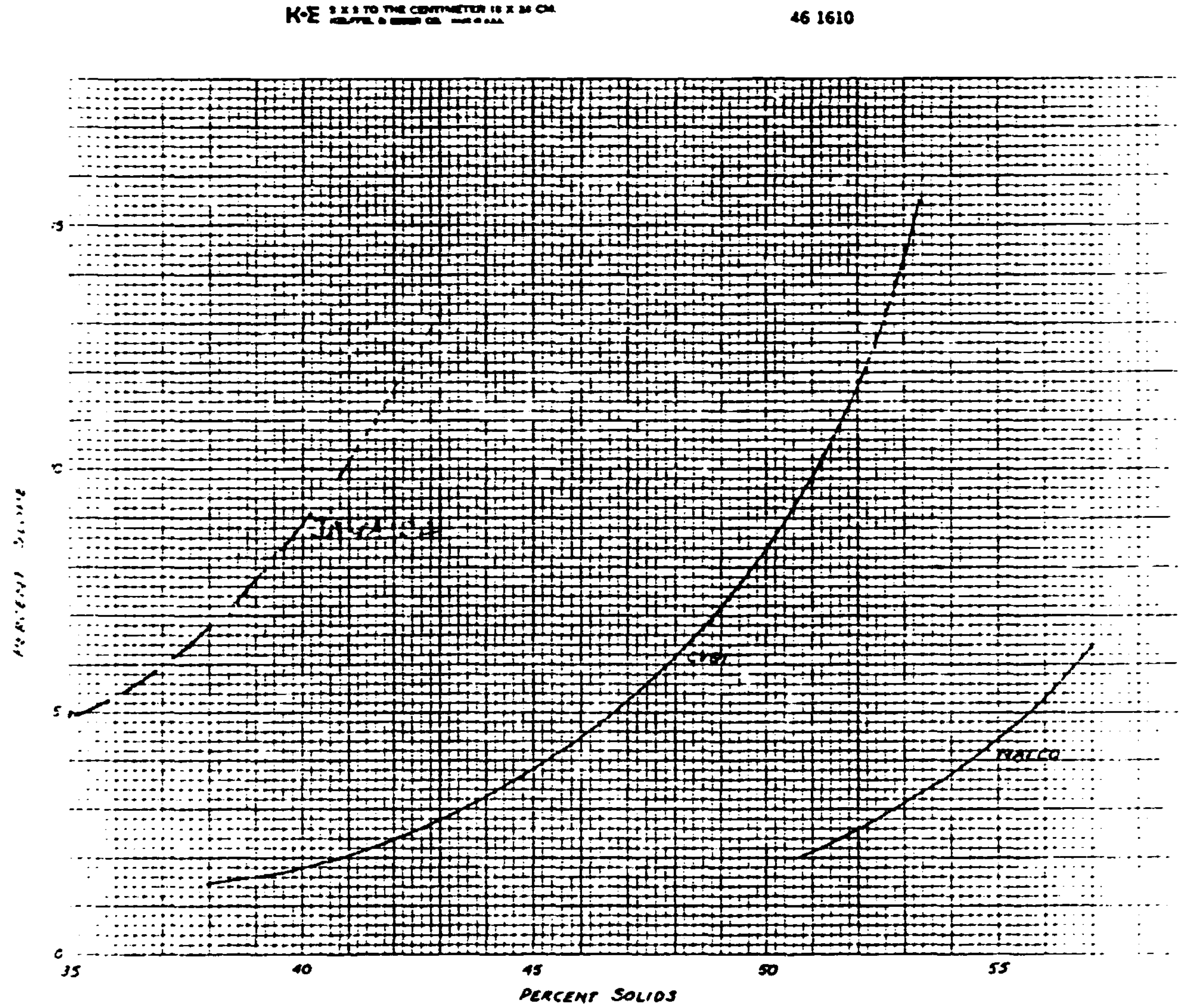


FIG. 3

APPROXIMATE RELATION BETWEEN PERCENT SOLIDS AND ANTICIPATED DEPOSITION SLOPE

7. DISPOSAL SYSTEMS

7.1. Disposal Methods

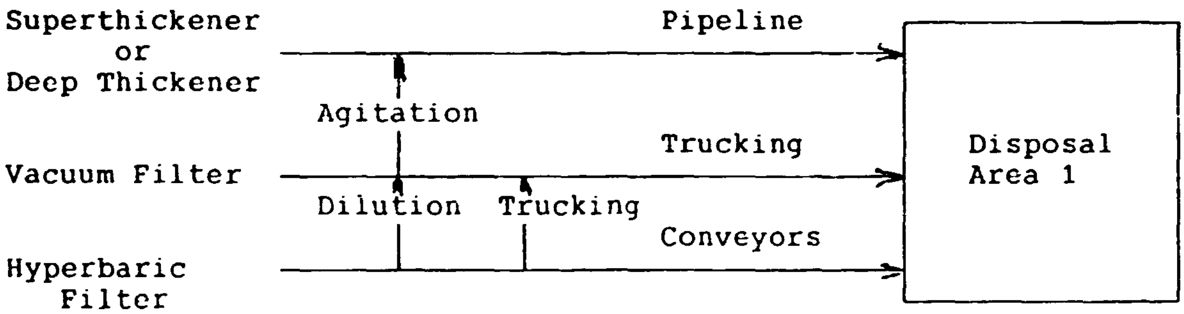
"Disposal" of red mud from a thickening or dewatering device, includes operations to transport the material to its final resting location and operations to distribute over an appropriate area at that location.

All modern disposal systems for red mud aim to avoid the separation of the mud into two layers at the disposal site. Such separation leaves an area which is too large and too wet.

Avoidance of separation involves using a separation device which is capable of enough dewatering to produce at least a stable slurry with a yield stress high enough to prevent segregation of solid particles. The solids concentration (by weight), for the lower limit cannot be specified with any certainity because it depends on the type of bauxite from which the red mud came. However, both Superthickeners and Deep Thickeners are capable of reaching it continuously, at least when properly controlled. Filters, when operated at differential pressures of over 0.75 bar and properly controlled, reach it continuously. This is so for vacuum and hyperbaric filters.

In selecting the dewatering device it is not necessarily best to choose the one which will produce the dryest and hardest product. Besides difference in cost, a disposal area which lies far from the plant will introduce problems in transporting the mud. Transporting highly dewatered mud involves either trucking or conveying - both expensive options if the distance is great.

Fig. 4. Disposal Systems - schematic drawing



7.2. Capacity of Disposal Areas

Two general areas have been identified (by INTERALUMINA) as being available for disposal of the mud from whichever equipment is chosen for dewatering.

Area (1), the larger of the two, averages 3 km (2 km to 4 km) from the mud wash thickeners of the plant. It includes Lagoons 2 and 3 and the hillside above them.

Area (2), the smaller, is of irregular shape, and averages 1.5 km (0.5 to 2.5) from the plant.

The storage capacity of both areas have been estimated by the usual method of estimating the vertical area of cross sections through the final pile of consolidated mud, averaging these areas and multiplying by the length of the pile.

At a later stage, INTERTALUMINA declared that they would rather use Area (2) for other purposes (expansion of bauxite storage, etc.), so further considerations relate only to Area (1).

Fig. 5. shows area (1) (outlined with a thick line) and the four cross sections chosen. They run at 45° to the map coordinates and are labelled A, B, C and D.

Figs. 6 through 9 show the cross sections. The scales are: 1 cm = 100 m horizontal, 1 cm = 10 m vertical, 1 cm^2 = 1000 m^2.

The computed cross-section areas are:

A	-	12,950 m^2
B	-	26,100 m^2
C	-	34,000 m^2
D	-	50,000 m^2
	Mean	30,762 m^2

Taking the length of the disposal area (90° to the cross sections) as 2000 m, the total volume is:

61,525,000 m^3

The above volume is that available above the existing contours of the area and below a mud surface starting at 5 m below the crest of the dykes, and sloping at 3 % slope to the highest point which can be reached without any mud flowing outside the boundaries marked by the thick line.

For the INTERALUMINA situation the mud transportation distances are:

	Nearest	Farthest
To Disposal Area (1) (350 ha)	2.0 km	4.0 km

These prevailing distances mean that a hyperbaric filter, which produces mud cake which can be handled by a conveyor belt, will be easier to use when the mud needs to be taken only to the begining of the Area (1) slope but more difficult later on when it has to go nearer the end of the slope.

Thickeners, deep or "Superthickener", produce dewatered mud which is thick enough to stack but thin enough to be pumped. Thus, thickener underflow can go easily to the nearer areas of Area (1). To pump to the furthest points of Area (1) will require a pressure of about 175 lb/in^2 (1.19 MPa) and are getting a bit beyond the pressure pumpable by centrifugal pumps. High pressure positive displacement pumps would then be preferable, but more expensive.

7.3. Environmental Impact

From the point of view of the environment, it matters little which of the four dewatering technologies is chosen to thicken mud and return the filtrate/supernatant to the Bayer process. All four are superior to the existing technology (conventional single-deck thickeners) which discharges too much liquor with the mud. It is this excess liquor which enforces the use of a mud pond instead of a mud stack. It is this excess liquor which is a danger to the Orinoco River - not the mud. We have been able to show (para 7.2) that Lagoons 2 and 3, and the hillside above them have the capacity to hold the solid part of the mud for many years to come (if stacked), but the dilute liquor at present separating from the mud threatens to overflow the dykes in about 2 to 3 years.

Environmentally, there is little to choose between Deep Thickening, Superthickening and Vacuum Filtration. It might seem that Vacuum Filtration cake should use less land than the underflow from Super or Deep Thickeners. In practice all three devices produce a thickened mud which can either be pumped (short distances by centrifugal pumps, longer distances by high-pressure pumps) or conveyed (by belt conveyors) and which can be stacked at angles between 2 % and 6 %. To attempt to

FIG. 5

PROFILE 'A'

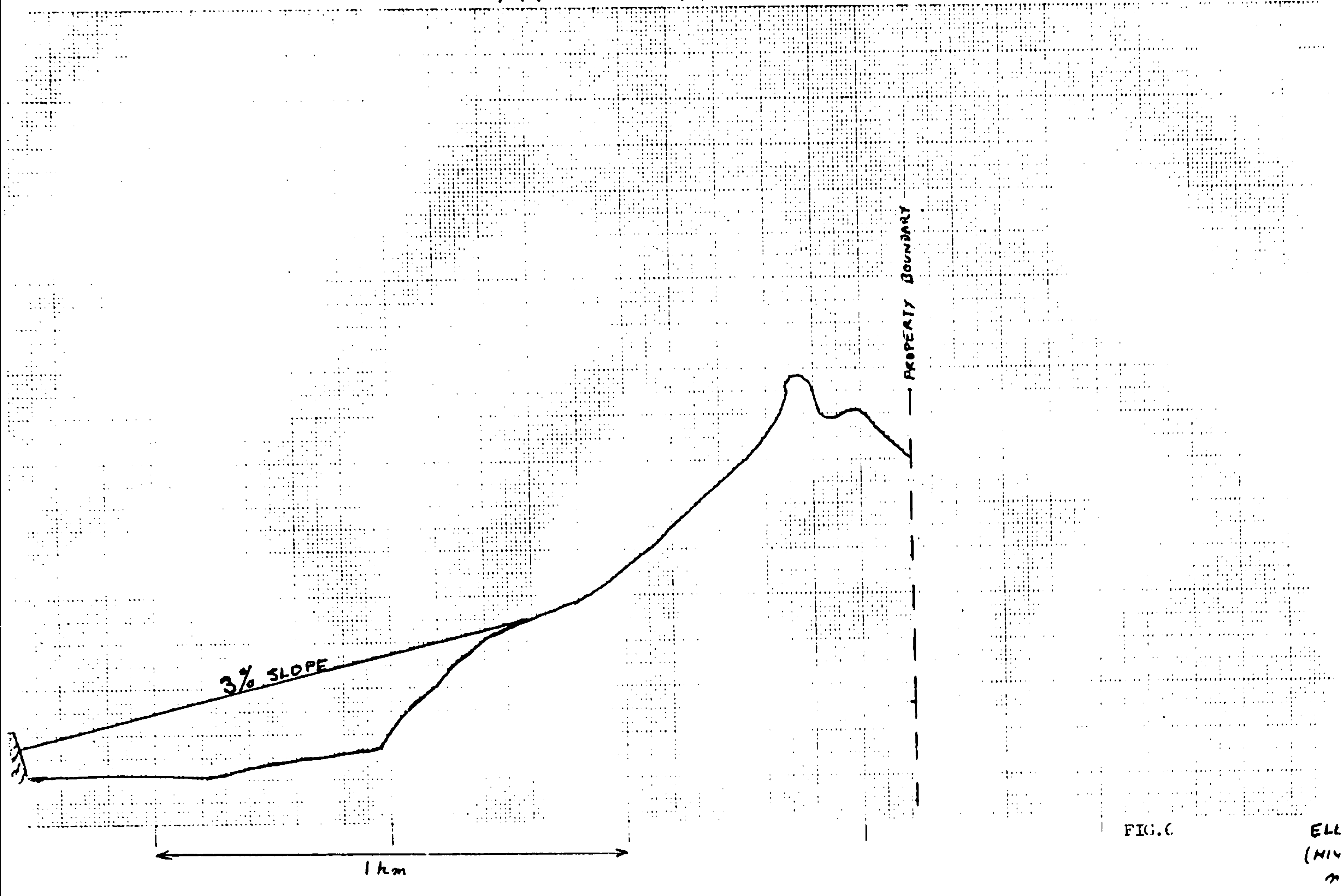


FIG.(

ELL
(MIN
m

PROFILE B

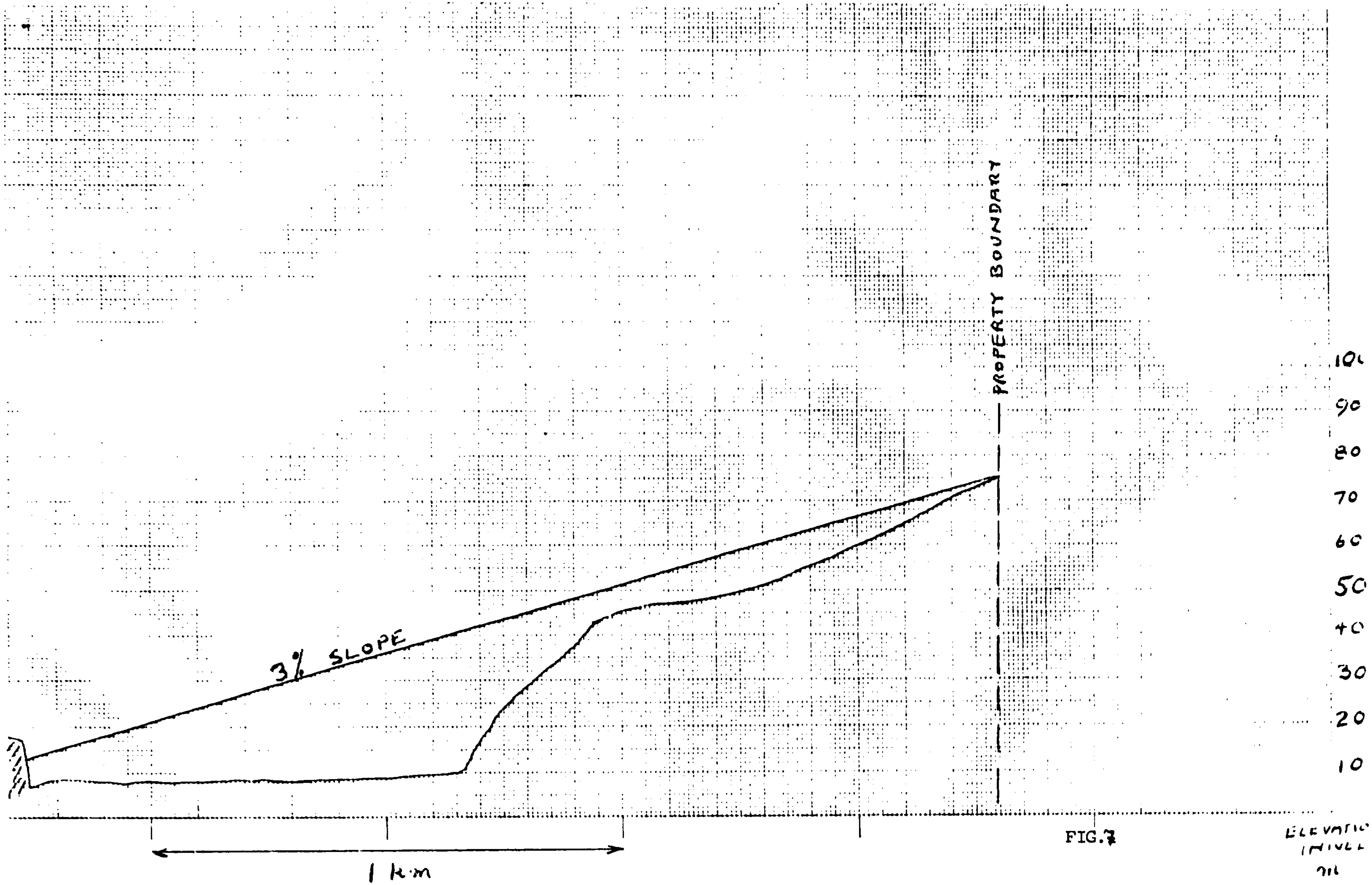


FIG.7

PROFILE C

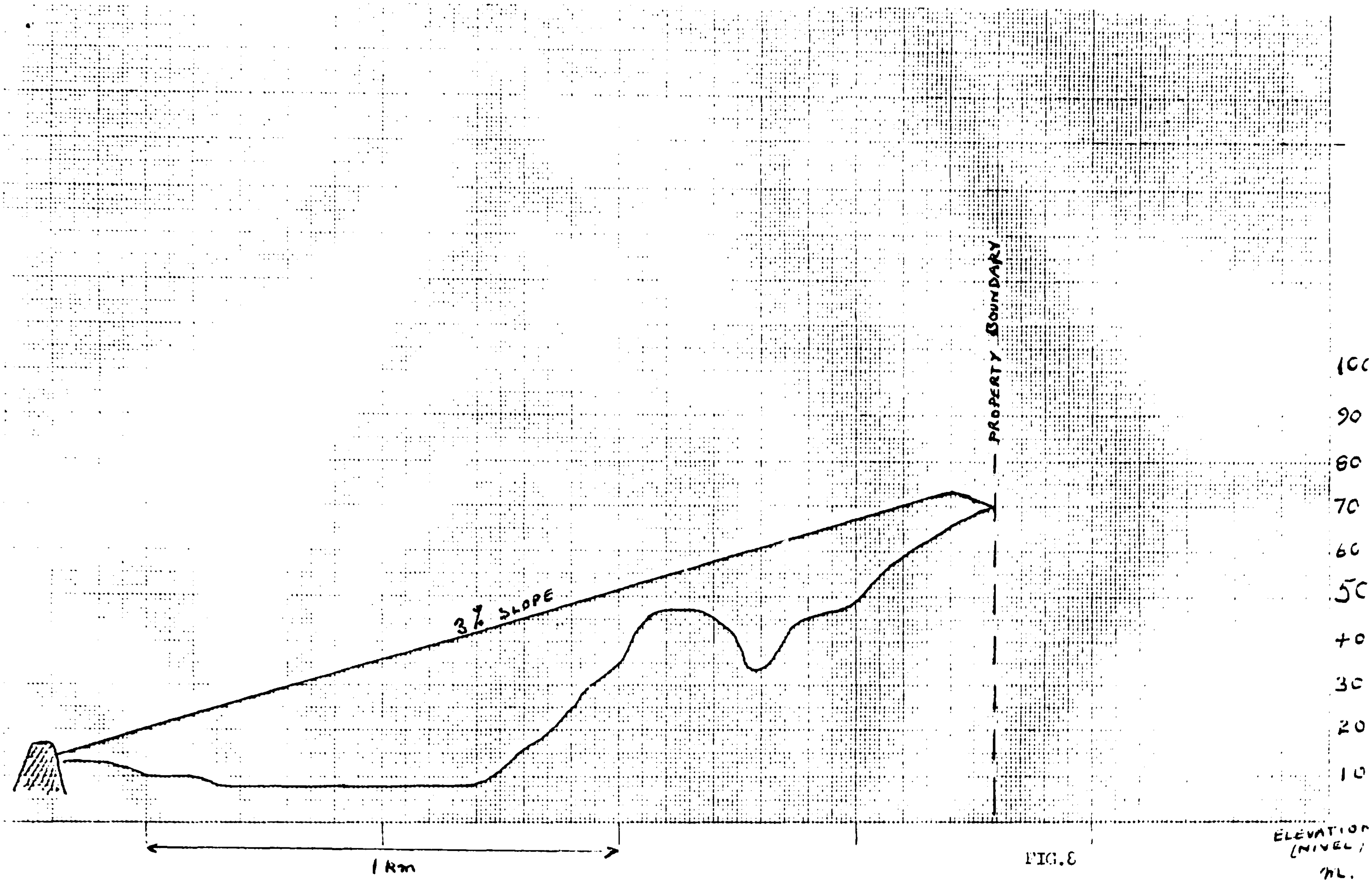


FIG.8

PROFILE 'D'

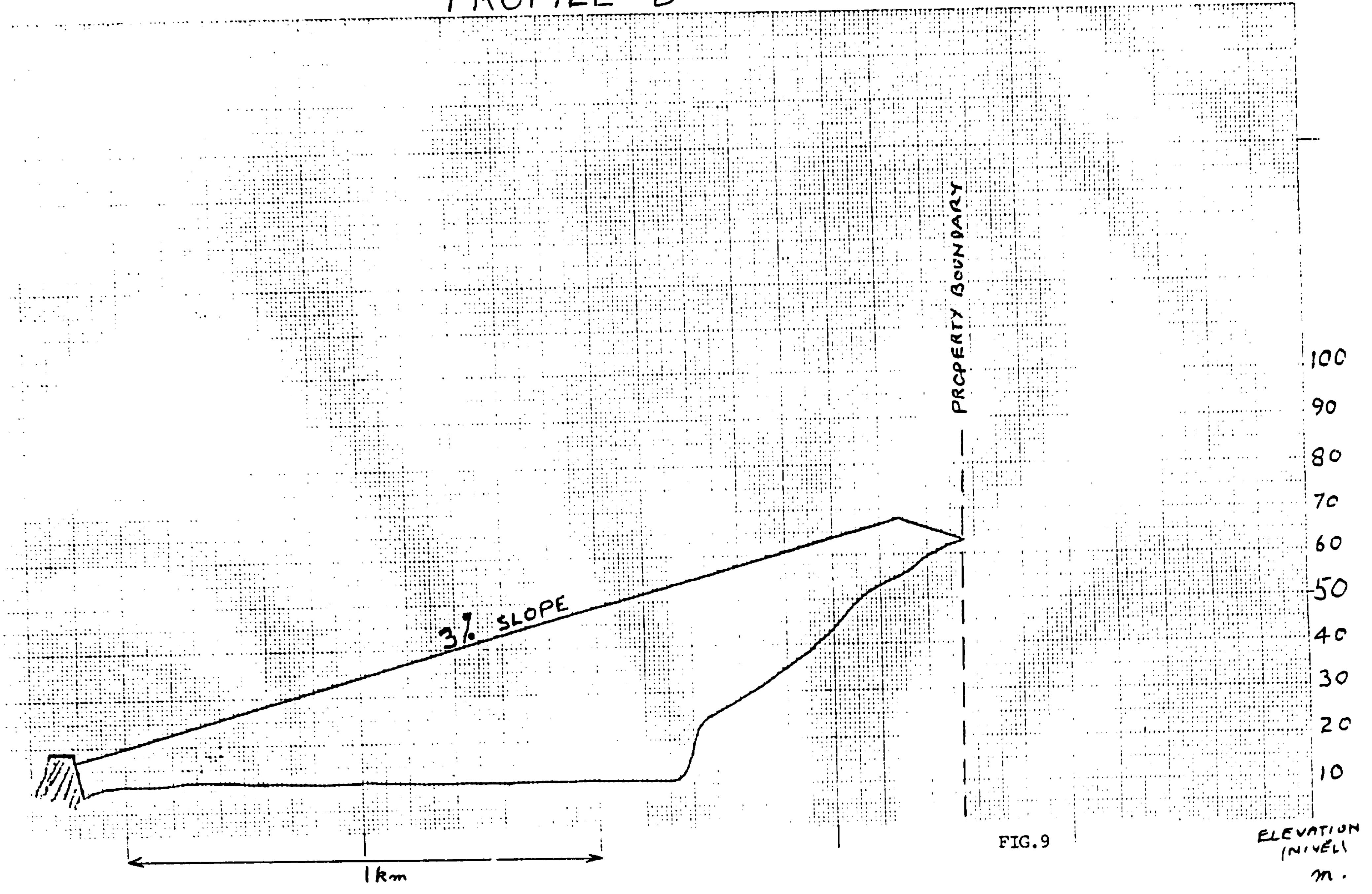


FIG.9

aim at stacking angles higher than this might be environmentally dangerous, even though theoretically a smaller stacking area would be needed. On large areas of mud, stacked at too high an angle, heavy showers of rain (tropical rain particularly) could cut deep gorges in the mud. These could destroy large areas of the stack, washing the mud down to the bottom of the slope. Fortunately, there would be sufficient time to make large scale tests to possibly allay these fears.

Hyperbaric Filtration The adoption of Hyperbaric Filters in preference to any of the other three dewaterers, is expected to reduce the solutes in cake. The extent of this saving has been estimated (para 9.2) but is difficult to calculate with confidence until the change in filtrate concentration has been computed for a complete range of input variables. Even at this stage, however, we can be sure that the low moisture cake will result in a marked reduction in the tonnage left in the stacked mud, and this must be considered a plus for the environment.

There is some expectation that the environment could benefit from the land saving effect from the higher angled stack which could result from conveying the filter cake to the stack and pushing it into place with bulldozers. This should be confirmed in operational practice.

If Hyperbaric Filtration is selected (for soda-saving reasons) there are two alternatives for disposal of the filter cake:

(a) convey it, with readily movable conveyors, to the disposal site. Then spread it with bulldozers to form a 6 % slope,

(b) re-slurry it, using rainwater run-off from the stack, and pump the thick slurry to the highest point of the stack (as if it was vacuum filter cake).

(a) and (b) are approximately equal, environmentally. The choice should be economic. (a) is heavier in labour cost (bulldozer operators) but more plausible (utilizing the patential of the hyperbaric filters). Alternative (a) is included in the further calculations, alternative (b) could be a worst case fall-back position.

7.4. Rainwater

Though changing to one of the dewatering devices dealt with in this report will put an end to the excessive dilute liquor accumulation due to the separation of thin mud into two layers, there will still be considerable accumulation of rainwater run-off from the semi-dry stack. This rainwater will pick up solutes as it runs over the stack, and will thereby become dilute liquor. Calculations need to be made to determine how the present and future capability of the plant to absorb dilute liquor compares with the anticipated average rainfall on the disposal area. This capability will obviously be less while the plant is still coping with the backlog of liquor accumulated over past years of separation from the thin mud.

Storage After provision has been made for removal of rainwater run-off at the same annual rate as it falls, provision still has to be made for storing run-off in periods of high rainfall for use in periods of low rainfall. The resevoir formed by the existing riverside dykes is the obvious choice. This resevoir has to be used in any case, as no pumps could cope with pumping away, to another resevoir, the run-off as fast as it forms during heavy rain.

To reduce the run-off, it is worth looking at the use of only part of the stacking area in the early stages. This would enable the rainwater falling on the remaining flat area to evaporate from there.

8. EVALUATION OF THE POSSIBLE RED MUD THICKENING AND FILTRATION PROCESSES

8.1. Superthickener (Hi-density Thickener)

A recent solution to the problem of red mud separation in settling equipment is the so-called Hi-density Thickener. By means of this equipment it is possible to obtain such underflow solids concentration (e.g. 48 to 50 % solids with INTERALUMINA red mud) which enables the storage of the latter to be realized in a solid state. The first of these equipment was constructed by Eimco in the Pinjarra (Australia) plant of Alcoa, put into operation in 1988. After quite favourable initial results (46 % solids in the underflow at a flocculant dosage rate of 65 g/t) the underflow solids concentration could be increased to 48 to 52 % and the flocculant dosage rate could be reduced to 60 g/t.

The next of these equipment was installed in Kwinana in 1989 and the third in Wagerup in 1992. There are only slight differences in the operational characteristics (solids concentration, flocculant usage, overflow clarity) of the three units, mainly resulting from differences between the characteristics of the bauxites processed.

The red mud leaving the thickener is thixotropic and loaded with flocculants. No agitator tank is required to reduce the yield stress and viscosity. A centrifugal pump, sucking the mud from the thickener outlet, is sufficient to reduce the yield stress.

The Hi-density Thickener would be used as a last washing stage. It would be set up in the red mud disposal area or close to it. This way the extra investment and operating costs due to the pumping of a dense mud slurry could be saved. The underflow of the last washers in the plant area would be pumped at its typical solids concentration (about 400 gpl) or in a somewhat diluted form to the Superthickener. A part of the overflow of the latter would be used for diluting the feed, the rest would be pumped back to the refinery.

On the basis of the tests carried out on the red mud samples of INTERALUMINA Eimco has stated that its Hi-Density Thickener is suitable to thicken this mud to a solids concentration of about 48 to 49 % at a flocculant usage of 45 to 50 g/t. For the present evaluation, however, based on the balances supplied by INTERALUMINA, a conservative solids concentration of 44 % is assumed (see also Sections 3.1 and 6).

8.1.1. Size of the Superthickener

According to Eimco's statement a settling surface area of 0.5 m^2 per mtpd is required to obtain an underflow solids concentration of 48.5 %. For the calculated amount of red mud (128 t/h dry mud at 2 MMTPY alumina production with an operating factor of 93 %) this requires a settling surface area of 1536 m^2, whereas in the case of an expansion of the alumina plant to 3 MMTPY about 2300 m^2. With some upward rounding this would mean 50 m diameter in the first and 60 m in the second case. Eimco suggested the use of a dia 75 m equipment, which would not cost significantly more than the smaller ones (taking into consideration the already existing and well-proven design of the latter one, whereas the smaller ones would have to be designed from scratch) and would provide a significant safety margin.

8.1.2. Transportation of the Mud

The level difference between the plant and the suggested location of the Hi-density Thickener would be about 20 m. The pumping distance would be about 4 km. The amount of the last washer underflow (within the plant) would be about 340 m^3/h (with a solids concentration of about 380 gpl and a density of about 1.245 t/m^3). (Data from INTERALUMINA.) When adding about 70 m^3/h wash water to this amount (see Table 1) the above data would change as follows: 410 m^3/h slurry, 317 gpl solids, 1.20

t/m^3. On the basis of DIN standards two pipe sizes may come into consideration for the flow of 340 m^3/h: dia 273 x 6.3 mm (with a flow velocity of 1.8 m/s) and dia 324 x 7.1 mm (with a flow velocity of 1.26 m/s). The pressure drop would amount to 9.0 and 4.4 bar, respectively.

When leaving out of consideration any expansion of the plant (above 2.0 MMTPY capacity) the pipe size of dia 273 x 6.3 mm would be acceptable since there are centrifugal pumps capable to provide the necessary pressure. However, since it would be advantageous to operate the Superthickener as an additional washing stage, and this would involve the above (larger) volumes, the larger pipe size was considered (dia 324 x 7.1 mm). For the increased amount the pressure drop would be about 5.3 bar.

The return overflow pipe would carry 140 and 210 m^3/h, respectively. For this purpose a dia 219 x 6.3 mm pipe was considered. The pump sizes would be the following:

	Red Mud pumps (2 pcs, 1 op, 1 sp)	Overflow pumps (2 pcs, 1 op, 1 sp)
Q =	420 m^3/h	220 m^3/h
H =	70 m	50 m
N =	170 kW	55 kW

8.1.3. Material and Energy Consumptions

Materials:	Flocculant:	6.4 kg/h	(50 g/t dry mud)
	Steam:	4 t/h	(reheating the overflow by about 10 °C)
Power:	Hi-density Thickener	30 kW	
	Main pumps	225 kW	
	Other pumps, etc.	50 kW	
	Total	305 kW	

For 1 t of dry mud this amounts to 2.4 kWh.

The liquor phase of the thickened mud should not exceed 5 g/l Na_2O (under steady state operation - which was not the case during the visit of the UNIDO team) corresponding to 0.6 % sol. Na_2O, i.e. 0.8 t Na_2O/hr loss for the two streets with an equivalent alumina loss of about 0.65 t/hr. At 48-49 % solids the loss would drop to 0.7 t Na_2O and 0.55 t Al_2O_3/hr.

8.1.4. Capital Cost Estimate (US$ Million)

According to data supplied by INTERALUMINA (based mostly on suppliers' quotations) the capital costs of the out-of-plant subvariant are the following:

Tank and rake mechanism	3.480
Pumps, tanks, agitators, electrical equipment, instrumentation	1.825
Earth works, foundations, building	4.327
Pipelines	0.888
Subtotal	10.520
Distributable direct (4 % of subtotal)	0.421
Subtotal	10.941
Engineering and project management (15 % of subtotal)	1.641
Subtotal	12.582
Vendor assistance & training (4 % of equipment)	212
Spare parts (4 % of equipment)	212
Subtotal	13.006

Contingency (20 % of subtotal)	2.601
Total	15.607

8.2. Deep Thickeners

Alcan has developed such so-called Deep Thickeners, in which the ratio of height to diameter is about 1.2 to 1. As a result of the increased height the mud thickens under its own weight and this raises the solids concentration of the underflow. The thickening of the red mud is helped by the use of flocculants (about 100 g/t). In the case of some bauxites the solids concentration may attain 50 % (by weight). In such cases the resulting mud - similarly to those obtained in Hi-density Thickeners or on vacuum filters - can be disposed of in a dry state.

The deep thickeners can be constructed both as flat-bottom or conical bottom equipment. Their diameter is typically between 10 m and 13 m.

Such thickeners work in Alcan's Jamaican (Kirkvine, Ewarton) and Canadian (Arvida) alumina plants and in some Australian refineries (Worsley, Gove). Alcan is usually ready to provide the necessary know-how for a negotiable fee, which may be about

- US$ 200,000 per deep thickener to be installed
- some extra fee for the necessary laboratory work and for providing the flocculant preparation technology.

For a unit consisting of four deep thickeners the total fee would amount to about US$ 1 million or less (at 1990 prices, which could be somewhat higher today).

8.2.1. Size and Number of the Required Thickeners

Only literary data can be used for sizing since no lab tests have been carried out with INTERALUMINA mud. With a typical mud load of 10 t/m^2d (i.e. 0.42 t/m^2h) the settling area required for 128 t/h dry mud amounts to 305 m^2. For a diameter of 13 m (133 m^2 cross-sectional area) 2.3 (i.e. 3) operating thickeners would be required (altogether four including one spare).

With the above height to diameter ratio the thickeners would be 16 m deep. Their volume would be 2125 m^3 each (for flat-bottom units). Their weight would be about 145 t each. They would be fitted with rakes, driven by 45 kW motors (practical power consumption would be about 20 kW per thickener).

8.2.2. Transportation of the Mud

The mud and the overflow would be pumped in the same way as in the case of the Superthickener, since they would be located in the same place, and the volumes, concentrations, etc. would also be similar.

8.2.3. Material and Energy Consumptions

Materials:	Flocculant:	12.8 kg/h	(100 g/t dry mud)
	Steam:	4 t/h	(reheating the overflow by about 10 °C)
Power:	Deep thickeners:	60 kW	(20 kW per operating thickener)
	Main pumps:	225 kW	
	Other pumps, etc.	50 kW	
		335 kW	

For 1 t of dry mud this amounts to 2.6 kWh.

For caustic and alumina losses the same considerations and figures apply as in Chapter 8.1.

8.2.4. Capital Cost Estimate (US$ Million)

For this variant the data were collected by Mr J. Chandler from Alcan International. They have been modified to eliminate the costs of the high-pressure pumps (out-of-plant subvariant) and to have the same additional items and the same percentage for contingency as the other variants.

Tank and rake mechanism	4.700
Pumps, tanks, agitators, electrical equipment, instrumentation	5.000
Earth works, foundations, building	0.150
Pipelines	2.000
Subtotal	11.850
Distributable direct (4 % of subtotal)	0.474
Subtotal	12.324
Engineering and project management (15 % of subtotal)	1.849
Subtotal	14.173
Vendor assistance & training (4 % of equipment)	388
Spare parts (4 % of equipment)	388
Subtotal	14.949
Contingency (20 % of subtotal)	2.990
Total	17.939

8.3. Vacuum Filtration

The modern method of red mud filtration (using vacuum drum filters with roller discharge) was first applied in 1962 in one of Alcan's Jamaican and VAW's German alumina plants (Kirkvine and Schwandorf, resp.). Subsequently a number of other alumina plants (Ludwigshafen and Lünen in Germany, Mosonmagyaróvár in Hungary, Korba and Renukoot in India, Guizhou in China, etc.) also introduced this process. Usually the underflow of the second or third mud washing stage is filtered with a solids content of 250 to 400 gpl, a caustic soda content of 30 to 40 gpl (as Na_2O) and a temperature of 65 to 85 °C. The solids content, the Na_2O concentration and the temperature of the slurry strongly influence the productivity of the filters.

Another important characteristic of the vacuum filtration is that the cake can be washed quite efficiently. Typically 1 to 3 m^3 of water is used for cake washing per dry tonne of red mud, with a temperature of 80 to 95 °C. The specific characteristics of the red mud strongly influence both the productivity and the washability of the same. To attain high productivity and efficient washing thin cake (about 2 to 3 mm) is filtered.

During vacuum filtration the filtrate typically cools by some 20 to 25 °C (depending on the feed temperature and the vacuum applied). As a result of this some amount of various salts and aluminium hydroxide precipitates leading to a reduced permeability of the filter cloth. To maintain the performance of the filters the filter cloth has to be cleaned by a high-pressure water jet every 1 to 3 days.

8.3.1. Required Number of Filters

As previously stated, the expected amount of dry red mud to be filtered amounts to 128 tph. Typical filtration rates are between 100 and 120 kg/m^2h (except for a few extreme cases like Jamaican muds on the low and Greek muds on the high ends).

The required filter surface is the following:

$$F_1 = \frac{128,000}{100} = 1280\ m^2$$

$$F_1 = \frac{128,000}{120} = 1067\ m^2$$

The filter surface of the largest available units is 100 m^2 and 120 m^2. The number of operating units required is accordingly:

kg/m²h / m²	100	120
100	13	11
120	11	9

Dorr Oliver specifies 14 units of 100 m^2 each including two spares which considers a conservative filtration rate of roughly 110 kg/m^2/hr. The present evaluation uses a slightly different variant (12x120 m^2; 10 operating, 2 spares) on the basis of a more recent offer.

8.3.2. Transportation of the Filtered Red Mud

The red mud leaving the vacuum filters has a high viscosity (about 10^5 cP) and a thixotrophic character. In order to improve its transportability it has to be agitated intensively in a reactor for some 5 minutes. During this time its viscosity is expected to drop nearly one order of magnitude. In this state it might be transported by a pipeline with an expected pressure drop of about 30 bar per km. For a distance of 4 km the total pressure drop could amount to 120 bar.

With an expected solids content of 55 % the volume to be pumped would amount to 143 m^3/h. Calculating with three positive displacement pumps (two operating plus one spare) the main parameters of the pumps would be the following:

Q = 80 m^3/h
p = 120 bar (max. 150)
N = 400/450 kW

The pipeline has to be sized corresponding to the pressure of the pumps. Since the flow velocity corresponding to the above pressure drop is about 0.5 m/s, a dia 324 x 11 mm pipeline would be required.

8.3.3. Material and Energy Consumptions

Material and energy consumptions are related to 10 operating filters and 128 tph of dry red mud.

Materials:

- Wash water: 1.5 t/t mud at 85 °C
- Steam: 15 t/h (for reheating the filtrate by about 25 °C)
- Cooling water: 1000 m^3/h (for the condensers before the vacuum pumps)

Power:

- Filters: 300 kW (30 kW per operating filter for drum drive, agitator, etc.)

Vacuum pumps:	445 kW	
High pressure pumps:	800 kW	(2 x 400 kW)
"Reactor":	350 kW	(35 kW per operating filter)
Other pumps, etc.:	60 kW	
Total	1955 kW	

For 1 t of dry mud this amounts to 15.3 kWh.

It is expected that the red mud filters after washer 3 would receive a slurry with a liquor concentration of 30 g/l Na_2O tot. At a washing efficiency of 85 % at 55 % solids the soluble caustic losses will amount to 0.37 % or about 0.5 t/hr with 0.4 t/hr Alumina.

8.3.4. Capital Cost Estimate (US$ Millions)

According to data supplied by INTERALUMINA (based mostly on suppliers' quotations) the capital costs of this variant are the following:

Filters (12x120 m^2)	6.358
Other equipment	4.826
Earth works, foundations, buildings, structures	5.000
Piping	1.384
Mounting	0.460
Subtotal	18.028
Distributable direct (4 % of subtotal)	0.721
Subtotal	18.749
Engineering and project management (15 % of subtotal)	2.812
Subtotal	21.561
Vendor assistance & training (4 % of equipment)	0.447
Spare parts (4 % of equipment)	0.447
Subtotal	22.455
Contingency (20 % of subtotal)	4.491
Total	26.946

8.4. Hyperbaric Filters

It is a new technology in the alumina industry to apply such filters which are capable to produce red mud cakes with moisture contents less than 30 %. With Kelly-type or other similar pressure filters applied earlier the productivity was poor (35 to 40 kg/m^2h) and the resulting moisture content high (40-45 %). Kelly-type filters could only be operated discontinuously and required a lot of labour (opening, closing, cleaning, etc.). The Hyperbaric Filter (a rotary disc filter put into a pressure vessel) enables the red mud to be filtered and dried to a moisture content of less than 30 % (typically to about 25 % in the case of INTERALUMINA mud), it has a high productivity (300 to 500 kg/m^2h) and its operation is practically continuous (except for the cake discharge, which is periodical, but so frequent, that it can also be considered to be continuous).

The filter is very flexible, pressures of up to 6 bar, filterspeed over 3 rpm and temperatures up to 165 °C can be used. The pilot test at INTERALUMINA permitted the following conclusions:

- Compressed air can be reduced with increasing filtration rates
- Optimum filtration conditions were achieved above 3 Bars
- Moisture content was at all times below 30 %
- Productivity increased considerably with decreasing caustic concentration in feed slurry
- Increasing solids concentration in feed slurry improved productivity

- Within limits,, higher pressure and filter speed produced lower moisture at higher rates
- Additives, not yet evaluated in detail, may further reduce air consumption due to a change in cake structure and increase in capacity.

The base case considered for the present evaluation, in accordance with test results and INTERALUMINA balances without any optimization uses the following data:

- Washer	6
- Feed	5-10 g Na_2O/l
	400-450 g/l solids
	90-100 °C
- Speed	1.5-2.0 rpm
- Pressure	5.0 Bar
- Washwater	1.0-0.5 m^3/t mud (dry)
- Capacity	400 kg/m^2/hr dry mud
- Air	300 Nm^3/t dry mud
- Moisture	25 %

An interesting phenomenon could be observed at elevated filtration temperatures (t ~ 100 °C): a significant part (about 1.5 % out of about 4-5 % in the original mud) of the red mud's Na_2O content could be washed out of the filter cake. Of course, this phenomenon has also increased the soluble Na_2O content of the washed cake, but to a smaller extent (say, to 0.8 %).

The details and results of the pilot scale tests carried out with the 2 m^2 Andritz hyperbaric filter in the CVG INTERALUMINA plant between the 4th January and 12th February, 1994 can be found in the report prepared by Maschinenfabrik Andritz Aktiengesellschaft.

8.4.1. Number of filters and compressors

For the 128 t/h dry mud to be filtered, 128,000 / 400 = 320 m^2 operating filter surface area would be required with a productivity of 400 kg/m^2h. Since the largest of the available filters is a 120 m^2 one, three such filters would be required for operation, plus one spare for maintenance, etc. Andritz suggests to install two compressors to each filter (including the spare one), i.e. a total of 8 compressors with capacities of 7000 Nm^3/h, N = 665 kW.

8.4.2. Transportation of the mud

The filter cake at 25 % moisture is a dry non thixotropic material suitable for transportation by truck or conveyor to the mud disposal area. Professional experience says that for such large quantities the transportation by belt conveyors is the most economic long-term solution (considering both capital and operating costs), so the present study takes this solution into consideration. The proposed route of the belt conveyor is shown in Fig. 10.

The total length of the conveying system consisting of seven sections would be about 3370 m. It is suggested to take conventional, 800 mm wide conveyors into consideration, since the latest, tube - belt systems are quite expensive. The conventional conveyors could be covered with a thin sheet roof. The total power required would be about 145 kW.

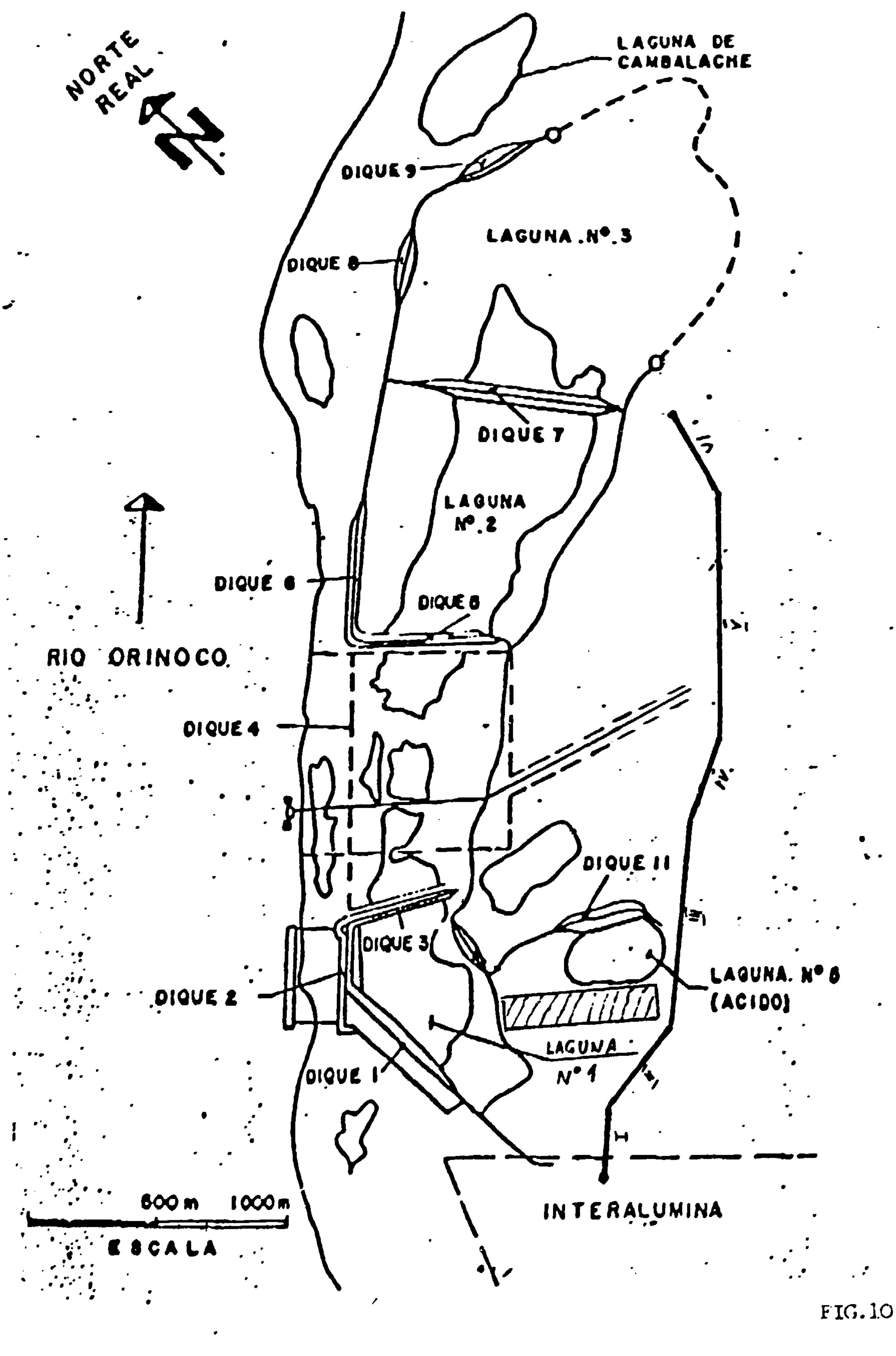

NORTE REAL
LAGUNA DE CAMBALACHE
DIQUE 9
LAGUNA .Nº.3
DIQUE 8
DIQUE 7
LAGUNA Nº.2
DIQUE 6
DIQUE 5
RIO ORINOCO
DIQUE 4
DIQUE 11
DIQUE 3
DIQUE 2
LAGUNA. Nº 6 (ACIDO)
LAGUNA Nº 1
DIQUE 1
500m 1000m
ESCALA
INTERALUMINA

FIG.10

8.4.3. Material and Energy Consumptions

Material and energy consumptions are related to 3 operating filters and 128 t/h of dry red mud.

Materials: Wash water:	$64\ m^3/h$ ($0.5\ m^3/t$ dry mud) at 100 °C	
Steam:	4 t/h	(30 kg/t dry mud)
Power: Filters (drive, etc.)	460 kW	
Plant operation (incl. belts)	180 kW	
Compressors	3840 kW	
Total	4480 kW	

For 1 t of dry mud this amounts to 35 kWh.

It is expected that the filtered and washed red mud would contain about 0.8 % Na_2O but 1.5 % would be recovered from the solid phase, i.e. a net saving of 0.7 % (0.90 t/h) would be attained. For calculating the Al_2O_3 loss an Na_2O loss of 0.05 % and a molar ratio of 2.0 were considered (0.05 t/h).

8.4.4. Capital Cost Estimate (US$ Millions)

According to data supplied by INTERALUMINA (based mostly on data from Andritz) a first subtotal of US$ 16.36 million was obtained. However, this figure seems to include the costs due to the filtration of sand together with the mud. Since the other variants do not include such costs, it seems appropriate to reduce the various cost components proportionally so that the figure of US$ 14.363 million (also provided by INTERALUMINA) be obtained. On the other hand, the costs of three bulldozers (2 operating, 1 spare) were added. So the capital costs are the following:

Filters and compressors	6.470
Pumps, tanks, agitators, electrical equipment, piping	2.397
Belt conveyor	3.617
Earth works, building, service	1.879
Bulldozers	0.500
Subtotal	14.863
Distributable direct (4 % of subtotal)	595
Subtotal	15.458
Engineering and project management (15 % of subtotal)	2.319
Subtotal	17.777
Vendor assistance & training (4 % of equipment)	0.519
Spare parts (4 % of equipment)	0.519
Subtotal	18.815
Contingency (20 % of subtotal)	3.763
Total	22.578

8.5. Summary

With the above data on hand, the evaluation of the three/four cases proposed, can be summarized as follows:

8.5.1. Consistency

None of the proposals will produce supernatant liquor to be returned to the plant (rain water to be diverted). However, only **Pressure Filters** will produce a non-thixotropic, dry mud. The other cases would utilize natural drying without major handling.

8.5.2. Experience

Super/Deepthickeners and **Vacuum Filters** including the relevant mud conveying procedures are conventional methods already adopted in the Alumina Industry, essential for remote areas (see sect. 8.5.3. below).

Pressure Filters and dry conveying have been used in the base Industry (Coal-Copper, etc.) for quite some years but have not yet been adopted in mud handling within the Alumina Industry.

8.5.3. Services

Super-Deepthickeners will be operated outside the plant area on top of the disposal locality, requiring however, little attention, which is important when operating in remote areas distant from suppliers and services.

Filters (vacuum/pressure) in turn will be installed within the plant area, being, however, rather demanding in regard to operation and maintenance.

8.5.4. Capital Costs

Super/Deepthickener require a minimum investment (US$ 15.6 and 17.9 Mio respectively) and **Pressure Filters**, with an investment of US$ 22.6, can be considered a medium one, whilst Vacuum Filtration involves the maximum investment (US$ 26.9).

8.5.5. Caustic and Alumina Losses

Looking at the caustic losses (& Alumina losses), expressed in kg Na_2O (kg Al_2O_3) per ton of Alumina produced, the following tabulation will be of assistance.

LOSSES/CASE	0	1	2	3
Soluble in Mud	6.0	3.5	2.0	4.5
Solid in Mud	25.0	25.0	25.0	17.5
Miscellaneous	29.0	29.0	29.0	29.0
TOTAL	60.0	57.5	56.0	51.0
Soluble Al_2O_3 in Mud	5.0	3.0	1.7	0.2

Pressure Filtration will yield a saving of 9.0 kg Na_2O with 4.8 kg Al_2O_3 approximatively per ton of alumina produced. Depending on costs and environmental problems, reduction of caustic losses may be crucial.

The savings achievable with Super/Deepthickeners and Vacuum Filtration are in the range of 2.5-4.0 kg Na_2O and 2.0-3.3 kg Al_2O_3, always expressed in soluble matter per ton of alumina produced.

8.5.6. Power

Super/Deepthickeners require a minimal amount of additional power for operation, whilst vacuum and in particular pressure filtration operates with a specific consumption in the range of 18.5-35.0 kWh/t mud respectively which under certain conditions may be prohibitive. The specific power consumption in pressure filtration, may however, with an increase of filtration rates and general optimization be reduced considerably, (30 % and more are realistic).

Nevertheless, wherever power is a problem, thickener operation is definitely to be preferred. This is evidently not the case with INTERALUMINA.

8.5. Conclusion

The above evaluation of operational data incl. investment leads to no conclusive or definite recommendation. The individual cases prevail depending on the weight the single issues are given.

The subsequent chapters with the financial aspects and last but not least the ecology of the different systems shall therefore be included herein below as a contribution to reach a final decision and establish a convincing and authoritative recommendation.

9. ECONOMIC COMPARISON OF THE POSSIBLE RED MUD THICKENING AND FILTRATION PROCESSES

For a financial appraisal in addition to the above capital costs a review of the individual operating costs and pay back periods is hence required.

9.1. Operating Costs

9.1.1. Operating Labour

The most labour-intensive of the discussed processes is Vacuum Filtration because of the large number of operating units and their relative sophistication (frequent cleaning of the filter cloth, etc.). The least labour would be required by the Hi-density and Deep Thickeners. Because of the high automation grade of the Hyperbaric Filters their labour requirement seems to be closer to that of the thickeners. However, the continuous operation of two of the bulldozers increase this figure to the same level as that of the Vacuum Filtration.

Estimated operating labour requirements (hours per year):

Hi-density Thickener	17,000
Deep Thickeners	17,000
Vacuum Filters	39,000
Hyperbaric Filters	39,000

9.1.2. Maintenance

The typical spare parts usage of alumina plants is about 4 % of the capital costs. For some equipment, like settlers, pipelines, etc. this figure can be as low as 2 %, for more complex ones, like filters, pumps, etc. up to 6 % or even more. Maintenance labour is supposed to be proportional to the spare parts usage (about 7000 hours per US$ million of spare parts). It is recommended to conclude a service contract with the suppliers of the hyperbaric filters and conveyors to superwise their operation (at least for the first three years of operation). On the basis of our calculations the following results were obtained:

	Spare parts	Service contract	Maintenance labour
	US$ millions/year		hours/year
Hi-density Thickener	0.35	-	2600
Deep Thickeners	0.32	-	2400
Vacuum Filters	0.95	-	6400
Hyperbaric Filters	0.48	0.10	4000

9.1.3. Filter Cloth

Vacuum Filters typically require 0.01 m^2 of filter cloth per ton of (dry) mud filtered. Because of the more favourable conditions (better trough arrangement, no contact at discharge) it is assumed that the Hyperbaric Filters would use half as much, i.e. 0.005 m^2/t. This means 10,500 m^2/y for Vacuum Filters, 5,250 m^2/y for Hyperbaric Filters.

9.1.4. Diesel Fuel

A consumption of 36 l/h/op.unit, i.e. some 630 m^3/y was taken into consideration for the Hyperbaric Filtration.

9.1.5. Unit Costs

In agreement with CVG INTERALUMINA the following unit costs were adopted in the following tabulation:

- Caustic (Na_2O)	US$ 267.-/t
- Alumina	US$ 120.-/t
- Power	US$ 13.-/MWh
- Steam	US$ 1.37/t
- Flocculant	US$ 2.40/kg
- Labour	US$ 3.00/hr
- Cloth	US$ 50.-/m^2
- Diesel fuel	US$ 0.05/l

9.1.6. Tabulation

Table 2. Additional Operating Costs/Savings

Item Saving (-) and Expenses	Superthickener (Case 1a) US$Mio/y	Deep Thickeners (Case 1b) US$Mio/y	Vacuum Filtration (Case 2) US$Mio/y	Hyperbaric Filtration (Case 3) US$Mio/y
Caustic	- 1.335	- 1.335	- 2.136	- 4.806
Alumina	- 0.480	- 0.480	- 0.792	- 1.152
Power	0.032	0.035	0.207	0.475
Steam	0.045	0.045	0.167	0.045
Flocculant	0.125	0.250	0	0
Op. Labour	0.051	0.051	0.117	0.117
Maint.Labour	0.008	0.007	0.019	0.012
Spares	0.350	0.320	0.950	0.480
Cloth	0	0	0.525	0.263
Diesel fuel	-	-	-	0.030
Services contract	-	-	-	0.100
TOTAL	- 1.204	- 1.107	- 0.943	- 4.436

Note: All savings/expenses are reductions/additions in comparison with the base case. No savings are included for reduced Nr. of washers. All data are based on a mud factor of 52.5 %. Savings for case 3 would drop to 2.727 Mio US$ if neglecting solid caustic recovery.

9.1.7. Summary

Pressure Filtration with or without solid caustic recovery will produce a saving in operating costs of US$ 4.4 to 2.7 million per year. The savings to be attained by the other variants are between US$ 0.9 and 1.2 million.

9.2. Rates of Return

As it can be seen, the operating costs of all four variants are lower than those of the base case, the expected savings in caustic and alumina losses overcompensate for the extra costs associated with the investigated variants. Of course, the situation would be different if the calculations were based on today's extraordinarily low caustic prices. However, the UNIDO team believes that the caustic soda market will sooner or later return to the long-term trend with NaOH prices around US$ 200 (i.e. Na_2O prices around US$ 267).

Table 3 shows the savings expected of the variants, compared to the estimated capital costs and giving the rates of returns.

Table 3 - Savings, Capital Costs and Rates of Return

Variant	Savings US$ Millions/Y	Capital Costs US$ Millions	Rates of Return years
Superthickener	1.204	15.607	12.96
Deep Thickeners	1.107	17.939	16.21
Vacuum Filters	0.943	26.946	28.57
Hyperbaric Filters			
with solid caustic recovery	4.436	22.578	5.09
w/o solid caustic recovery	2.727	22.578	8.28

9.3. Sensitivity

The factors having the greatest influence on the economics of the suggested solutions are the prices of caustic soda and alumina. Therefore, the team decided to repeat the calculations with caustic soda and alumina prices reduced by 25 and 50 %, respectively. Without giving all the details, the results are given in Tables 4 and 5:

Table 4 - Savings, Capital Costs and Rates of Return with Caustic Soda and Alumina Prices Reduced by 25 %

Variant	Savings US$ Millions/Y	Capital Costs US$ Millions	Rates of Return years
Superthickener	0.750	15.607	20.81
Deep Thickeners	0.653	17.939	27.47
Vacuum Filters	0.211	26.946	127.71
Hyperbaric Filters			
with solid caustic recovery	2.947	22.578	7.66
w/o solid caustic recovery	1.665	22.578	13.56

Table 5 - Savings, Capital Costs and Rates of Return with Caustic Soda and Alumina Prices Reduced by 50 %

Variant	Savings US$ Millions/Y	Capital Costs US$ Millions	Rates of Return years
Superthickener	0.297	15.607	52.55
Deep Thickeners	0.200	17.939	89.70
Vacuum Filters	- 0.521	26.946	-
Hyperbaric Filters			
with solid caustic recovery	1.457	22.578	15.50
w/o solid caustic recovery	0.003	22.578	37.44

9.4. Summary

The above rates of return now definitely favour case 3 with **pressure filtration** using the standard approach.

CVG INTERALUMINA will have to make its own financial appraisal evaluating possible optimisation in line with its strategy.

UNIDO in turn, will add hereinbelow an ecological appraisal, considered today vital for alumina plants and its bauxite residue disposal in line with the papers published on this subject amongst others in 1986 at the Bauxite Tailings Conference, Kingston, Jamaica. Although local considerations and legislation may differ, the ecological aspects must be included in an ultimate recommendation for industrial development and investment.

With the three cases described less water will leave the plant and hence more impurities will have to be handled. INTERALUMINA has to evaluate the actions to be taken, based on statistical analysis of the process liquor.

10. ECOLOGY

As earlier outlined (section 1, etc) the present system, also if properly operated, will soon become an ecologic threat and hazard with a disposal of a dilute mud of about 30 % solids still containing 5 g soluble Na_2O/l at the best, the ponds' capacity being exhausted.

A prime objective of all proposals submitted herein refers to the elimination of the supernatant liquor, being a hazard and burden to the environment and plant operation.

Further, the mud to be disposed off should be as dry as possible to lower the soluble caustic in the disposal area, to reduce additional handling, minimize area requirements, facilitate recultivation and hence be under all aspects ecologically compatible without risks.

10.1. Case 1a/b

Superthickener and Deepthickener produce a mud of at least 44 % solids, possibly up to 49 %, of a highly thixotropic consistency which requires particular care during disposal. At such density rain water may still reclaim or drain some soluble caustic which may constitute relatively low hazard.

The standard disposal method, therefore, considers alternate ponds and/or proper distribution to allow for intermediate drying to say 60-70 % solids which calls obviously for additional pond management but allows to reduce the risk of contamination and unexpected slides within the disposal area which would jeopardize the surrounding dykes.

Recultivation after covering the dried area with sand and humus becomes feasible.

10.2. Case 2

Vacuum filters produce a cake with 55 % solids, still in the thixotropic i.e. plastic range but less caustic. The same standard disposal method as outlined above is usually applied in combination with vacuum filters to ultimately create a deposit suitable for recultivation.

10.3. Case 3

Pressure Filtration, in turn, produces the non-thixotropic, dry cake at 75 % solids. Solid Caustic recovered by pressure filtration, however, may easily bring the soluble caustic to levels comparable with the other cases, without however, increasing the risk of contamination since this caustic cannot be drained or reclaimed by rain water which does not penetrate a mud deposit of this density after proper disposal and compaction.

No alternate ponds are required since no intermediate drying is required. Hence, less area is needed also on account of the feasibility to stack to a greater height with a bigger angle of repose.

Recultivation is simple and requires little additional handling nor excessive amounts of humus.

10.4. Summary

An ecological survey leaves no doubt. **Pressure Filtration** will produce the mud offering definitively the safest disposal possible and ever obtained. To quantify such benefits depends on the location and prevailing legislation as already mentioned.

Nevertheless, the disposal area required for the individual cases should be capitalized, thus obtaining a valid yardstick for the ecology as provided by the following example:

Unit cost	US$	2.70/m^2
Case 1 & 2		
Area requirement	m^2	1,000,000
Total cost	US$	2,700,000
Case 3		
Area requirement	m^2	500,000
Total cost	US$	1,350,000

11. RECOMMENDATION

Taking in addition to the basic evaluation a financial and ecological appraisal into account, CVG INTERALUMINA should select Pressure Filtration to resolve its dramatic situation, although the proposed system has not yet been realized within Alumina industries for mud services.

The potential of such filtration, however, should not be neglected, since substantial optimisation can still be realized, using apropriate additives, filtercloths, mechanical adjustments and combination of mud/sand filtration. An arrangement after the seventh washer should also be contemplated and a comprehensive service contract for the first years of operation should be included for filtration, conveying and disposal as well as recultivation. Mud conveying and disposal should be engineered to meet highest standards in line with the filter station and assure full reliability; additional investment, if necessary, can easily be justified to have a full proven system available.

The UNIDO team, in line with its environmental philosophy, becoming more and more a preponderant issue, will and must in due consideration of all other aspects and possibilities recommend **Pressure Filtration**.