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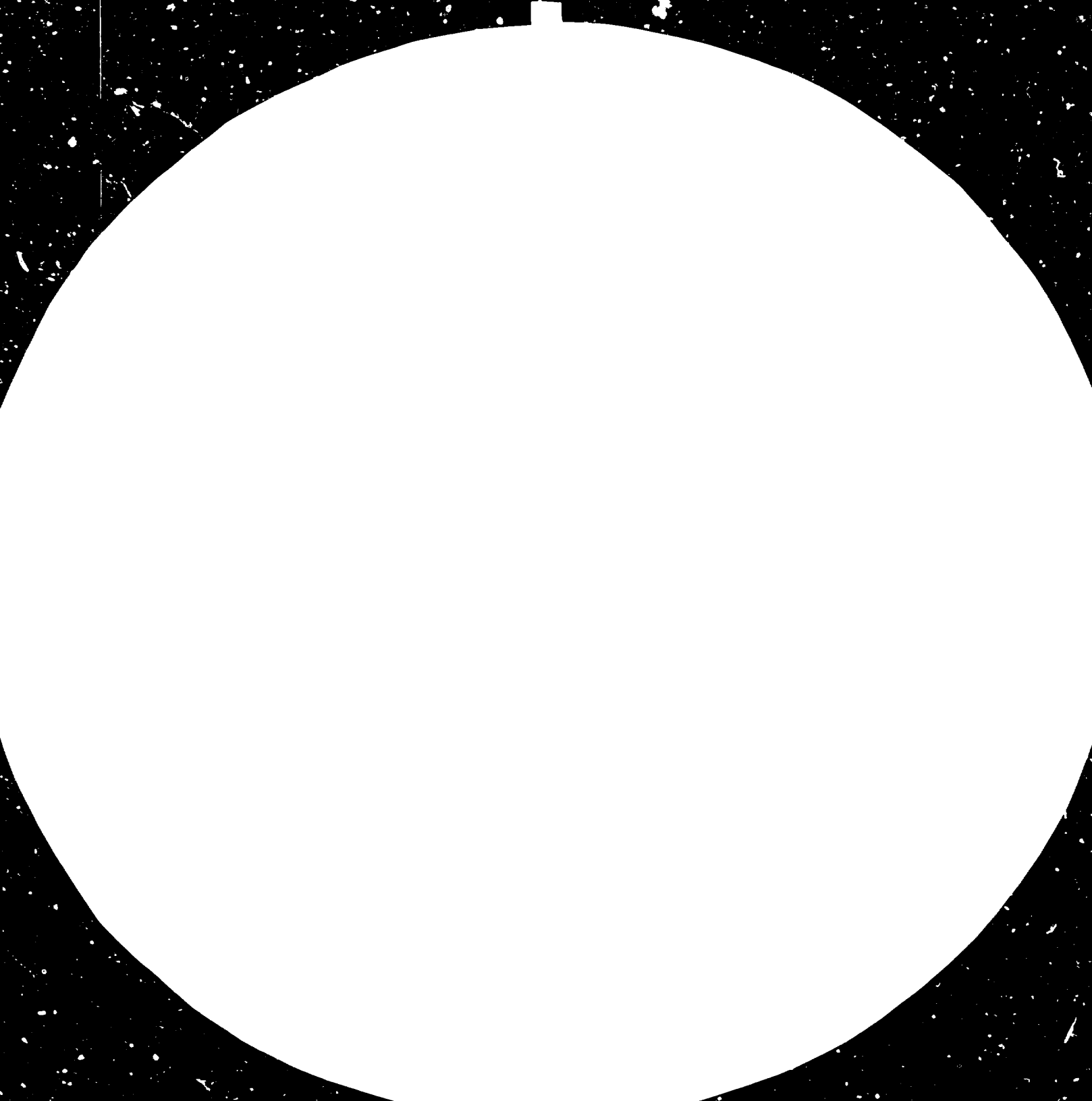
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MICROCOPY RESOLUTION TEST CHART

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World Review
on
Environmental Aspects and Protection
in the
Bauxite/Alumina Industry.

Jenes Bulkai

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ALUTERV-FKI

Budapest

1983

United Nations Industrial Development Organization

World Review on Environmental Aspects and Protection in the
Bauxite/Alumina Industry

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1983.

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The issue of this study does not constitute formal publication. The views expressed do not necessarily present decisions or the stated policy of UNIDO, nor does mention of trade names or commercial processes constitute endorsement.

0. EXECUTIVE SUMMARY

0.1. Environmental effects of bauxite processing

By the second half of the twentieth century aluminium has become an important commodity, being used in a wide range of products from cooking utensils, food and beverage packing materials, high voltage cables to structural metal in all kinds of vehicles and aircraft. It is one of the most abundant metals in the earth's crust and, consequently, there is little likelihood of any ultimate shortages, but it is relatively costly to produce it. Furthermore, its manufacture leads to considerable environmental degradation and pollution if no stringent precautions are taken.

Bauxite deposits contain abundant amounts of the material, hence its use is likely to dominate the world alumina production for some time to come. The technologies of mining the ore and extracting alumina, namely the Bayer process, have not changed much over the years. Compared with other mining processes, for example with heavy metals, bauxite mining is not highly polluting, yet it can take up and degrade large tracts of land either during mining or at the disposal of residues after alumina extraction.

Undoubtedly, the main environmental hazard of alumina production is the bauxite residue, the red mud. In an average, as much as one ton of mud is produced for each ton of alumina, although the actual quantities vary according to the given ore and, considering a world production of more than 30 million ton per year, the disposal of the residue is a major undertaking. The best way to dispose the bauxite residue is through its utilization as raw material. The technologies for such use are available: indeed, alumina

residue has been used as an aggregate in road construction, as a base for cement production, as raw material in the production of iron, steel and other metals, and in the manufacture of ceramics. Verifying of these projects is doubtful due to the rather uneconomical return of the investment. However, had all the parameters been taken into consideration, particularly those which are considered to impose a burden on society ? (See Ref. 01.)

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Aluminium production from alumina is energy consuming, some 80 to 90 gigajoules (in form of heat and electric power) being required on average to produce one ton of the metal from bauxite. Consequently, aluminium smelting plants must be sited reasonably close to an appropriate electricity supply; indeed a reduction plant with an annual capacity of 150.000 ton requires approximately 250 to 300 megawatts of direct current electric power. The siting of both the reduction plant and electricity supply within the same area can cause important environmental impacts and these types of schemes have to be considered very carefully.

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Typically, the Hall-Héroult process is used for the reduction of alumina to aluminium. Apart from its very high energy consumption, this process produces exceedingly toxic wastes, in particular fluorides and carcinogen tars. Up-to-date plants use dry or wet gas scrubbing techniques to lower the level of emission, however, it is strongly recommended to select carefully the site of a new aluminium smelter construction. Narrow valleys or the wind-side of residential areas and farmlands must be avoided.

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In addition to emissions into the outside environment, fluorides, sulphur-oxides and polycyclic hydrocarbonates together with dust, heat and noise cause problems within the

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on, working environment of the smelter.

anu- Due to the need to reduce energy consumption and
:- environment pollution, the importance of aluminium recycl-
- ing has increased and in some countries it reaches 50 per
1- cent of the total aluminium production. Recycling needs
n- only 7 per cent of the energy used for the Bayer/Hall-Hérault
processes and it is practically nonpolluting. Its extra cost
factor is the collection of aluminium wastes and the classi-
fic- fication by the sort and quantity of alloying metals.

0.2. Aims and objectives of the Study

nts On the basis of available literature and of own experi-
city ences we provide for a worldwide review on the environmental
of aspects of bauxite exploration. The main problems are the
of rehabilitation of the open pit mining sites and the protec-
duc- tion of the area against the damages of dusting and noise
an pollution.

igh A special way of bauxite exploration is deep mining of
xic karstic type bauxite in some areas. These deep mines are
to- often below the karstic water table. By pumping out several
ower thousands of cubic meters of good quality karstic water,
ed these deposits become dry for the period of mining. This
so-called active water protection rises several environ-
mental problems which we are dealing with through examples
in this book.

tial This Study deals especially with the environmental
hazards caused by the alumina production, and provides
it, some solutions for the protection of the environment.
Special part is devoted to red mud disposal and processing
the techniques.

The gravest environment pollution problems of aluminium production occur at the stage of electrolysis. Problems and solutions are only mentioned: in this study only the connection between the environmental problems of smelters and the quality of alumina are emphasized. Alumina production is an energy intensive branch of industry. Practically, all alumina refineries work in close cooperation with a power station or have their own boiler house.

Energy production heavily pollutes the environment. Coal-fired or oil-fired power stations emit dust, carbon-dioxide, sulphur-dioxide, some polycarbonates etc. Power stations on coal basis produce also calciumoxide and silica containing ash. Disposal of the coal residue raises similar problems to that of red mud. There are certain solutions for their combined utilization.

Environmental aspects of energy production are discussed by other authors. The present study does not aim at summarizing them, only the aspects linked to our industry are mentioned here (02, 03, 04, 05, 06).

Environment protection is based on proper monitoring of polluting materials in the environment (07). There is a short summary at the end of the Study about the principles of sampling of soil near red mud lakes, of dust, of waste water, ground water, and stack sampling of power plants, calciners and aluminium smelters. In addition, a summary is given about the most appropriate analytical methods which are applied in environment monitoring.

0.3. Acknowledgements

I would like to express my special thanks to Miss Gertrude

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to Dr. György 'Sigmund, consultant of ALUTERV-FKI for his kind contribution in writing chapters about environment protection of alumina industry and red mud disposal; to Mrs. Vilma Horváth at ALUTERV-FKI for her kind contribution in writing the chapter about aluminium smelters; to Dr. László Tomcsányi at ALUTERV-FKI for his kind help in writing the chapter about the analytical aspects of environment protection.

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24. October 1983, Budapest

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Dr. Dénes Bulkai

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	CONTENTS	Page
iron-	1. Environment protection in bauxite mining	11
'	1.1. Open pit mining	15
.	1.2. Deep mining	16
on	1.3. Problems of water protection (B.Vizy, HAC)	22
	References to bauxite mining	34
	2. General environment protection of the alumina plants (Dr. Gy. 'Sigmoid, Aluterv)	35
	2.1. Disclosure of the sources of contamination	36
74.	2.2. Analysis of the possibilities of influencing the contamination	38
	2.3. Provisions for the control of contaminants	45
	2.4. Measurement of contaminants	51
lonal	References to environment protection of alumina plants	55
	3. Bauxite residue (red mud)	57
	3.1. Formation and properties	57
	3.2. Handling of the bauxite residue in the process technology	69
	3.3. Disposal of bauxite residue	71
	3.4. Recultivation of red mud disposal areas	110
ry.	3.5. Utilization of bauxite residue (Dr. Gy. Horváth, Aluterv-FKI)	116
	3.6. Economic aspects and evaluation of the environmental compatibility	134
	References to red mud disposal and utilization	138
	4. Environmental aspects of aluminium electrolysis (Vilma Horváth, Aluterv-FKI)	143
	4.1. Pollution effects of the aluminium smelter technology	143
	4.2. Characterisation of the processing operations causing pollution	146

4.3. Biological effects of pollution caused by aluminium smelters	149	1.
4.4. Threshold limits for fluoride emission	151	
4.5. Technological possibilities to reduce emission levels	151	2.
4.6. Ecological aspects of erecting new plants	156	3.
References to aluminium electrolysis	157	
5. Environmental analytical chemistry in the alumina and aluminium industry (Dr. L. Tomcsányi)	159	4.
5.1. Sampling of different materials for environmental analysis	161	5.
5.2. Analysis, detection	162	7.
5.3. Source monitoring	164	8.
5.4. Data handling and evaluation	166	9.
References to analytical aspects	167	10.
		11.
		12.
		13.
		14.
		15.
		16
		17
		18
		19
		20
		21
		22

	LIST OF FIGURES	Page
149	1. Subsidence of karstic water level in Dunántul	
151	Mountains	20
151	2. Dewatering from the main karstic water system of	
156	the Dunántul Mountains, for the protection of mines	24
157	3. Dewatering and subsidence of the water level in case	
	of Nyirád bauxite mine, Hungary	27
	4. Dewatering and subsidence of the water level in case	
159	of Kincsesbánya bauxite mine, Hungary	29
161	5. Dewatering and water utilization by the bauxite	
162	mines	32
164	7. Volume of red mud + water for 1 ton of dry mud	66
166	8. Technology of red mud storage	77
167	9. Model section of a dam	79
	10. Angle of friction of red mud	82
	11. Strength of colusion of red mud	83
	12. Typical barrage section	94
	13. Red mud disposal with barrage	97
	14. Typical inhomogeneous barrage section with dry core	
	or front sealing	99
	15. Production of molten iron (steel), alumina and cement	
	from red mud (Soviet process)	118
	16. Reductive smelting of causticized red mud flow-sheet	121
	17. Modified series combined process flow-sheet (Hunga-	
	rian process)	122
	18. Production of steel from red mud (USA and GFR	
	process)	127
	19. Preliminary elimination of iron from bauxite	
	(Hungarian process)	130
	20. Flow-sheet of a typical semlter utilizing prebeaked	
	anodes	144
	21. Flow-sheet of a typical wet scrubbing system	153
	22. Fume treatment system of ALCOA	155

LIST OF TABLES

	Page	
		1.
1. Distribution of bauxite mining areas in Hungary according to sites and method	17	1.0
2. Raw materials of the Bayer alumina plants	37	
3. Threshold limit values of materials used in the alumina plants	51	men pre
4. Optical emission spectrographic analyses of mud samples	59	dir
5. Characteristic phase transformations during digestion	61	con
6. Specific surface areas of bauxites and red muds	62	
7. Grain size distribution of two red muds	63	doe
8. Characterization of red mud using Atterberg limits	67	the
9. Review of the utilization of red mud	133	wit
10. Instrumentation used for monitoring environmental pollution of alumina and aluminium industry	165	ba

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1. ENVIRONMENT PROTECTION IN BAUXITE MINING

1.0. Introduction

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Due to the rapid technical development, human environment is exposed to harmful damages of contaminants that have previously been unknown.

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Not only the individuals but the whole society is directly influenced by these damages, consequently, it is a common interest to prevent the occurrence of such phenomena.

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An up-to-date economic and technological system, however, does not only create contaminating, harmful conditions, but, on the other hand, it provides the proper means of protection, with the aim of reconstructing or maintaining a healthy balance of the natural system.

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In modern law the environment protection, the themes of soil, water, and air protection, moreover, the protection of the biosphere, land and the surroundings of residential areas are treated separately. Besides the protection against contaminants and other harmful effects, the concept of environment protection includes protection against the damages caused by the natural elements, moreover, it includes the reasonable and economical utilization of the natural resources.

Environment protection may be either of regenerative or of preventive character. It is advisable to apply principally preventive methods. The concept of regeneration can only be accepted in case the technical (or economical) conditions prohibit any other solution.

The main tasks of environment protection, in the order of importance are as follows:

- elimination of the effects directly influencing and damaging life, health and the physical conditions of man;
- prevention of causing damages in the state of environment;
- to take the necessary measures urgently, in case any postponing would induce irremediable damages or if the costs of reconstruction were significantly higher than that of the preventive measures;
- coordinated provisions in case the contamination of the actual site is above the critical level and, in case the sites have special importance from the point of view of tourism, recreation, therapeutics, etc.

The harmful influences of mining have been experienced for a long time. However, there is a simultaneous tendency to make efforts in order to prevent or, at least, to reduce these damages.

The past and present conditions of bauxite mining will be outlined in the followings, in relation with the protection of the human environment:

1.0.1. Soil Protection

Soil protection refers to the soil, bedrock, and to the raw minerals. Based on the decisions of national authorities, the most efficient branch of economy is presented with the right of utilization. The user receives the land by expropriation. In case of the mines, this happens by the marking out and expropriation of the mining territory. Depending on the position of the ore-seam, underground or open pit mining is applied. The bedrock, soil and vegetation is damaged by both methods, however, open pit mining is especially harmful in this respect.

By the end of the mining activity, the territory must be transferred to some other branch of the economy (generally, to the agriculture or forestry), in an adequate condition for further utilization. The costs of recultivation necessary for the reconstruction must be taken into account during the elaboration of the investment project.

1.0.2. Protection of Water

Protection of water extends to underground waters (mineral water and medicinal waters as well), and to their beds and banks.

The most significant influence of bauxite mining refers to the underground water, principally to the karstic water. The drainage of subterranean waters and the protection of their quality is of minor importance.

Any activity of water protection is conditioned by the permissions of the central authorities of mining and water-maintenance. Special care is taken in order to protect the valuable natural resources, such as, for example, the medicinal waters (mineral waters). The effect of water protection methods planned to be realized in the future are to be tested jointly with the responsible environment protection authorities.

1.0.3. Air Protection

Bauxite mining (especially in case of open pit mining), storage and transportation produce dust, contaminating the air and the residential areas. Its prevention has not yet been solved at present. The contamination of roads, for example, is removed by temporary cleaning. The problem could be satisfactorily solved by the invention of protective wood belts, systematic irrigation, cleaning, or by the establish-

ment of transportation roads avoiding the settlements.

1.0.4. Protection of the Biosphere

The mining activity connected to the protection of vegetation and animals can be the following:

- water protection concerning the changes in the moisture-content of the soil (change of the level of the water table), that may influence the flora of a territory: e.g. dessication of a karstic marshland.
- the damages must be reduced to the lowest possible level, in order to protect the animal stock; the surface must be recultivated, the chemicals must be utilized and cleaned off with special care.

1.0.5. Land Protection

Land protection refers to those natural lands, territories and subjects that have some significance from scientific, cultural or other aspects. Generally, it is related to the protection of soil, water, air and to the biosphere. It is a complex task, consequently, the research and mining activities must be co-ordinated with the actual prescriptions referring to this field.

1.0.6. Protection of the Residential Areas

It involves residential, recreational and institutional areas, moreover, any other areas permanently inhabited by people.

In case of mining, the problem is generally solved by keeping the prescribed distance between the mine and the inhabited areas. However, the question of environment contamination due to bauxite transportation, moreover, the direct influence of the mining activity on the residential areas (such as, e.g.

prevention of damages caused by undermining) is raised here again.

1.1. Open Pit Mining

Depending on the location of the bauxite deposit, it is explored either by underground or open pit mining. The actual bedrock, soil and vegetation is damaged in both cases, 95 per cent of the world's bauxite consumption is supplied, from open pit mines. The huge open pit mines basically change the original landscape.

Lateritic bauxite deposits are predominantly located in the tropical belt of the globe. The latest geological prospecting data indicate that, out of the world's total bauxite reserves amounting to 30 billion tons, 90 per cent belongs to the lateritic type. The genetics of the lateritic bauxites is the following: in shallow seagulfs clay minerals sedimented onto the surface of the seabed. Later on this seabed has risen and broken, thus plateaux were formed. Tropical rains had washed out kaolinite and other finely dispersed minerals from among gibbsite, hematite, maghemite, anatase, rutile, quartz, etc. Only a very thin layer of soil had accumulated on the surface of these plateaux for rooting the vegetation in.

At the exploitation of these ore bodies, special care must be paid to the stockpiling and returning of the soil because, due to the heavy rainfalls, rainwater leaches the bedrock from time to time that makes natural revegetation of drainage control very important.

Lateritic bauxites are of very good quality, aluminium is predominantly present in trihydrate alumina, namely

gibbsite which can be digested at 100 or 140 °C and at a liquor concentration of 100 to 120 gpl caustic Na₂O. However, countries having no lateritic bauxite mines (in the subtropical and moderate climatic zones of the globe) generally process bauxites containing boehmite and diasporite (both being monohydrate aluminium oxides).

Karstic deposits are sedimented into deep holes of karst rocks and covered by thinner or thicker overburden.

In case of Jamaican bauxite, the overburden is rather thin while in Europe it can be as thick as ten meters or even one or two hundreds (see deep mining).

When the covering layer is a few ten meters, it can be removed from over the ore body but it must be stockpiled and refilled when the ore is mined out of the pit. The soil of the upper surface must be stockpiled separately and returned to the surface of the filled back overburden. Mining areas are occupied by the mines only for 10 to 15 years and given back to agriculture or forestry. Rehabilitation of exploited mines is a natural requirement, so nowadays in any case when governments give concession on prospecting and exploitation, they insist on rehabilitation of the mining site (12, 13, 14, 15).

Open pit mining causes additional health hazards by dusting, noise and exhaust gases of heavy mining machines. There are national and international prescriptions about the acceptable level of pollution of working environment (07).

1.2. Deep mining

As a matter of fact, underground mining may also cause

considerable damages: ruptures, subsidence, remnants of the open pit establishments. The decrees having been issued since the 1960-ies prescribe increasing demands of soil protection and recultivation, and their transfer to the agricultural or forest economy branches.

Table 1.

Distribution of bauxite mining areas in Hungary according to sites and method:^{*}

	Underground	Open pit	Total			
Halimba	4,4 km ²	0,8	5,2			
Nyirád	9,1	0,2	9,3			
Kislőd	-	1,1	1,1			
Iharkut	-	0,2	0,2			
Bakony Bauxite-Mines	13,5	2,3	15,8	62 %		
Kincsesbánya	6,7	0,4	7,1			
Gánt	-	1,1	1,1			
Fenyőfő	1,0	0,4	1,4			
Fejér Bauxite-Mines	7,7	1,9	0,6	38 %		
Bauxite mining	21,2	83 %	4,2	17 %	25,4	100 %

About 40 per cent of the total area is the so-called expropriated land. The distribution of the remaining 60 per cent between the types of cultivation before mining is as follows:

forest	27 per cent
meadow, pasture, rushes	14 per cent
arable land	18 per cent
vineyard	<u>1 per cent</u>
Total	60 per cent

^{*}source: B. Víz, HAC

Distribution according to utilization:

central establishments roads, strip-pits	12 per cent
areas influenced by underground mining	73 per cent
areas influenced by open pit mining	15 per cent

After finishing the mining activities, the territory must be transferred to another user (generally to the branches of agriculture or forest cultivation), in an adequate condition for further utilization.

The process of recultivation consists of two phases:

- Regional development (technical recultivation) means the reconstruction of lands that have been destroyed or affected during the mining activities, for further utilization. It includes terrain correction (levelling the subsidences and dumping places, filling back the mining holes or pits), removal of artificial objects remaining in the soil, reconstruction of the soil strata.
- Reutilization (biological recultivation) includes the activities required for the reconstruction of the territory, in order to utilize it as agricultural or forest area (melioration, afforestation, revegetation, etc.).

According to the law, the mining company is liable for the technological recultivation of the land, whereas biological recultivation is the duty of the actual organs for which the landed property is transferred.

The tasks of biological recultivation and the sources of investment are different in case of underground and open pit mining.

Underground mines are not so harmful from the aspect of soil protection, as compared to the open pit technology. The space can be utilized in two basic ways:

- plant buildings, areas occupied by objects and by the tailing pond;
- areas exposed to the danger of cave-in, with no surface objects in them.

In the first case, the original conditions can only be reconstructed by significant investment therefore, establishments planned to operate for at least 10-15 years must carefully be located to less valuable areas.

Areas exposed to the danger of cave-in are more extensive but their reconstruction raises no significant problems. The mining technology of undercut caving produces depressions in the surface - depending on the thickness of the extracted bauxite layer, and on the slackening factors of the covering rocks. Depressions principally affect the conditions of soil cultivation (formation of areas of no natural drainage; alterations of the water system and of the microclimate; damages of the soil and forests). These changes may be repaired after the mining activities and after the motion of the ground cease, however, in case the depressions caused irreparable damages (e.g. nature conservation areas), the realization of a more expensive mining technology must be taken into consideration (e.g. to fill back refuse rocks into the place of the extracted ore).

Some informative data on the ratio of investment required for reutilization will be mentioned in the followings, with regard to the plans elaborated in the previous years:

Reconstruction of areas cultivated by open pit method

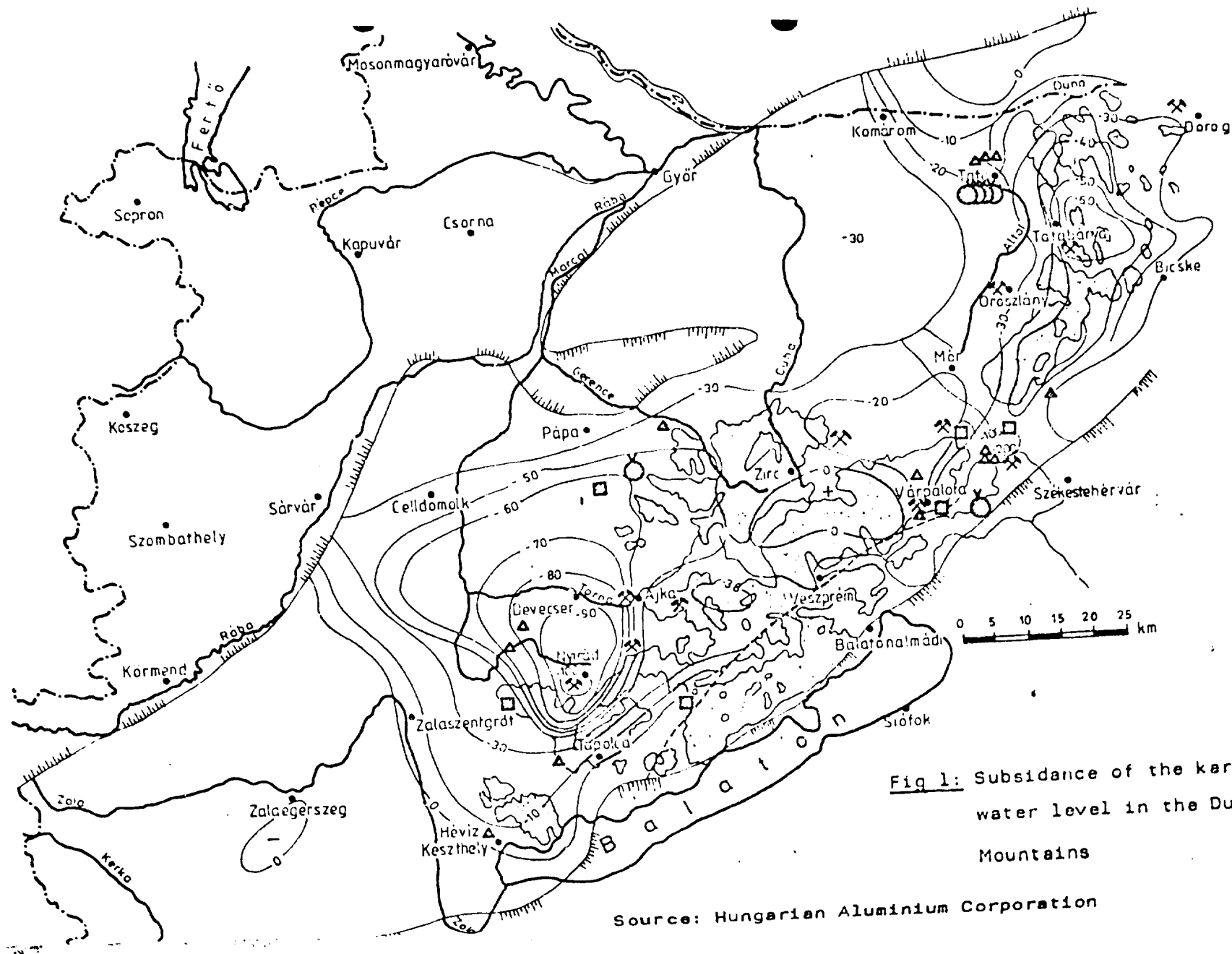
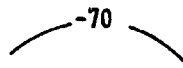
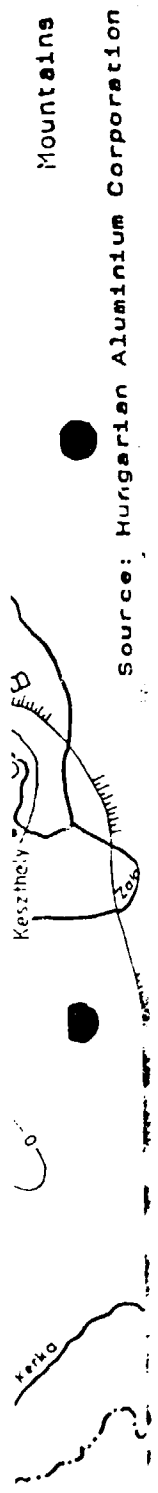


Fig 1: Subsidence of the karstic water level in the Dunántul Mountains

Source: Hungarian Aluminium Corporation

Explanations of signs to Fig 1.:



Subsidence of karstic water level, as compared to the original conditions



Boundary of paleozoic geological formations



Meozoic geological formations



Ceased karstic wells:

water work in towns

water work well

significant well



operating mines

Source: Hungarian Aluminium Corporation

requires about 15,000 USD/hectare, increasing the costs of bauxite by 2.5 per cent (0.4 USD) for each ton. The specific costs of recultivation in case of underground mining are less significant (including the strip pits, roads, etc.): about 1000-2000 USD/ha, or 0.05-0.1 USD/t.

1.3. Problems of Water Protection

(Special study from B. Vizy, Hungarian Aluminium Corp.)

The activities connected to the exploration and processing of bauxite disturb the ground water, the substratum- and karstic waters. According to the Hungarian practice, the damages of ground water systems are not significant and only of local character. However, the influence of mining upon the karstic waters and substratum waters is very considerable, due to the fact that the dominant part of the Hungarian bauxite deposits is found in mountains built up of rocks of carbonate content, having a more or less complex karstic water system.

Due to its geological construction, the Dunántuli Mountains of Hungary have the greatest reserves of karstic water. The area of the karstic water table exceeds 10,000 km²: only 15-20 per cent of it is open, the remaining part is underground water system, under pressure (Fig. 1.).

The water is situated in ten different tables, referring to the layers of carbonate rocks having been originated in 10 different geological epochs, from the lower-Carbon to the upper-Pliocen.

The waters form more or less independent systems in the different layers of rocks. The most significant table extends to the entire mountain:

this so called main karstic water system is hydraulically

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homogeneous. Its bedrock consists mainly of carbonate rocks, limestone and dolomite of the upper-Trias epoch.

Before artificial interventions, the amount of water filtrating into the system was in natural equilibrium with the amount leaving the area in the form of wells and karstic marshlands.

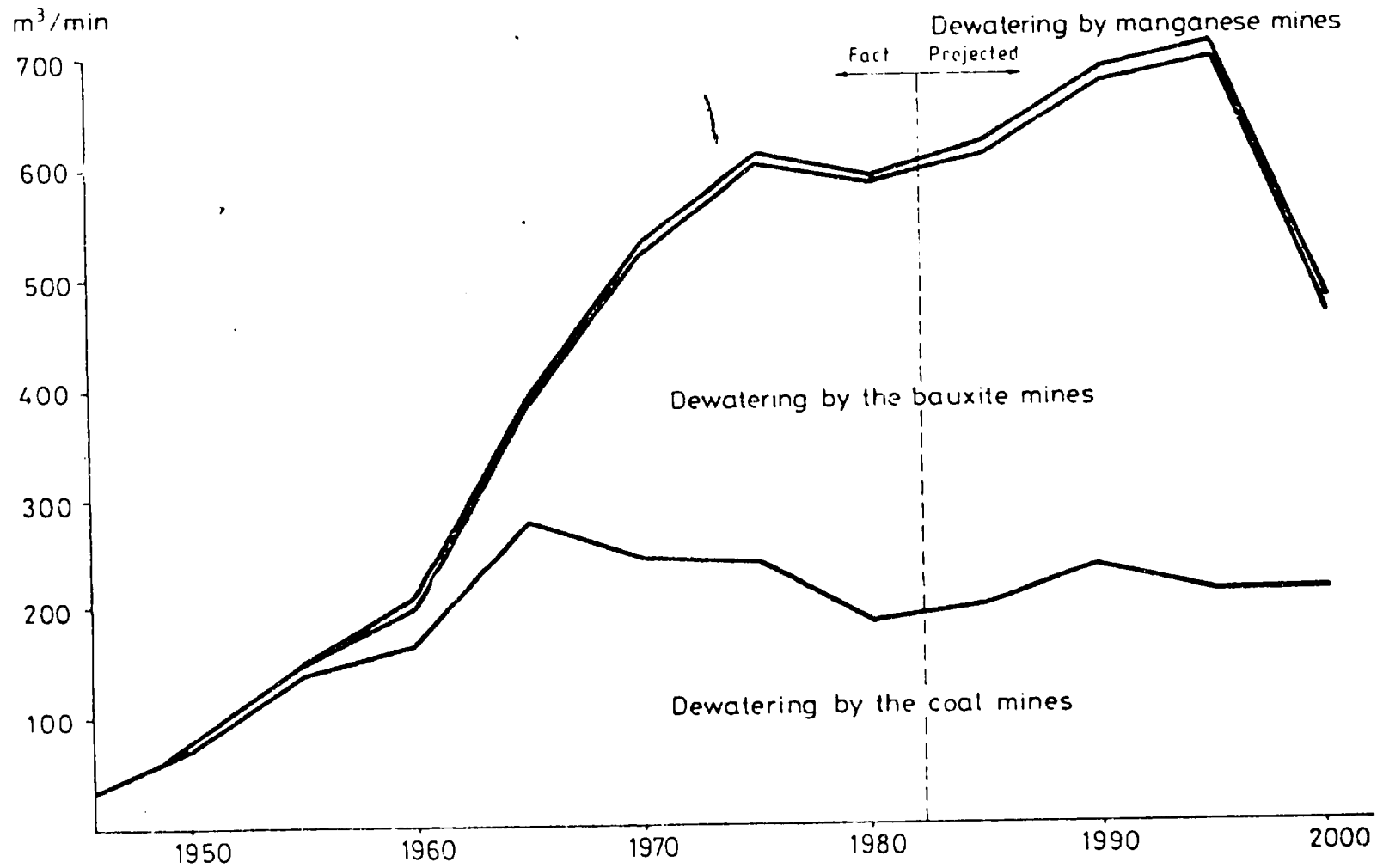
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Test results of water homeostasis in the region show that the amount of the general water make-up of the main karstic water system is between 700-750 m³/min in the entire area of the mountain: out of this value, the make-up of the Bakony Mountain is about 490 m³/min. Depending on the yearly distribution of precipitation, the stock of refilled water displays a scattering of 50-60 per cents. Before the artificial interventions into the karstic water system, this fact was responsible for the changes in the level of water table and in the water flow. The natural water-homeostasis of a karstic water system is disturbed in case the decrease of the level of the water table brought about by artificial interventions is greater than that experienced under natural conditions, for a longer period (5-10 years).

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The original conditions of the above mentioned water system has already been disturbed at the beginning of the century by artificial draw-off when, in order to protect the neighbouring coal-mines (Tatabánya, Ajka), bailing was started. Bailing has significantly increased since the 1950-ies in the mining industry: in the past ten years its value has been between 550-600 m³/min (Fig. 2.). At present, several mines in the affected area are protected by this method, however, mainly the bauxite mines resort to this technique: in 1982, 65 per cent of the waters were bailed by the bauxite mines, principally from the main karstic water system.

Fig 21 Dewatering from the main karstic water system of the Dunántuli Mountains, for the protection of mines.



Source: Hungarian Aluminium Corporation

In the recent 25 years, bailing for communal (infra-structural) purposes has rapidly increased, also contributing to the unfavourable changes of water homeostasys. At present, an amount of about 70-80 m³/min, i.e. 12 per cent of the total bailing is utilized for such purposes.

Artificial bailing has two sources:

- continual water make-up, due to precipitation and other infiltrations (dynamic water stock, 83 per cent).
- utilization of waters stored within the rocks (static water stock, 17 per cent).

In case of the dynamic water stock, bailing procedures consume more than 75 per cent of the make-up waters:

- Dunántul Mountains: 76 per cent
- Out of this, in the Bakony Mountain: 82 per cent.

According to the long term plans, by the 1990-ies the amount of bailed water will amount to 100 per cent of the natural make-up water stocks, thus bringing about a further damage of the karstic water homeostasys, and more rapid lowering of the level of the subsoil water tables.

The decrease of the water reserves has exceeded 1 billion m³ by the present, bringing about a lowering of the level of the water table, with local differences in its degree, of course. Due to this fact:

- wells dry out partly or entirely;
- karstic marshlands dry out;
- the amount of karstic water filtrating up into the intermediate water tables decreases, and then the water of the intermediate layers start to infiltrate into the karstic waters;

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for the protection of water system of the Dunántul mountains.

to be followed by the appropriate measures.

- the output of water works built on wells or gallerdes decreases and then ceases;
- the changes in the natural flow rate conditions may bring about a simultaneous change in the temperature of the natural wells as well.

Since the 1950-ies, the continuously lowering extraction level of the bauxite mines has reached down to the original level of the karstic water table in the Dunántuli Mountains, consequently, the water level was lowered by artificial means, in order to ensure the necessary protection of the mines. The ratio of bauxite extracted from below the original water level has gradually increased since that time:

1950	42 per cent
1960	39 per cent
1970	71 per cent
1980	82 per cent.

Environmental effects occuring due to the lowering of the level of the karstic water table can be grouped into two major cathegories:

- a.) Damages of the communal water stock (springs, wells). The mining institutes are obliged to compensate for these damages somehow (lowering of the outlet level of the wells), drilling of new wells or supplying water from other areas.

Significant damages of the essential springs of luke-warm or warm water supply (like the ones around Budapest) would cause serious troubles, therefore, the mining activity in these regions is allowed on condition of preventing any significant decrease of the

Fig 3: Dewatering and the subsidence of the water level in case of the Hungarian bauxite mine at Nyirád.

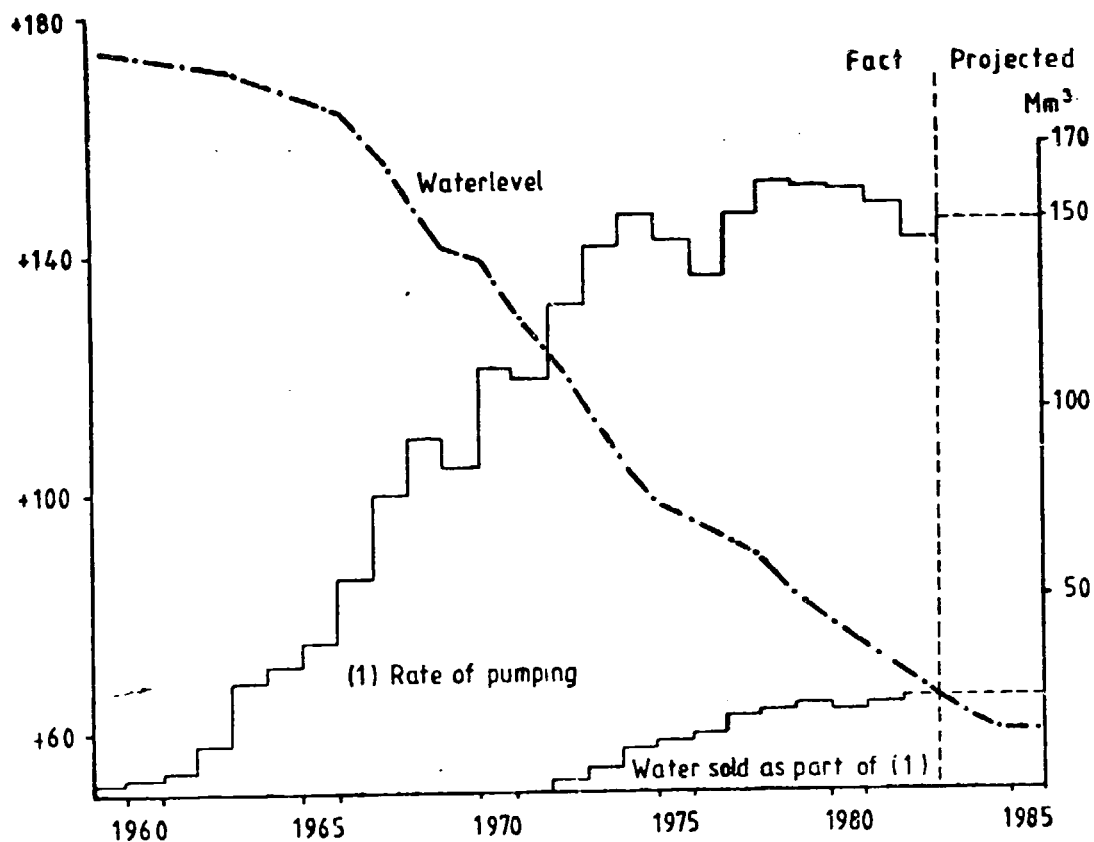
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Source: Bakony Bauxite Mines, Hungary

flow-rate.

As a result of extensive researches and tests carried out with the aim of protecting the springs around Buda, the Hungarian authorities determined the allowed maximum amount of water to be bailed by the mines located at the north-eastern part of the Dunántuli Mountains: this amount is $200 \text{ m}^3/\text{min}$. Similar measures have been taken in case of the Héviz lakespring situated at the south-western part of the mountain: in the region of Nyirád, the allowed maximum amount of bailing was determined to be $350 \text{ m}^3/\text{sec}$. The supervision of this amount is in progress. Certain damages must be prevented principally from the aspects of environmental reservation and of tourism. This requires the reconstruction of medicinal springs enjoying international popularity, and the preservation of landscape (town picture) in case of touristic centres. Environmental damages belonging into this category must be prevented by all means or, in case the natural system is disturbed, the losses of water must be compensated somehow. The costs of preventing or correcting the damages are very high: reconstruction is sponsored by the state, from the funds accumulated for the compensation of mining damages.

- b.) the second category includes the damages caused by the decrease of the level of the water table, that are not necessary to be compensated (because, e.g. the water was not utilized for industrial purposes), or that can not be compensated (e.g. karstic marshlands).

Environmental damages can be prevented by the introduction of complex measures. According to the methods required to their solution, these measures can be grouped into 3



Fig 4: Dewatering and subsidence of the water level in case of the Hungarian bauxite mine at Kincsesbánya.

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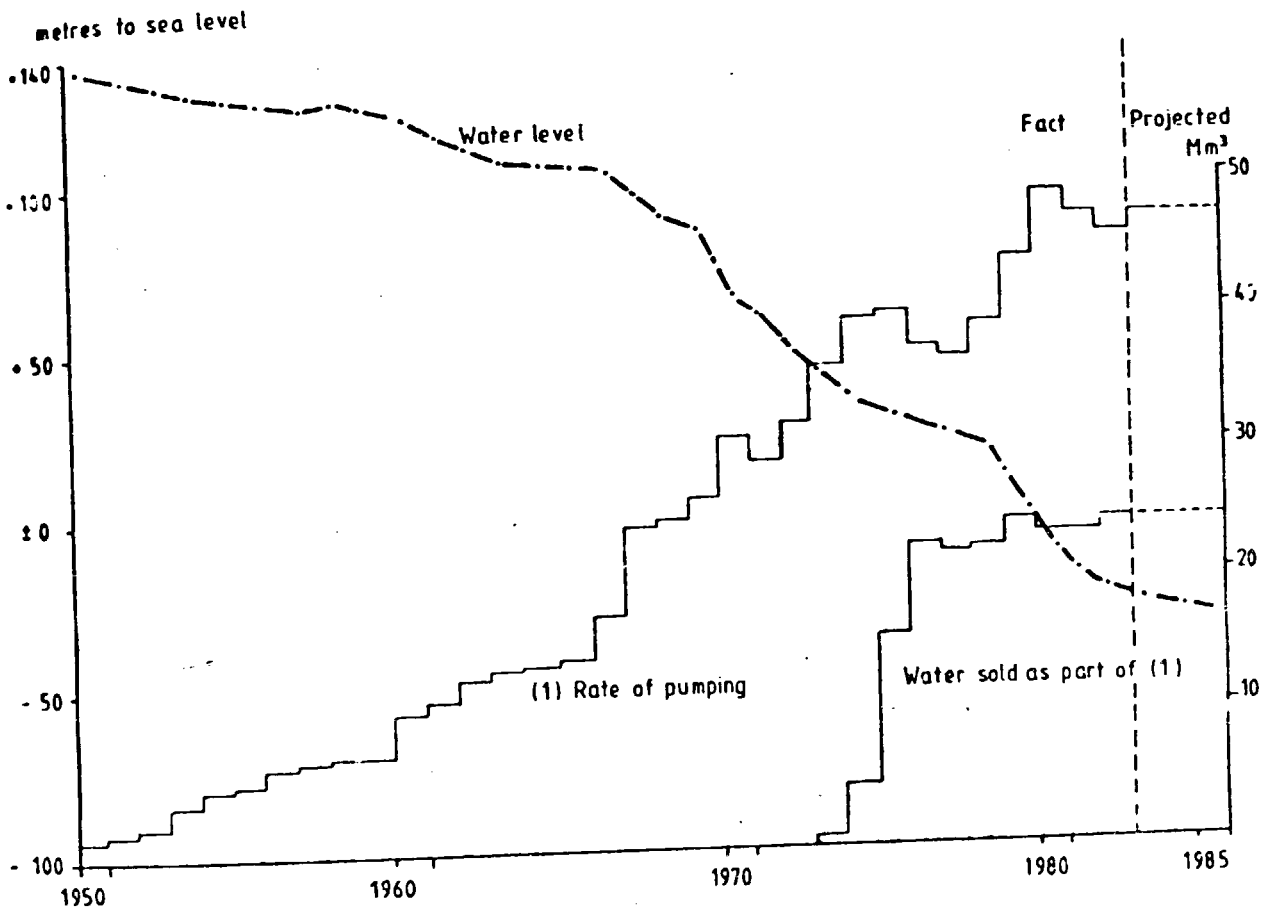
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Source: Fejér Bauxite Mines, Hungary

categories: tasks concerned with mining, environment protection, or water economics. The solutions discussed in the followings have general validity, however, they will be discussed on the basis of the experiences gained at the analysis of the bailing procedure at Nyirád and its influence on the lake Héviz.

- a.) The direct aim of solving the environmental problems from the aspect of mining is to introduce water protection methods that make possible to extract the mineral wealth by reduced amounts of subsoil water to be bailed, thus decreasing the environmental hazards. b.)

Such methods may be the following:

- back-filling of rocks into the place of the extracted minerals, in order to decrease the water transferring capacity of the secondary rocks of the mineral stock. This may be done by packing the pits, galleries or faults, or by regional packing.

Several kinds of packing material can be used. In the Hungarian mines, packing possibilities with plastic or with clay slurry rocks was tested. The exclusive or regional application of these methods is not economical, because they require intensive drilling work and large amounts of packing material. As the packing effect is not quite excellent, the danger of bauxite wetting must further be taken into consideration, moreover, dewatering may become necessary later on.

- local dewatering, limited in time and space. The terrain of the Nyirád region has favourable water conducting capacity. In this case, two solutions

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are given for saving the water during lowering the level of the water table:

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- Reducing the area of dewatering: instead of simultaneous drainages, the required level of water is attained by drawcuts of moving gravity extending to small areas, or by depressions.
- The amount of bailed water can significantly be reduced by the rapid shaping of the depression area and by the increased rate of ore extraction.

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b.) Solutions directly attached to the environment protection must be carried out in the damaged or endangered area itself. Such solutions may be the following:

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- Filling back a certain part of the bailed karstic water into the karstic water system, in order to maintain the required pressure-conditions (water level) at the crucial sections.

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Due to the great depth of the bed-rock and to the repeated bailing of the waters that have been filled back, this solution seems to be uneconomical in case of certain Hungarian mines. On the other hand, the filled back water may have a cooling effect on the thermal waters of the region.

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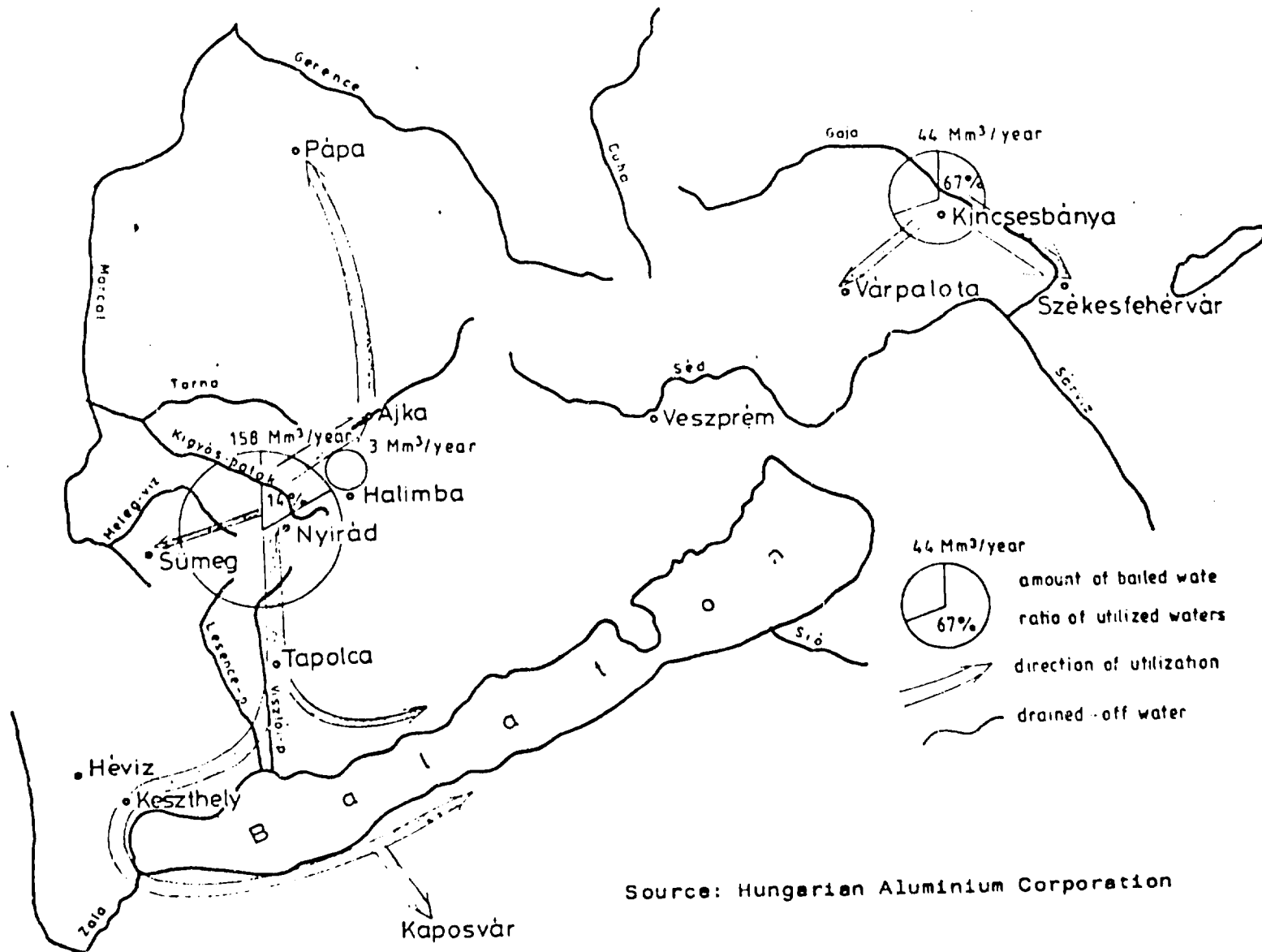
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- Protective measures to be realized directly at the endangered region or objects, in order to prevent any decrease of the flow-rate or temperature, in case of thermal lakes, may be the following:

- As a consequence of the decrease of the flow-rate, the temperature of the water surface cools down during the winter period. In order to maintain its original temperature, warm water is pumped from



Source: Hungarian Aluminium Corporation

the spring into that part of the water surface that is used for bathing during the winter.

- Compensation of the decreasing flow-rate from the natural water supply area of the lake-spring.
- pumping of the lake-spring.

c.) Measures taken in the field of water economy may also significantly promote the improvement of the natural water exchange equilibrium of the damaged water-system.

- It is necessary to control the amount of water flowing out of the lake and the amount bailed in its vicinity (control of artificial wells), moreover, to utilize the medicinal waters economically.
- Damages of the main karstic water system in the Dunántuli Mountains may be reduced by the large scale utilization of the bailed water extracted by the mines. In this way, it would not be necessary to bail further amounts of water for communal and industrial purposes.

Apart from the direct costs of water protection, the profitability of mining in areas where the deposit is situated close to the natural water reserves depends on the costs of preventing environmental damages. An additional factor in this respect is whether the bailed water can be utilized (Fig. 5.).

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2. GENERAL ENVIRONMENT PROTECTION OF THE ALUMINA PLANTS

Technical development induces an ever increasing influence on the human environment. Therefore, the problems of environment protection must be taken into consideration in each phase of the productive practice: during the preparation of the projects and of the conceptual and detailed engineering designs, and in the operating plants, which must also provide for the environment protection.

The supplementary solution of the problems arising in this field naturally requires much higher investment costs than if these problems had been primarily dealt with in the projecting work.

It must be stressed, however, that environment protection cannot be restricted to the protection of man and his direct surroundings. Man and the biological sphere are in close connection. If any part of this system is disturbed by some disadvantageous influence, it will have far reaching consequences on the whole biological system. If, for example, the contaminated water destroys the plants, the animals would also leave the territory. Man can accommodate himself to a certain extent to the changing environmental influences, however, the rapid technological development experienced in our days raises ever increasing problems that must be solved in order to maintain healthy conditions of living.

Main tasks of the environment protection are:

- land protection
- reasonable utilization of the soil and its recultivation
- maintaining the purity of waters
- forest protection
- prevention of air pollution

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- utilization or neutralization of solid wastes
- noise control

Measures taken for environmental protection can be grouped into four major tasks:

- 1.) Disclosure of the sources of contamination
- 2.) Analysis of possibilities of influencing the contaminants from technical-economical aspects
- 3.) Elaboration of provisions to decrease or eliminate contamination
- 4.) Measurement of contaminants, realization of the measuring network.

2.1. Disclosure of the sources of contamination

In order to comprehend the sources of contamination, Table 2.1 enumerates the raw and auxiliary materials of the alumina production, their utilization and final products and, in addition, their further treatment in the plant. The data of the table refer to alumina plants based on the Bayer technology equipped with own power plant as well.

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Table 2.

Raw materials of the Bayer alumina plants

Raw material	Utilization	Final products and their further treatment
Bauxite	Source of alumina	Alumina, red mud, water, by-products
Caustic soda	Dissolving the alumina and descaling	Recycled in plant. Losses in red mud, alumina and with spillages
Soda ash	Generation of caustic soda	Caustic soda and CaCO_3
Limestone	Lime-burning	Burnt lime and CO_2
Burnt lime	Substitution of caustic soda in the red mud, digestion of diasporic bauxite, salt causticization, phosphorous control, precoat/filter aid	Lost with red mud, small portion lost with alumina
Fuel oil	Steam- and power generation, alumina calcination, lime-burning	SO_2 , CO_2 (CO), NO_x power
Natural gas	Steam- and power generation, alumina calcination, lime-burning	(SO_2), CO_2 , (CO), NO_x , power
Coal	Steam- and power generation	SO_2 , CO_2 , (CO), NO_x , slag, fly ash, power
Starch (flour)	Settling aid	Lost with residu, partly accumulates as organics in the circuit
Syntethic settling aid	Settling aid	Lost with residu
Sulphur, sodium-sulphate and bisulphate	For the reduction of the Zn-content of the alumina	Accumulates as sulphate in the process
Acids (HCl, H_2SO_4 , HF)	Removal of scalings	Discarded to the acid pit or residue lake

Source: see ref 0.1

On the basis of the above table, the materials used in the alumina production can be grouped into two great categories from the aspect of environment contamination:

- contaminants occurring also in other plants of the chemical industry (liquors, acids, non-aggressive hard materials, lime, oil, gases SO_2 , CO_2 , CO, NO_x content, slag, fly ash, power)
- the special contaminant of alumina production red mud inducing significant problems in the environment protection, first of all due to its abundant mass.

In the following chapter we shall discuss environment protection against contaminants occurring also in other plants of the chemical industry, whereas the formation, storage and utilization of red mud will be dealt with in the third part.

2.2. Analysis of the possibilities of influencing the contaminants

In the course of analysing the possibilities of influencing the contaminants, the primary task is to reduce or eliminate the emission of contaminants that present the main hazards to environment protection. From the point of view of alumina production, there exist a wide variety of such possibilities, a selection of which is presented below:

- substitution of raw materials and auxiliary products dangerous for the environment by other, less harmful materials (change of raw materials);
- preliminary purification of the raw materials and auxiliary products;

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- technological alterations, in order to reduce contamination;
- introduction of new technological methods;
- introduction of equipment for removal of contaminants;
- utilization of contaminants;
- recirculation of contaminants.

Ref. 2.1, 2.2, 2.3

In the followings, the expected advantages of the above mentioned measures will be discussed separately, with special regard to the alumina plants.

2.2.1. Change of raw material

The substitution of bauxite with other raw materials (clay, silicates, nepheline, alunite) provides environment protectional advantages only in case the new technology does not produce any waste or if the wastes can be utilized (e.g. nepheline, alunite processing). However, the specific raw material demand of processes based on other auxiliary materials instead of bauxite is always higher (the Al_2O_3 content of the raw material is lower) and, as a result, the dust formation during transportation, storage and preparation will be of a greater extent.

It has to be mentioned that these technologies are generally less economical than the Bayer process based on high quality bauxite, consequently, their application may only induce local economical advantages within the vicinity of the raw material and power-sources.

The substitution of caustic soda by other raw materials, first of all by lime is an interesting problem. Under the present conditions, this method reduces the caustic content of the red mud by 15-20 per cent in the

process of digestion with additives. Some years ago, the use of lime was regarded unambiguously disadvantageous from environment protectional aspects, because its transportation, storage and processing caused aggressive dust formation that was difficult to be controlled. At present, the use of containers in lime transportation makes possible to avoid the formation of lime-dust within the plant. At the same time, the caustic content of the red mud decreases, thus favourably decreasing the danger of liquor leakage into the soil. On the other hand, lime is less soluble in water than caustic soda, and finally it is transformed into carbonate.

2.2.2. Preliminary purification of the raw material

At several deposits it is a well established practice to beneficiate the bauxite by washing, screening or by cycloning. These methods not only reduce the specific amount of raw material to be processed in the alumina plant - as both the Al_2O_3 content and the expected recovery is increased - but, due to the decrease of the different contaminants (SiO_2 , iron oxide), the specific mass of the red mud will also be less.

Among such process technologies, the one elaborated by ALUTERV-FKI may gain significant importance in the future: this process is a registered patent of ALUTERV-FKI, at present tested at pilot plant level - preliminary de-ironing of bauxites by ammonium-chloride, bringing about a significant decrease in the wastes of alumina production. This method will also be discussed in Chapter 3.

2.2.3. Technological alterations

The most appropriate example of contaminant reduction by technological alterations can be regarded as a fact of industrial history: the switch-over from dry grinding to the wet grinding method. The dry grinding process sometimes caused dust formation of several per cents. Though it had no aggressive effects, it was an unpleasant and unaesthetic contamination. A 2-3 per cent loss on the dust formation in an alumina plant of 500 thousand t/year capacity resulted in 20-30 thousand tons of yearly dust production - that was rather troublesome to endure for those who lived in the direct surroundings of the plant.

2.2.4. Introduction of new technological methods

An example for this measure is the switch-over from the production of floury alumina to sandy alumina. Although the American technology has always produced sandy alumina, at present the alumina plants based on the European technology are switching over as well, one after the other, from floury to sandy alumina production that provides excellent results in the dry gas scrubbing process of the reduction plants. The advantages of this switch-over are directly perceptible in the alumina plants, too, because the loss on dust formation during calcination and alumina transportation is substantially decreased by this way. Alumina plants based on floury alumina production have not been built lately, neither is it expected that such plants would be built in the future, as the new smelters are also constructed on the basis of technological projects of electrolysing solely sandy alumina with prebaked anodes.

It must be stressed that the grain fraction of alumina between 0 to 20 micrometers may specially be harmful from sanitary points of view, and the amount of this fraction in sandy alumina has already been reduced to 1-2 per cents.

Another significant environmental measure is the filtration of red mud and its storage in solid form. That will be discussed in more details in the second part.

2.2.5. Introduction of equipment for removal of contaminants

It had already been mentioned that neither bauxite dust nor alumina dust are harmful for the health: they are rather regarded as unpleasent contaminants. The high dust content of the air around the working places, naturally, causes troubles in visibility and, consequently, may be the potential source of accidents. The allowed maximum dust content in the workshops is 10 mg/m^3 .

In case of bauxites apt to heavy dust formation, the protective measures can include artificial wetting, covering the belt conveyors, or the introduction of exhaustion devices. These exhaustion devices (fans) are connected to dust controlling devices that can be simple cyclones, multicyclones, separators based on filtration, wet separators or electric dust separators.

The selective capacity of the cyclones is little: they separate the coarser dust fraction with higher efficiency. The separating capacity of the cyclone, however, may be increased by reducing its diameter - this phenomenon led to the construction of multicyclones consisting of several cyclones of little diameter, having a common feeder and dust hopper.

During the period of dry grinding, textile separators were favoured for dust separation. They are used presently as well, in case the bauxite dust is exhausted at the transferring points or in the crushing plant.

Wet separators are generally not used in the alumina production processes because the storage of slurry containing bauxite-dust causes troubles, and if it is sprayed back onto the bauxite, the amount of recycled dust will increase.

The dust controlling devices already delivered with the calcining equipment are cyclones and electric filters. These devices reduce the loss on dust formation to below 1 per cent even in case of floury alumina, however, results attained in case of sandy alumina are even more favourable (in the past several plants producing sandy alumina did not apply electric dust separators at all).

Both in case of lime-burning and coal firing of boilers, dust (or fly ash) separation is carried out by cyclones and multicyclones. It is advisable to use even electric dust separators.

Naturally, the value of dust pollution at the working area is much higher than the environmental imission. Apart from the natural dispersing due to spreading and to the air motion, imission can be controlled to remain below the values prescribed by the authorities by selecting the proper site for the plant, and by the application of high chimneys.

2.2.6. Utilization of the contaminants of the different processes

The mud of Chinese alumina plants processing diasporic bauxites by sinter technology is processed into cement without any waste, in the cement plants. Similarly, the alumina production technology based on nepheline and alunite in the Soviet Union works also without any waste. These will be discussed in the third part.

In case of the Bayer process, the contaminants dissolved in the liquor are removed in the form of the so called soda salt (salt separation process). In the previous times, this salt was either stored up as an unpleasant contaminant or it was dissolved and pumped to the mud pond, thus increasing the environmental hazards. At the present this salt may be the source of some by-products (vanadium, artificial cryolithe, etc.). After their recovery the remaining part is transformed into caustic soda by causticization, thus substantially reducing the soda losses.

2.2.7. Recycling of contaminants

Beside the above procedure, another good example for the recycling of contaminants is that at most of the plants the diluted liquor discharged together with the mud into the red mud disposal area is repumped after settling, into the counter-current red mud washing system. If the permeability of the mud is satisfactory, the pressure of liquor against the soil will decrease, thus bringing about a decrease in the leakage as well. Moreover, the red mud can shrink more quickly, thus decreasing the volume of the mud disposal area.

2.3. Provisions for the control of contaminants

2.3.1 Storage

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- Fuel oil

The storage of fuel oil is not a special problem of the alumina industry; the conditions of storage are generally regulated by decrees. The oil is generally stored in large tanks of proper foundation and the tank is surrounded by dikes or by embankment. The air space thus enclosed must be greater than the volume of the stored oil. In case the oil is transported in container trucks, it may spill onto the road. In order to avoid the skidding of the vehicles, the spilled oil must be covered by sand or by soil. This may simultaneously decrease the danger of fire as well.

- Caustic soda

It generally arrives at the plant in form of 50 per cent solution or in solid form, stored in iron drums. The solution is stored in large, ventilated tanks surrounded by embankment. If necessary, however, it can also be stored in tanks of the technological process (for example in the precipitators). The provisions concerned with this problem are discussed in chapter 2.3.2.

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- Bauxite-alumina

The possibilities of protection against dust formation were detailed in chapter 2.2.5.

- Limestone

Its storage is not problematical from the aspects of environment protection.

- Burnt lime

The prescribed usage of protective helmets and safety goggles has hardly provided any protection against the irritative effects of burnt lime in the past. In the present Hungarian practice lime is transported solely in containers, and it arrives into the silos made of concrete in a closed conveyor belt system. This method eliminates any environment contamination. In the control filtration process, generally lime hydrate forming little dust is used.

- Acids

They are stored in acid-proof tanks provided with ventilation. In the working phases where acid treatment is involved, it is compulsory to use rubber boots and gloves, safety clothing and safety goggles.

2.3.2. Material handling inside the plant

- Bauxite

In case of dry bauxite it may be necessary to carry the bauxite on closed conveyor belts and to apply dust controlling methods at the transfer points: see paragraph 2.2.5.

- Alumina: see paragraph 2.2.5.

- Caustic soda

The caustic soda used for filling up the circuit or making up the soda losses passes all stages of dilution in the plant, from a Na_2O concentration of 500 g/l to 1 g/l.

The principal phenomenon to be controlled is the spillage of caustic soda, since it attacks the concrete and contaminates the subsoil water. The circuit liquor contains Al_2O_3 as well: its precipitation in form of hydrate causes an increase in volume and, in case it flows under the flooring concrete, it is able to raise a sheet of concrete or move the foundation of a pump from its place. The danger of accidents must be taken into consideration in this respect, too. Consequently, neither the closed, covered channel, nor the open channels covered by passage grates proved to be satisfactory for the drainage of liquor spillage.

The best solution is to prepare a floor made of high solidity rupturless concrete, with minimum 3 per cent slope and, at the same time, caution must be paid to the protection of engines, in case of an overflow. The foundation must be made of crushed limestone instead of pebbles because the silica would be apt to dissolution. Dilatation gaps must be filled with bitumen or with plastic.

At the liquor accumulation points of the floor as many waste collecting sumps must be placed as possible, provided with stirrers and, if possible, the liquor must be removed by concealed pumps. Precipitated hydrate (or spilled hydrate slurry) occurring occasionally in the plant sections must be sprinkled by warm spent liquor using a rubber hose, and then the liquor must be washed up by water.

- Burnt lime

Lime is stored in concrete silos and transported to the processing section by closed conveyor belts. It is slaked into lime slurry. In case of lime slurry, the same

prescriptions must be taken into consideration as those related to the caustic soda solution.

- Slag and fly ash

The slag or fly ash of the power plants must be slurried by water and transported into insulated storage ponds. Controlling measures are necessary to prohibit the leakage of acidic water into the soil. In later periods the ponds may be sown with grass, for example by the Verdiol-Hydrosa method.

- Acids

As far as possible, the acid treatment procedures have to be realized in a closed system or in a closed place equipped with exhaustion devices. After cleaning the equipment, the remaining acids must be neutralized before they are drained or pumped into the red mud pond.

- Waters

Alumina production consumes substantial quantities of water, consequently, it is concomittant with the production of waters of varied composition, containing different types and amounts of solid and dissolved materials. Regardless of the water-liquor circulation of the red mud pond (that is discussed in the second part), it may be stated that no excess water is produced in the alumina plant. The spillage of the alkaline water or its leakage into the soil can be prevented by the floor construction method discussed in the paragraph on caustic soda, consequently, it gives no additional problems from environment protectional aspects. Naturally, special measures must be taken in order

to ensure the separation of industrial waters and of the potable waters in the plant, moreover, to keep the latter free of dust, soda or oil contaminants.

- Aerosols

The leakages of liquor pipelines under pressure, the steam of the flash tanks and dilution tanks, moreover, the liquor of the cooling tower produce alkaline aerosols dangerous for the health. This can be prevented by the elimination of spillings, and by supplying the dilution tanks with separate condensers. Cooling towers of forced draught and of smaller volume, located at a distant area of the plant, proved to be more adequate than the ones utilizing natural draught.

- Gaseous emissions

During the processes of calcination, steam- and power generation, gases presenting health risks are produced: SO_2 , CO_2 , CO , NO_x .

The most widespread protective method is the dilution of the emission by discharging the gases through a high chimney where they expand and dilute with the air, thus reducing the concentration of the local imission. The height of the chimney is determined by national standards in each country. The results achieved by this technique can not yet exactly be calculated because, apart from the height of the chimney, the efficiency depends on several local conditions, such as meteorological factors.

Under given conditions (like in case of the Ajka Alumina Plant in Hungary), there is a possibility to switch over from fuel oil to natural gas firing, thus bringing about a significant decrease in gas contamination,

especially in that of SO_2 . Unfortunately, due to the price-explosion induced by the oil crisis, it can generally be experienced that power plants originally based on oil firing turn back to the coal firing method although it has more disadvantages from environment protectional points of view, due to the additional slag and fly ash formation besides the contaminating gases. This must be taken into consideration when determining the height of the chimney.

2.3.3. Noise control

Noise is produced at several sections of the alumina plant, and during several processes: bauxite crushing, grinding, steam blows, air compressors, vacuum pumps and turbines may all cause noise in the workshops. These noises are not so intensive, however, as to cause any trouble for the neighbouring population. Noise protection is of local character: according to its prescriptions, the affected workers must use ear-muffs above a certain noise level, moreover, they are subjected to periodical medical supervision as well. In case of establishing a new alumina plant, it is advisable to introduce a protective zone between the plant and the closest residential area, by afforestation.

2.3.4. By-products

- Gallium

In several plants gallium recovery is based on mercury cathode analysis. Care must be taken to keep the mercury content of the spillages below the allowed level. There are processes eliminating the use of mercury and a switch over to such a technology is being just in progress in the Ajka Alumina Plant.

- Vanadium

Vanadium compounds attack the mucous membrane and the nervous system, therefore, the solutions must be treated in closed, ventillated tanks. Ammonium-vanadate is especially dangerous because its respiration may cause death.

2.4. Measurment of contaminants

2.4.1. Threshold limit values (TLV)

The allowed maximum concentration of the most frequent industrial air contaminants is determined by the public health service authorities, parallely with the value of the maximum amission concerning the nearby residential areas, and these threshold limit values are regularly controlled.

Table 3.

Threshold limit values of materials used in the alumina plants

Material	Working place mg/m ³	Imission average of 24 hours mg/m ³	Hazard
Alumina	10	0,15	Silicosis
Fluorides	1,0	0,01	Attacks the nervous system
Mercury	0,02	0,0003	Attacks the nervous-system and kidneys
Sulphur dioxide	0,008	0,0005	Irritates the respiratory organs

continuation of Table 3

Material	Working place mg/m ³	Emission average of 24 hours mg/m ³	Hazard
Sulphuric acid, H ₂ SO ₄	1,0	0,03	Irritates and attacks the respiratory organs
Nitrosous gases	5	0,1	Attack the lungs
Hydrochloric acid, HCl	10	0,015	Attacks the upper respiratory sections
Carbon monoxide, CO	30		May cause suffocation
Vanadium pentoxide	0,1-0,5		Attack the nervous-system, respiration and blood circulation
Non-toxicating dust	10	0,15	Causes troubles in respiration
Noise (converted to 1000 Hz values)	80 dBA	50 dBA	dBA=noise level measured with "A" type filters, decibel

Source: see ref 2.4

2.4.2. Measuring methods

Measuring of gaseous contaminants

The analysed air is led through an adsorption or absorption system for a long time. The most simple devices used for sample taking are the scrubbers, coupled into series. Impingers, having smaller diameters can be used for the same purpose. In the latter case, the absorbed material is tested by microanalytical methods: volumetric

analysis, photometry, spectrophotometry, polarography, gas-chromatography.

- Measurement of dusts

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- a) Determination according to weight: the most simple method for dust separation is filtration. Generally, filters made of colloid paper are used for this purpose, and the increase of weight within a unit of time is recorded.
- b) Determination according to the number of grains: the dust is separated in a way that later the number of grains can be determined under microscope. In Europe, conimeters are used for this purpose. By the help of a piston pump, 2-5 cm³ contaminated air is pumped into the equipment. At the first stage the air passes through a screen filter keeping up the particles above 50 microns. In the following stage the air is accelerated by passing through a narrow nozzle, and dashes against a glass sheet covered with adhesive, retaining the particles and thus the sample can be evaluated by a microscope of 200 fold magnification fitted onto the equipment. It can generally be used down to the size of 1-2 microns.

The long term imission of residential areas is measured by dust precipitation tests carried out either by devices similar to the conimeters or by dust catching foils. The connection of the measuring points of similar values results in isoconia. Here it is mentioned that the allowed maximum level of dust precipitation at the residential areas must be kept below 150 t/km² year.

- Measurement of water contamination

The contamination of soil water within the vicinity of the alumina plant generally does not exceed the limits of health provision. Systematic control is performed only around the territory of the red mud pond.

The degree of water contamination is generally determined on the basis of the total Na_2O content.

- Noise-level, measurement of noise

The perception of sounds depends on the frequency and intensity. Therefore, such limit-curves were determined that provide the acceptable threshold limit values in the different frequency bands. According to the Hungarian standard, there is no permanent damage of hearing if the octave band spectrum of the noise remains below the so called N 80 curve in each band (this is 80 dBA at 1000 Hz, and the other frequencies converted to this value). At present, the process can be realized by portable noise-level meters equipped with band filters.

The organization of an environment protection laboratory and the principles of monitoring relevant TLVs is described in chapter 5.

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3. BAUXITE RESIDUE (RED MUD)

3.1 Formation and properties

3.1.1 Chemical composition

The waste material of the alumina production based on bauxite processing, named bauxite residue or red mud, is formed during the digestion in the Bayer process or during the sintering-leaching operation in the sintering processes. Both the chemical and mineralogical compositions of red mud are influenced partly by the same of the bauxite processed, partly by the refining technology applied.

In the course of alkaline treatment of bauxite some 76 to 93 per cent of its alumina content is dissolved in the plant liquor and the rest gets into the residue. Silica in the bauxite readily reacts with sodium aluminate liquor, then precipitates in form of sodium aluminium silicates of various composition into the residue. The other main bauxite components, such as iron and titania, remain enriched in the solid phase, and the minor impurities of bauxite, such as gallium, vanadium, phosphorus, nickel, chromium, magnesium etc., can also be found in the bauxite residue.

Sodium and calcium are two major components of bauxite residues usually found only in minor amounts in bauxites and which get into the residue during the refining process: sodium as a desilication product from the reaction of silica with plant liquor; calcium as a chemical for causticization, an additive to digestion, or as one of the components in the mixture to be sintered.

The chemical composition of bauxite residue can vary widely. The range for the major components in muds from the Bayer process can usually be represented as follows:

	Per cent (on dry basis)
Fe_2O_3	25-60
Al_2O_3	5-25
SiO_2	1-20
TiO_2	1-10
Na_2O	1-10
CaO	2-8
L.O.I.	5-15

Significant differences in the chemical composition of bauxite residue coming from the sintering process can be experienced, compared to the above range, in the percentage of Fe_2O_3 and CaO generally ranging from 19 to 34 per cent and 24 to 48 per cent respectively.

Most of components found in the bauxite residue of four alumina plants are shown in Table 4.

3.1.2 Mineralogical composition

The mineralogical composition of bauxite residue plays a great role in forming the mud characteristics influencing its behaviour in the process technology and subsequent storage and/or reprocessing. It is determined partly by the unchanged phases of bauxite, partly by the new phases formed during the refining process.

In the reaction of silica in bauxite with the plant liquor in the Bayer process, depending on technological parameters such as temperature, caustic concentration,

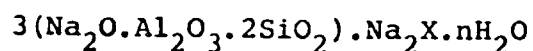
Table 4.

Optical emission spectrographic analyses
of mud samples (per cent by weight)

Element	Kaiser Aluminum (Jamaican)	Alcoa Mobile, Alabama (Surinam-African)	Alcoa Point Comfort, Texas (Surinam-Australian- African)	Reynolds Metals, Hurricane Creek, Arkansas Arkansas
Al	2-4	5-10	3-8	1.3
B	< 0.005	0.005	0.005	0.005
Ba	0.02	0.01	0.01	0.01
Be	< 0.0001	< 0.0001	< 0.001	< 0.001
Ca	5-10	3-6	4-6	20-40
Co	0.01	< 0.005	0.01	< 0.002
Cu	0.02	< 0.005	0.01	0.002
Cr	0.1	0.05	0.1	0.005
Fe	10-20	5-10	20-40	5-10
K	0.03	0.2	0.1	0.3
Mg	0.1	0.03	0.1	0.3
Mn	1.0	0.02	0.4	0.2
Na	0.5	1-3	2-4	1.0
Ni	0.1	< 0.005	0.03	0.002
Pb	0.02	0.01	0.02	0.005
Si	0.8	2-4	2-4	5-10
Sr	0.05	0.01	0.03	0.03
Ti	2-4	3-6	2-4	1-2
V	0.1	0.1	0.03	0.01
Zr	0.1	0.2	0.1	0.2

(Source: see Ref. 3.1)

retention time, solids content and quality, as well as quantity of impurities in plant liquor, sodium aluminium silicates of variable composition (commonly known as DSP, desilication products) are formed according to the following formula:



where X may be CO_3^{2-} , SO_4^{2-} , Cl^- , OH^- , AlO_2^- , etc.

Under certain conditions also TiO_2 of bauxite reacts with the plant liquor forming sodium titanates of various composition.

Iron content of most bauxites remains virtually insoluble in the Bayer plant liquor. It is known that bauxites having a certain amount of their iron content in form goethite usually produce red mud of poor settling and filtration characteristics. Red mud handling equipment, settlers, washers and filters, must be oversized causing excess investment and operating costs compared to the handling of red mud of hematite type bauxites. In such cases various additives, such as CaO , sulphates, chlorides etc. may be charged to the digestion operation. Under controlled conditions goethite will undergo a phase-transformation into hematite as a result of which both settling-compaction and filtration characteristics of bauxite residue will be improved resulting in important savings.

In Table 5. characteristic phase-transformations during the Bayer digestion can be seen.

3.1.3 Specific surface area of red mud

Investigations on the microstructure and morphology of both bauxites and bauxite residues revealed close correlations of certain characteristics with the technological behaviour of the residues.

Table 5.

Characteristic phase transformations during digestion

Bauxite Minerals	Reaction products formed without additives	Reaction products formed with CaO-addition
Gibbsite, Boehmite, Diaspore		(CA) (CA), Al(OH)_4^-
Quartz, Kaolinite, Halloysite	NAS*	CAS**
Chamosite	NAS	CAS
Hematite	$\text{Fe}_{2-x}\text{Al}_x\text{O}_3$	$(\text{Fe}_2\text{O}_3 + \text{Al(OH)}_4^-)$
Goethite	$\text{Fe}_{1-x}\text{Al}_x\text{OOH}$	$\text{Fe}_3\text{O}_3 + \text{Al(OH)}_4^-$
Ilmenite	FeTiO_3	FeTiO_3
Anatase, Rutile	Na-titanates	CaTiO_3
Calcite, Dolomite	Ca- and Mg-compounds	Ca- and Mg-compounds
Siderite		
		CO_3^{2-}
		Fe^{2+}
Crandallite, Apatite	$\text{Ca}_3(\text{PO}_4)_2$	$\text{Ca}_3(\text{PO}_4)_2$
Alunite		
		PO_4^{3-}
		Al(OH)_4^-
		SO_4^{2-}
		Fe^{2+}
Pyrite		$\text{S}^{2-}, \text{SO}_3^{2-}$
Lithiophorite, Todorokite		$\text{Mn}^{2+}, \text{Mn}^{4+}$

* NAS = Na-Al-silicates

** CAS = Ca-Al-silicates

(Source: see Ref. 32)

Porosity of bauxites and red muds, expressed as specific surface area in m^2/g , shows rather definite correlation with settling and compaction properties of bauxite residue.

The specific surface areas of three bauxites and that of the resulting red muds are given in Table 6. It can be seen from the table that bauxite residues have specific surface areas similar to their bauxite. The settling tests performed proved that Jamaican and Brazilian red muds of high surface area have poor settling characteristics. Lower surface area like that of Greek mud results in much better settling and compaction. It can be noticed that high temperature digestion of Jamaican bauxite with hydrogarnet additive resulted in lower surface area. The settling and compaction also improved.

Table 6.

Specific surface areas of bauxites and red muds

Sample	Specific surface area m^2/g
BAUXITES	
Jamaican	22.8
Brazilian	32.5
Greek	6.4
RED MUDS	
Jamaican 250 °C, hydrogarnet addition	22.2
140 °C, 0.5 h digestion	36.0
Brazilian	34.5
Greek	7.3

(Source: see Ref. 33)

Specific surface areas of other red muds are e.g.:

West African	19 m ² /g
Australian	15 m ² /g

3.1.4 Grain-size distribution

The grain-size of bauxite residue from the Bayer process lies in the range of 1 micron to 2 mm. Most residues pass completely the -100 micron sieve, but residues from the refining of bauxites of high quartz content may have a sand fraction of plus 100 micron, up to about 30 per cent.

Table 7. shows the grain-size distribution of two red muds.

Table 7.

Grain-size distribution of two red muds

Mesh size	Micron-size	Per cent by weight	
		Jamaican mud	Alcan, Arvida plant mud
+ 10	+1.680 μm	0	2.0
+ 20	+840 μm	0.2	9.5
+ 35	+420 μm	-	16.5
+ 50	+290 μm	1.0	-
+ 65	+210 μm	1.8	24.0
+100	+149 μm	2.6	28.1
+200	+ 74 μm	-	34.9
-200	- 74 μm	-	65.1
+325	+ 44 μm	4.5	-
-325	- 44 μm	95.5	-

(Source: see Ref. 34)

It is noteworthy that, in case of Jamaican mud about 60 per cent of the 95.5 per cent minus 44 microns

lies between 5 and 44 microns, and some 35 per cent is less than 5 microns in size. This grain-size distribution and the pertinent large specific surface area partly explain the tendency of mud to retain much water.

Bauxite residues of coarser grain-structure give more compacted slurries when settling in ponds and after longer settling period their solids content rise to 50 to 60 per cent compared to fine grained residues, especially when they contain iron minerals in form of goethite, containing only 28 to 40 per cent solids. Red mud from Jamaican bauxites is a characteristic example for the behaviour of fine grained muds.

The grain structure of bauxite residues from the sintering process, in a Chinese plant is as follows (35):

\emptyset mm	> 0.1	0.1-0.05	0.05-0.01	0.01-0.005	< 0.005
wt %	12.5	13.5	44	20	10

3.1.5 Mass and volume of the bauxite residue

The amount of bauxite residue varies in wide range and highly depends on bauxite grade and to some extent on the process technology. A characteristic figure is the amount of red mud referred to one ton of calcined alumina.

The least amount of red mud is produced when refining Surinam bauxites, reportedly 0.3 ton/ton of alumina. Refining of other bauxites produces red muds in the range of 0.8 to 2.0 ton for 1 ton of alumina. Refineries applying the sintering or combined process technology have to reckon with the handling and storage of some 2 to 3.5 tons of residue.

For rough estimations, considering the informative weighted average of the bauxite residues originating from the world's alumina plants refining bauxites of various

grade and using different process technologies, one can say that about 1 ton of dry bauxite residue must be handled and disposed of for 1 ton of alumina produced.

Density of bauxite residues ranges from about 2.7 to 3.2 ton/m³. Taking 3 ton/m³ as a realistic average value, the volume of 1 ton of red mud theoretically would amount to 0.33 m³. In practice the volume necessary to disposal of bauxite residues is much larger due to the high accompanying water content. The amount of this water is highly influenced by the physicomineralogical properties of bauxite residue, by the climatic conditions and by the method of disposal.

Fig. 7 illustrates the change of volume in the function of the water content for 1 ton of dry mud.

Red mud is generally pumped from the plant in form of a slurry of 200 to 350 g/l solids content which settles and compacts to 40 to 60 per cent solids content on the disposal area. In case red mud is filtered, solids content of the cake is about 60 to 70 per cent on the disposal area.

Taking into account some 30 Mt/year of world alumina production, generation of at least the same amount of dry residue must be reckoned with annually. The volume occupied by this residue, in form of wet mud of about 50 per cent solids amounts to about 45 Mm³/year. The storage of this residue in ponds of say 10 m depth, would require up to 500 ha area/year which is often robbed from cultivable land.

3.1.6 Atterberg limits of red mud

According to Lotze (37), over a period of time the water content of red mud in a storage site decreases as the mud consolidates. The change in water content is accompanied by changes in the consistency of the mud from liquid to plastic and to semisolids states. The condition of the mud as it changes from one consistency to another can be defined quantitatively by using Atterberg limits. These are arbitrarily as-

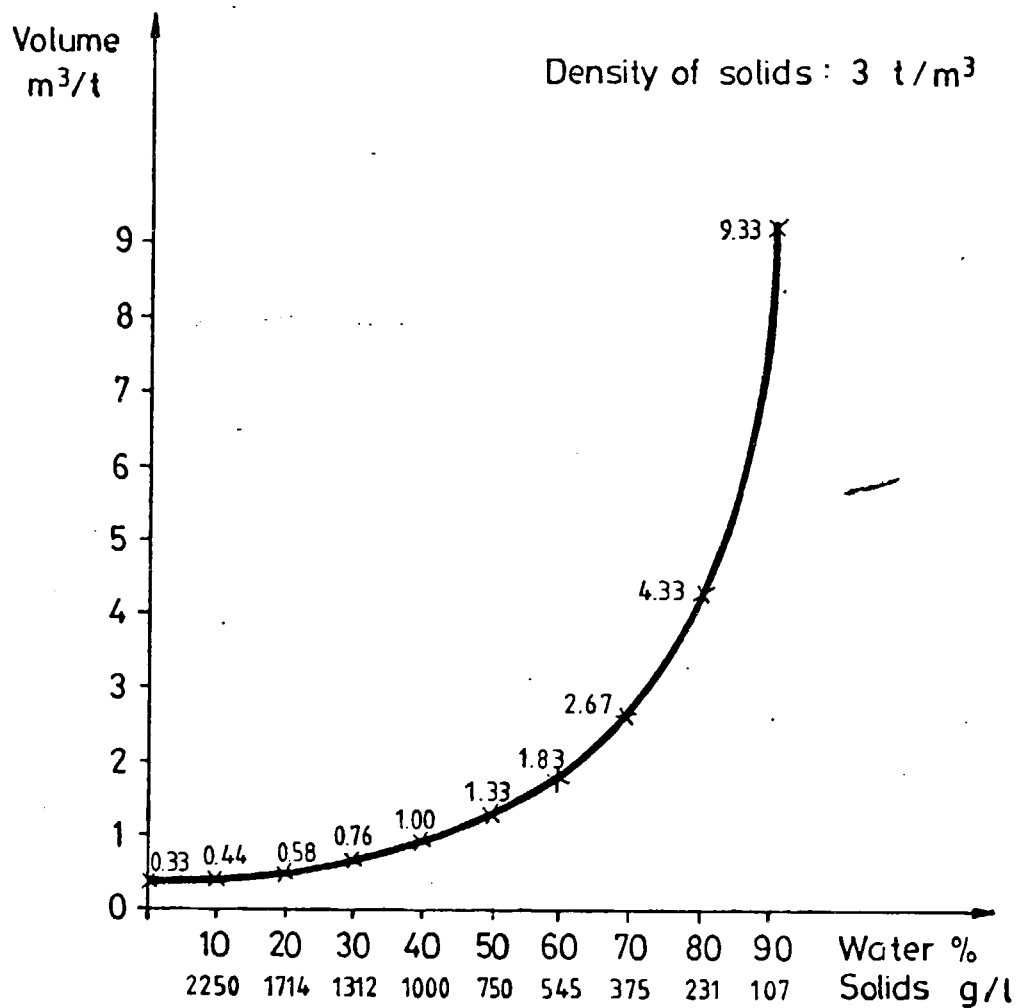


Fig 7

Volume of red mud + water
For 1 ton of dry mud

(Source: see Ref. 36)

signed indices which can be used to establish the water content of mud at its liquid, plastic, and shrinkage limits. In Table 8. the different water contents of the red muds investigated by Lotze are given at the relevant Atterberg limits.

Table 8.

Characterization of red mud using Atterberg limits

State depending on water content	Atterberg limits	Symbol	Water content (w) of wet red mud at Atterberg limit %	
decreasing water content	liquid			
	plastic	liquid limit	LL	37 ± 5
	semisolid	plastic limit	PL	27 ± 5
	solid	shrinkage limit	SL	22.5 ± 1.5

(Source: see Ref. 3.7)

It can easily be calculated that in case the bauxite residue is pumped to the storage area in form of a slurry of say 300 g/l solids content, this amounts to about 3.33 m³ slurry per ton of residue. If it settles to 60 per cent water content, it will need a volume of about 1.83 m³/t. In case the residue is filtered its water content is usually about 45 per cent, corresponding to 1.15 m³/t. Dewatered on site it would reach a final consolidation stage of 25 per cent water content after decades - a value close to the shrinkage limit - and its volume would decrease to about 0.66 m³/t, i.e. about 20 per cent of the pumped slurry volume.

Stinson (38) demonstrated that the extent of settlement and rate of consolidation of a given red mud may be predicted. Differences in consolidation properties correlate with the moisture content at which the various muds change from liquid to plastic state as indicated by the Atterberg liquid and plastic limits. Coefficients of volume compressibility, consolidation and permeability all can be calculated using LL and PL as parameters.

3.1.7 Liquid phase accompanying the bauxite residue

The liquid phase of the bauxite residue in the digestion process is the extracting liquor of high caustic and alumina concentration. This liquid phase also contains a number of impurities in various concentrations.

Washing of bauxite residue in the process technology is aimed at recovering most of the caustic and alumina content of the liquid phase. The liquid phase entrained by the bauxite residue to be disposed has virtually the same components as the plant liquor but in much lower concentrations.

The main components of the liquid phase of bauxite residue to be disposed are the following:

Na ₂ O total	0.6 to 8.0 gpl
Na ₂ O caustic	0.5 to 6.0 gpl
Al ₂ O ₃	0.5 to 3.0 gpl

Depending on the method of storage an important part of these values may be recovered.

Other components, such as calcium, magnesium, vanadium phosphorous, sulphides, chlorides etc. are found in max. a few hundred mgpl concentration in the liquid phase.

3.2 Handling of the bauxite residue in the process technology

In the first stage of the process technology bauxite is comminuted to a certain fineness primarily determined by the hardness of bauxite. Processing of hard diasporic bauxites requires a milling product of minus 60 micron in order to reduce the wearing effect of slurry and provide sufficient digestion efficiency.

Soft bauxites require no such fine grinding, therefore the grain-size range of milling product is much wider and often has a coarse fraction of plus 1 mm, too.

In the course of digestion, due to the extraction of alumina minerals, formation of desilication product and multi-stage flashing, the grain-size of bauxite residue is further diminished, but it is only slightly changed during the subsequent operations.

The solid and liquid phase have to be separated in the following stage. In case the bauxite residues contain coarse sand fraction, the latter is separated first from the diluted slurry. The removal and separate handling of the sand fraction make possible the trouble-free operation of settling, washing and filtration of fine mud. This sand fraction is mixed later to the residue to be disposed of resulting in a higher final solids concentration on the waste area, and a looser structure of the solid waste increasing its permeability. The main object of the handling of bauxite residue separated from sodium aluminate liquor is to minimize caustic and alumina losses in the liquid phase. It is performed by settling the residue and washing it with hot water, usually in a counter current washing-thickening system of 4 to 7 stages. Then bauxite residue is discharged in form of slurry with 18 to 28 per cent of solids and disposed of on land. In this case a two-way connection can

be developed between the plant and the red mud disposal area. Most of the liquid phase may be returned to the plant and reused as make-up water for red mud washing or as other process water, reducing at the same time both the fresh water and make-up caustic consumption. If bauxite residue is disposed of in sea or is neutralized in mud lake by seawater, return water cannot be used in the process, only for eventual dilution of the last washer underflow slurry.

Mud filtration is usually practised when bauxite residue has good filtrability, which can be somewhat improved by lime addition. The remaining caustic in the washed filter cake amounts to about 0.5 per cent Na_2O referred to dry mud weight. Generally two to four washing stages are used prior to filtration.

When dry mud disposal method is used or the bauxite residue is to be reprocessed, the maximum possible dewatering of residue is required. In this case, vacuum or pressure filtration of red mud slurry is indispensable.

3.3 Disposal of bauxite residue

Various methods have been worked out for the economic utilization of bauxite residue, however, no final practical solution has been found so far. Therefore tailing of bauxite, red mud is considered nowadays as a useless waste of the alumina production, and its disposal causes difficult environmental problems everywhere. Alumina plants are generally storing their red mud in impoundment areas, called red mud ponds, but the storage methods differ from one plant to another and the majority of them are still considered as environmental offences.

Possibilities of red mud disposal can be divided in two main groups:

- disposal on land, and
- disposal in water

Advantages and disadvantages of both main groups from the point of view of both economy and environmental protection will be treated separately.

3.3.1 Environmental compatibility

It have become clear during the last decade that the tasks of the environmental control can not be separated, they have to be treated in entirety. The time-to-time and local upsetting of the biosphere can only be controlled, respectively, counter-balanced or prevented by considering the correlation and interaction of processes taking place within the earth, water and air space. This way of complex thinking should also be adopted with the alumina production particularly in solving red mud disposing problem.

The environmental aspects to be considered in the course of siting an alumina plant had already been dealt

with by several authors and in many ways. A good review is obtained from the check-list prepared by the IPAI Environmental Committee in 1977 for the analysis of the environmental factors and their interaction.

3.3.2 Disposal on land

3.3.2.1 Selection of suitable site for disposal area

A red mud disposal area built and operated suitably has to meet the requirements of safety, environmental protection - first of all protection of underground water quality - disposal capacity and economy. Soil and hydrogeological problems and the requirement of the technological process of the alumina plant are to be taken into consideration. As a consequence a very close co-operation of the professionals (technologists, soil investigators, hydrogeologists, civil engineers, etc.) is needed.

Under favourable conditions the disposal area is located in the close vicinity of the alumina plant, thus minimizing the transportation costs of red mud. However, some protective distance between the plant and the disposal area is to be taken into account in order to meet the regulations of the environmental control.

For site selection, data of previous investigations, such as topographic, hydrologic, geologic, seismic, meteorologic and soil investigations, further data about agricultural value of the selected area and possibility of land use are needed. Regional development plans and regulations of the government and authorities have to be taken into consideration. For the time being in almost every country of the world development plans or drafts are available for the social and industrial development of various

con-

regions, further on the environmental protection and natural conservation areas. Water economics plan of the region, availability of building and construction materials, capacity of contractors and permitted emissions in natural receivers (river, lake, sea or underground water) are to be well-known to the designer.

Several alternatives are to be analysed for selection considering the principles mentioned previously. The final site and construction of the red mud disposal area is to be selected on the basis of technical and economical calculations, however, in accordance with the regulations of the authorities and of the customer as well.

When the final site is (or alternative sites are) selected detailed investigations and calculations are to be done. Maps in a scale of 1:5,000 to 1:20,000 and with contour lines of 1 to 10 m depending on the type of the region are needed in order to investigate the detailed topography of the areas.

Air photogrammetric data can be used as well. Detailed soil tests have to be made to evaluate the permeability and other characteristics of the bottom. In case of a mud area of big capacity a very detailed investigation is needed so as to ensure the preparation of a safe but economical plan. The plan has also to cover all requirements of technology and water economics.

Selection between the alternatives is a complicated work and also needs close co-operation among the technical and sociologist experts.

Various authorities take part in most countries in the decision about regulations for the protection of water quality and environment. Such are the authorities of fishing, revegetation, natural conservation, forestry, agriculture, public health, etc. Authorities generally

require to operate the disposal system in a closed circuit in order to prevent water run-offs from the disposal area into the living or underground water. Wells are suggested to be sited around the disposal area for monitoring seepage and accidental contaminations of underground water.

Complying with these regulations increases the costs of red mud disposal. By all means these costs are to be regarded as a necessary part of the capital and operation costs of the alumina production.

In the following all important factors to be taken into consideration during the survey, engineering, construction and operation period will be treated in detail. Such are the main types of the red mud disposal areas together with their advantages, and disadvantages, problems of sealing the disposal area, instruments and measuring methods to be used during both the construction and operation period.

During the construction period of the alumina plant it would be neither economical nor expedient to build a red mud disposal area for storage capacity of 20 to 30 years considering the significant capital costs involved. Therefore, red mud disposal areas are built gradually, first for say 6 to 8 years and later extended parallel to the alumina production. In the next phase of disposal area's expansion or construction all experiences collected during the first operation period concerning filling technology, water economy, building and sealing etc. can be used in order to attain a more suitable and economical solution.

3.3.2.2 Methods of disposal on land

The most suitable type of disposal to be used is determined by the local circumstances. The main types are as follows:

- disposal on an area surrounded by dikes
- disposal in a valley with barrage
- stacking of red mud after filtration
- disposal in excavation of mines no longer in use.

Disposal area surrounded by dikes

Red mud is transported as slurry from the plant to the disposal area. If no valley or natural basin with a sloping bottom can be found at an economical transporting distance from the alumina plant, the disposal area can be sited on the available flat terrain. In any case a suitable artificial slope of the bottom has to be provided. Disposal area is to be surrounded by dikes of 6 to 10 m height. Dimensions of the disposal area are calculated on the basis of yearly red mud quantity, its moisture content and the foreseen duration of disposal. Impoundment areas up to 800 hectares are in operation. According to experiences the solids content of settled wet red mud - because of difficulties involved in its drying out - is 50 per cent as a maximum, the minimum volume requirement related to 1 ton of solid material is about 1.3 m^3 .

Supposing 1:1 red mud to alumina ratio an alumina plant of 900,000 tpy capacity would require an area of about 350 hectares for a disposal period of 20 years, i.e. about ten times the area of the plant itself. This would raise capital costs considerably.

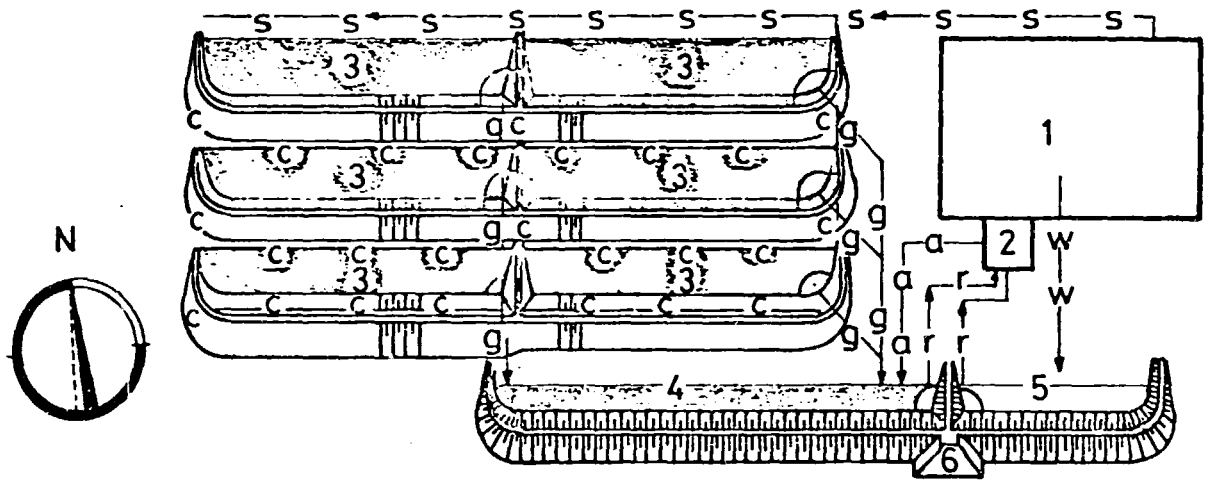
Therefore, it is suggested to distribute the total planned disposal area into chambers and to build only one or two chambers in the first phase of operation.

Another advantage of dividing disposal area into chambers is that the chambers can be filled up cyclically in thin layers of say 10 cm, the chambers filled up can dry

out in the air: so called shallow DREW system. Dikes separating the chambers can be constructed from permeable material, thus liquor filtered through can be collected on the lowest point of the area and recycled to the plant.

An example is shown in Fig. 8. The selected disposal area has uniform slope of 6 to 7 per cent southwards. The impermeability of the original soil is so high that it should not be excavated. The red mud area is distributed into six wide chambers on three rows of two each as a first construction phase of the envisaged red mud disposal as a whole. One chamber is calculated for a year. The frontal dams of the four northern chambers are permeable while the dams of the two southern chambers must be constructed with an impermeable clay core. In these outer walls a sand layer with permeable drainage pipes is also incorporated. The outer side dikes are to be sealed, while the center dike is permeable. The slurry, when flowing down the slope, is able to discharge as much water as possible. This water will be conducted away from the storage area. The slope of the chamber ensures that slurry will flow over a dry surface for a long time and the sedimentation of material of greater specific weight will start immediately, while smaller particles will take a longer time to separate from the water flowing at the bottom. The volume of water led away by the underground drain can be replaced by the solid matter within the slurry. On the crown of the dams a circumferential pipeline is located to facilitate the even distribution of red mud. In this way the chambers can be filled alternately enhancing the water discharge and the desiccation of the mud layers. The solid material settles gradually and water flows by gravity towards the deeper areas. There the submerged drain pipes are replaced by filter-dams (i.e. stone-heaps)

- S — slurry transporting pipe
- g — gravity flow returnwater pipe
- r — returnwater feed pipe
- c — circumferencial pipe for red mud
- a — gravity flow alkaline contaminated water pipe
- W — gravity flow rainwater from the alumina plant



1. Alumina plant
2. Water works
3. Red mud / storage ponds / disposal area
4. Emergency pond storage for alkaline-contaminated water from the alumina plant
 - for rain water from the red mud storage, and
 - for returnwater from the red mud storage
5. Emergency pond: storage for pure rainwater from alumina plant
6. Pump and filter station

Fig 8

Technology of red mud storage before completion

(Source: see Ref. 3,10)

constructed at the southeastern parts of the chambers. From here water will be recirculated into the alumina plant.

If red mud contains grains above 60 micron size (sand) in a significant quantity, this fraction can be separated by hydrocyclones and used to the construction of these intermediate dikes.

Surrounding dikes themselves can be built in more phases. In the beginning an initial dike of 3 to 4 m height is to be built with a good impermeable construction. Later on this dike is to be heightened up to the necessary or possible height in more phases following extension of the disposal area (see Fig. 9.).

In order to ensure the stability of the dike and to collect contaminated seepage, a drainage system is to be constructed inside the extended dike. This drainage leads off water still penetrated through the initial dike thus protecting stability of the retaining dike built during the extension work on the external side of the initial dike. This drainage system consists of back-blanket and collector drains. Water will be collected on the lowest point of drainage and can be recycled to the alumina plant.

Experiences collected about dike construction and operation during the first phase can be used for revision of the filling system, dike construction, etc. in order to ensure a more economical and technically correct solution and improved water balance for the alumina plant. Therefore, from the start-up on and during the normal process operation a diary is to be kept about various data such as: changes in the water level of the disposal area, quantity of rainfall, evaporation ratio and return water quan-

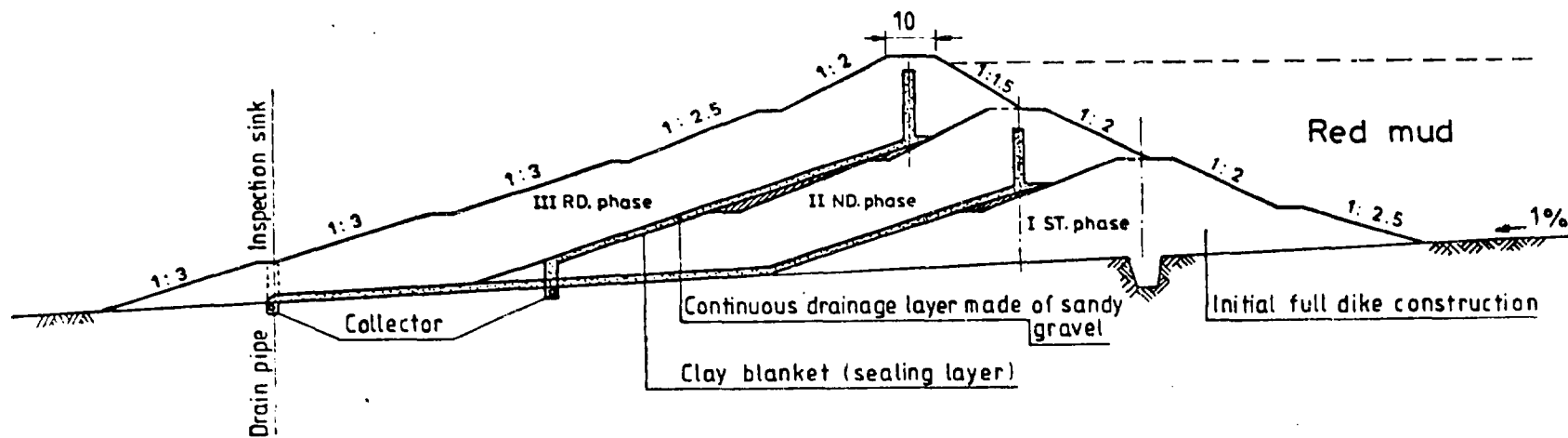


Fig 9

Model section of dam

(Source: see Ref. 3.10)

tity. On the basis of these data modifications can be made in the further dike construction and operation of the red mud disposal area, respectively.

The inside slope of the dike is to be protected from water rolling caused by the prevailing wind. Protective stone-pavements can be built or a suitable foil-type can be used. The external side is to be covered by a humus layer and planted with grass to avoid erosion. At the foot of the dike a ditch is to be built so as to conduct away rainwater.

A circumferential pipeline is to be located on the crown of the surrounding intermediate dikes in order to facilitate even distribution of red mud slurry and cyclical filling. The place of slurry inlet and return water outlet must not disturb each other.

Red mud can be settled most successfully in undisturbed, stagnant water free from any outer influences. The slurry loosing its kinetic energy also loses its ability to carry silt and so the latter settles down. If there is enough surface area and enough time given, even the finest silt particles will settle, too. The extent of settling surface is to be calculated on the basis of settling properties of mud. In case of too fine mud of poor settling properties the necessary settling surface can be decreased by increasing the duration of settling using the cyclical system mentioned above. Clarified water has to be pumped back to the alumina plant, so as to ensure the possibility for settled mud layer to dry out in air. This solution needs more capital cost and a strict discipline in the technological process, but it is worth realizing because the water balance of the plant can be ameliorated and the maximum quantity of solid material will be stored within a given volume of the disposal area. So as a consequence of the more favourable ratio of solid material and water the storage

capacity of the red mud disposal area can be used for a longer (even double) duration.

Dikes of disposal areas are normally built of earth. However, dewatered or lime-stabilized red mud too can achieve the high material strength generally required for dam construction.

The strength of soil as building material is best quantified by means of its shear strength - given by the friction angle ϕ - and by the cohesion c . As shown in Figure 10 the red mud shear strength which is zero above the liquid limit (LL), grows steeply as water content decreases. For a red mud e.g. with a water content lowered to $w = 33\%$, i.e. close to its plastic limit (PL), a friction angle of $\phi = 34^\circ$ is obtained. Consequently, with a sufficiently dewatered red mud the shear strength of natural cohesive soils and of sand materials can be reached.

The steep increase of the other important property, cohesion c of red mud, as its water content is lowered, is shown in Figure 11. Values obtained are absolutely comparable to those of natural building materials.

By lime-stabilizing of freshly pumped red mud, the cohesive strength of the mud is greatly increased to $c = 100$ to 200 kN/m^2 and exceeds by far even commonly known values for natural cohesive soils.

Overall conclusions are that red mud dam construction is technically safe and environmentally acceptable. All requirements regarding dam stability can be met.

Furthermore, the use of red mud for dam construction significantly reduces land requirements. There is a cost saving since no other dam building materials will be needed.

If the power station of the alumina plant uses coal as fuel, it is suggested to use that sort of coal, the ash of which has good hydraulic binding capability, for dike

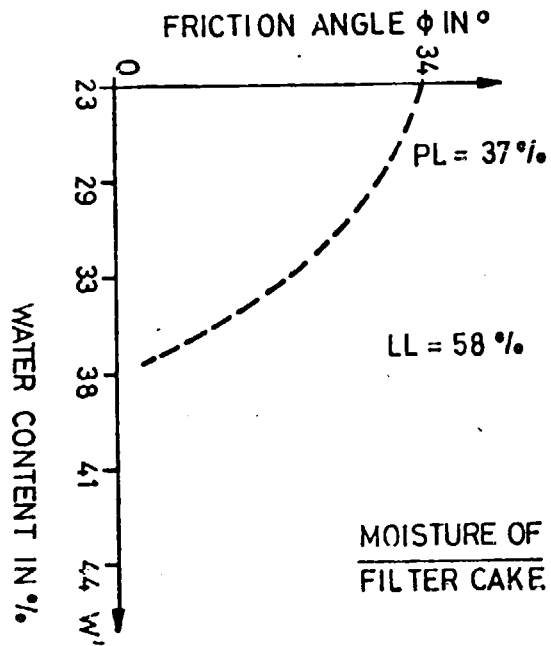


Fig 10

Angle of friction of red mud

(Source: see Ref. 37)

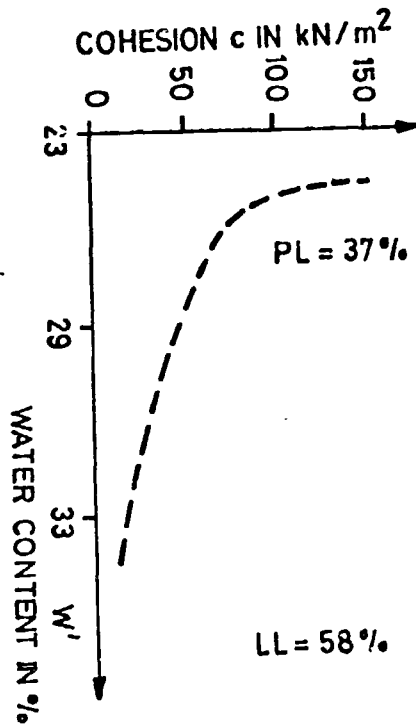


Fig 11

Strength of cohesion of red mud

(Course: see Ref. 3.7)

construction. Ash will be delivered by a hydromechanical system from the power station to the red mud disposal area: first relatively low longitudinal parallel dikes are to be constructed from some other material then the intermediate space is filled with ash (the so-called "grey mud") slurry. Transport water is to be recycled to the power station to be used for slurry transport again. Grey mud settles and solidifies in a short time (a few days) and so the dike construction can be continued in this way first on the top level of the initial dikes then further, until finally, the required height of the dike will be built. This dike heightening can be built fully from ash, if the required quantity is available. This solution is economical because a sort of tailings can be used as a productive material replacing building materials of the dike constructions.

Deep DREW system is considered as a special example of disposal area surrounded by dikes used e.g. by Kaiser Aluminum and Chemical Corporation for its Gramercy plant, Louisiana, USA. This system is a combination of decantation, drainage and evaporation. A sand drainage blanket is installed beneath the red mud disposal area. Consolidation that can be achieved is over 50 per cent solids and reclamation of impoundment area is feasible. Even alumina plants with red mud of coarser grain-size containing sand (e.g. Alcoa of Australia, Pinjarra Plant) have adopted this method. It is obvious that in case of coarser red mud the advantages enumerated under 3.2 are more significant. VAW has developed even further this system as it will be seen later.

As a general conclusion red mud must not be kept under water or in contact with water. Possibility shall be given to its shrinkage and natural drying. Evaporative drying is normally less expensive, than filtration, but the latter has its advantages, too, in certain cases.

Disposal areas at the same time can serve as receiver of other streams from the plant, such as condenser water, treated sanitary waste effluents, effluents of acid cleaning, etc. This can also ameliorate water balance and decrease caustic soda losses of the plant.

An up-to-date method is disposal of deep thickened tailing, as planned by Alcan in Canada. A combination of deep thickening and division of disposal area in a number of small units has been worked out at Jamalco, Jamaica.

Types of sealing

Seepage of contaminated water from the red mud disposal area first will fill the gaps of soil and then, reaching the level of underground water, will move in its flow direction. So a permanent contamination will originate from the seepage of red mud area.

Solid and hydrogeological investigations have to determine characteristics and permeability of the soil layers and movement of underground water. On the basis of data of these investigations and considering the regulation for environmental protection the required degree of sealing of the disposal area can be determined in order to prevent contamination of aquifers, through which near-by living waters (rivers, lakes, etc.) would be contaminated as well. During the investigation period monitoring wells are to be located on the selected disposal area and its environment in order to observe level, flow and quality of underground water periodically. Data from monitoring wells will give informations about changes of water quality during the preliminary investigation, construction and operation periods of the red mud area.

Considering various technical architectural, technological and economical points of view together with local

circumstances and capacity of contractors the suitable type of sealing construction can be selected from possible alternatives on the basis of data mentioned beforehand.

The sealing of the red mud disposal area can be constructed in various types as follows:

- compaction of the surface layer of the original soil,
- construction of a clay-blanket,
- sinking of underground water level by filter-wells,
- sealing with plastic foil,
- sealing with consolidated red mud,
- bentonite sealing,
- bituminous cement stabilization.

Compaction of the surface layer of the original soil

Experiments proved that permeability of various sort of clay-layers of 0.5 m thickness after some terrain correction and compaction work is as follows:

- lean clay or brown humous mud: 10^{-5} cm/sec,
- rich or brown humous clay and rollable yellow mud:
 10^{-7} cm/sec.

Test have to be made with the original soil of the selected area. If the original top layer of the disposal area is clay with a thickness of minimum 1.0 m and the tests give acceptable results (permeability factor 10^{-6} cm/sec as a maximum) the original top layer of soil can be used as bottom of the red mud area after compaction, in consequence of which impermeability of the bottom can be increased and it will be more steady.

Work-phases of the compaction are the following:

- deforestation and eradication, removal of vegetation
- removal of humus
- extirpation of weeds by chemicals

- necessary terrain corrections with addition of clay-layer where needed
- compaction of the layer up to a relative compactness of 90 per cent.

Depending on bauxite quality colmation of the soil by red mud can be taken into account, too, when calculating its permeability.

Construction of a clay-blanket

This solution can be suggested, if

- the original top layers of the selected area are not suitable for sealing even by compaction and
- impermeable clay is available in the environment.

According to experience normal and rich clay-layer of about 60 cm thickness with an optimum water content of 18 per cent and relative compactness is able to ensure a permeability factor of 10^{-7} cm/sec. Consequently the quantity of alkaline contaminated water seepage would be about 8.6 m³/hectare day. This value is acceptable if the soluble Na₂O-content related to solid dry mud does not exceed 0.8 to 1.0 per cent.

Work phases of the clay-blanket sealing are as follows:

- deforestation and eradication, removal of vegetation
- removal of humus
- extirpation of weeds by chemicals if needed
- necessary terrain corrections
- compaction of the original top layer (up to a relative compactness of 85 per cent)
- clay-blanket sealing

The clay-blanket is to be constructed from 3 layers of 20 cm thickness each both on the bottom and the sides of the disposal area. Each clay-layer is to be compacted separately.

The normal and rich clay is hard to be compacted, therefore, work has to be done with thoroughness. Deviation from the optimal water-content can be ± 5 per cent. During construction work optimal water content of clay is to be taken into account independently from weather. Consequently in some cases clay must be dried and in other case wetted in order to ensure the suitable water-content. The required 90 per cent value of the relative compactness is to be controlled permanently as well. Because of these circumstances construction work of a clay-blanket sealing needs a relatively long duration.

Sinking of underground water level by filter-wells

In some circumstances contamination of underground water can be decreased by location of filter-wells surrounding the disposal area for sinking underground water level. Depression produced by the wells is able to influence the flow direction of underground water and contamination will be diluted in the water.

Contaminated underground water can be pumped from the wells to supply the alumina plant.

Sealing with plastic foil

In several countries red mud disposal is to be sited on karstic limestone. In this case probability of contamination of underground water reserves and living waters is very high, as a consequence of the great permeability of

soil. If clay of acceptable quantity were not available in the region, sealing with plastic foil proved to be a technically good, though expensive solution. (Mostar, Yugoslavia) Various sorts and types of plastic and rubber foils are available commercially. Informative data about the characteristics of foils are as follows:

- thickness 1.2 to 3.0 mm
- weight 1.5 to 3.0 kg/m²
- tensile strength 100 to 200 kg/cm²
- water permeability 0.05 to 0.10 lit/m² day

The work phases of sealing are as follows:

- from deforestation to the compaction of the original top layer the same as those of clay-blanket sealing
- laying of foil, connection of foil-strips by sticking or vulcanization
- fixing of foil on the slope of embankments and crown edge of dikes
- soil covering of 30 to 40 cm thickness as a protective layer.

Strips of foil are to be overlapped and stucked or vulcanized according to the prescriptions and specifications of the manufacturer with special materials and process.

Sealing with consolidated mud

Consolidated red mud of minimized water content excavated from disposal areas no longer in use can be used instead of clay as an economically and technically suitable construction for sealing of new chambers of the disposal areas. Construction and compacting of mud layers are to be done similarly to that of the clay-blanket sealing.

Current VAW practice is as follows:

- Red mud, without additives for solidification, is deposited over a period of a half to one year in those sectors of the storage area available for use.
- A special type of scraper is then used on the surface to recover the mud in thin layers (this is best done in the dry season of the year or in frosty weather).
- The red mud is then transported to a dam construction site where the mud is compressed statically. The optimum water content of red mud for dam construction is close to the plastic limit. Coefficient of permeability is between 1 and $2 \cdot 10^{-8}$ cm/sec.

At one of the disposal sites operated by VAW, where no consolidated red mud or other suitable material for constructing the lowest dam was available, lime-stabilized red mud was used as the construction material. The addition of lime to red mud increases hydraulic stability and improves its cohesion. Coefficient of permeability: $20-25 \cdot 10^{-8}$ cm/sec.

Bentonite sealing

Bentonite, a milling product more coarser than cement, is dispersed in water in order to form a suitable suspension. Its permeability factor is 10^{-7} to 10^{-9} cm/sec surpassing that of clay.

According to experience bentonite is resistant against alkaline, but will become crumbled after drying and its sealing ability decreases.

This type of sealing can be used where bentonite is available in the environment of the disposal area and the original top soil layer mixed with bentonite produces

a suitable good impermeability similar to that of a clay-blanket. Therefore, in all cases tests and investigations have to be made in order to determine the suitable mixture ratio for the required impermeability and the technology of the construction work. To prevent drying of bentonite it is suggested to cover the finished layer of bentonite-soil mixture with a protective soil-layer and to build the sealing construction just before beginning of filling. The work phases of the construction and compaction of the mixed sealing layers are similar to those of clay-blanket sealing.

Bituminous cement stabilization

This type of sealing can be suggested if

- the original top layers of the area are thin clay or sandy clay-layers and their impermeability is not satisfactory even after compaction
- clay or bentonite are not available in the environment.

The original top layer of the area is to be mixed in a thickness of 15 to 30 cm depending on the original permeability with about 7 per cent bitumen and 4 per cent cement as stabilizers. This work can be done by agricultural engines. Finally compaction is needed.

Tests and investigations are to be made before the construction work in order to determine the correct mixture ratio of the stabilizers and the suitable thickness of the soil layer to be stabilized.

Disposal in a valley with barrage

If a valley (or valleys) of suitable capacity can be found in the neighbourhood of the alumina plant it is expedient to use this valley for red mud disposal, closing it crosswise by barrage(s). Other favourable circumstances needed are as follows:

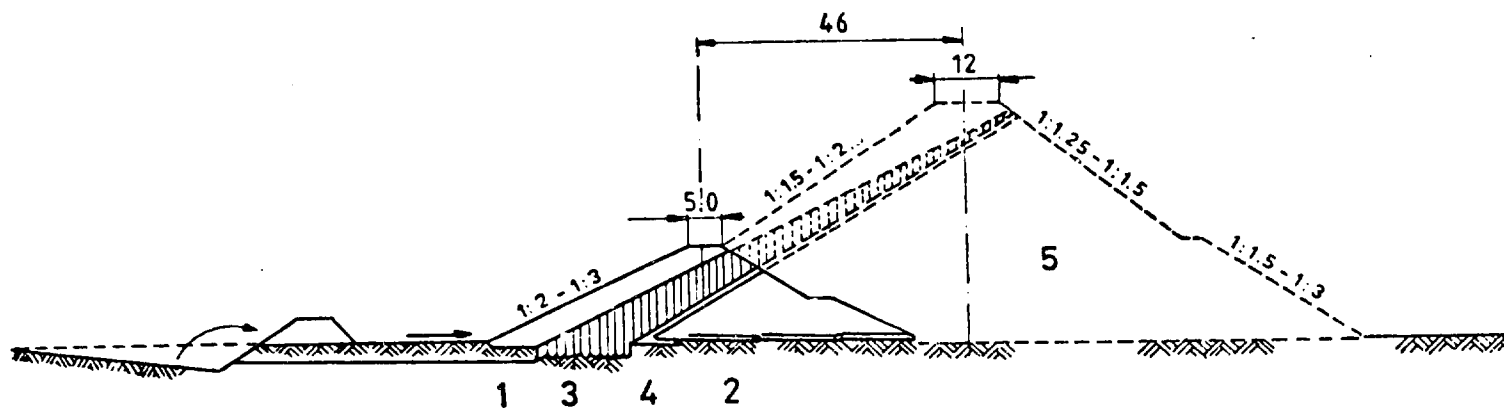
- natural slope of valley bottom
- possibility of control of surface waterways
- contamination of the water-currents may be prevented
- the height of barrage makes a safe embankment possible
- the barrage is not endangering buildings, human settlements, etc.

In order to ensure the correct engineering design work for the project, preliminary tests and investigations of various circumstances have to be performed such as:

- hydrogeological conditions
- sections of soil and rock layers
- permeability of soil and rock
- bearing capacity of the various layers
- available building material for barrage construction
- seismicity
- climatic conditions
- defectiveness of the bedrock (fissures, faultages, prints of earlier rock-slips)
- the design has to meet all regulations for the protection of water quality.

As regards valley bottom, the required investigations are the same as mentioned in para 3.2.1. Further investigations to be done depend on the calculated height of the barrage and the general feature of the sections of soil and rock layers. Where the sections show irregularities, an important task is the determination of differences between the various soil and rock samples. Soil tests must be made from the envisaged level of barrage foundation down to a depth one and a half deeper than the width of the barrage-foot. With the aid of prospect holes excavated on the region the kind of available building materials (stone, earth, rubble, etc.) can be determined. Suitable earth and stone material can be produced by neighbouring mines in the course of removal of the overburden. Also terrain correction of the alumina plant can produce a big quantity of building material when sited on a hilly terrain with a natural slope. In this case it is expedient to avoid the balance of filling and cutting in the terrain correction in order to diminish foundation costs and to give building material for the barrage and dams from the surplus cutting. If also clay-layer exist on the plant area this can be stockpiled separately as sealing material.

During the plant operation the granules of red mud of minimum 60 micron size can be separated by hydrocyclones for heightening of the barrage. If the mud is too fine, the barrage as a whole is to be built from stones with covering materials. On Fig. 12 a typical barrage-section built from rock rubble can be seen. If stone, earth and rubble originated from mines or from terrain correction of the alumina plant are available, the barrage can be built with similar technology as a barrage of a normal natural water reservoir. This solution is advantageous especially on areas endangered of high seismicity when the

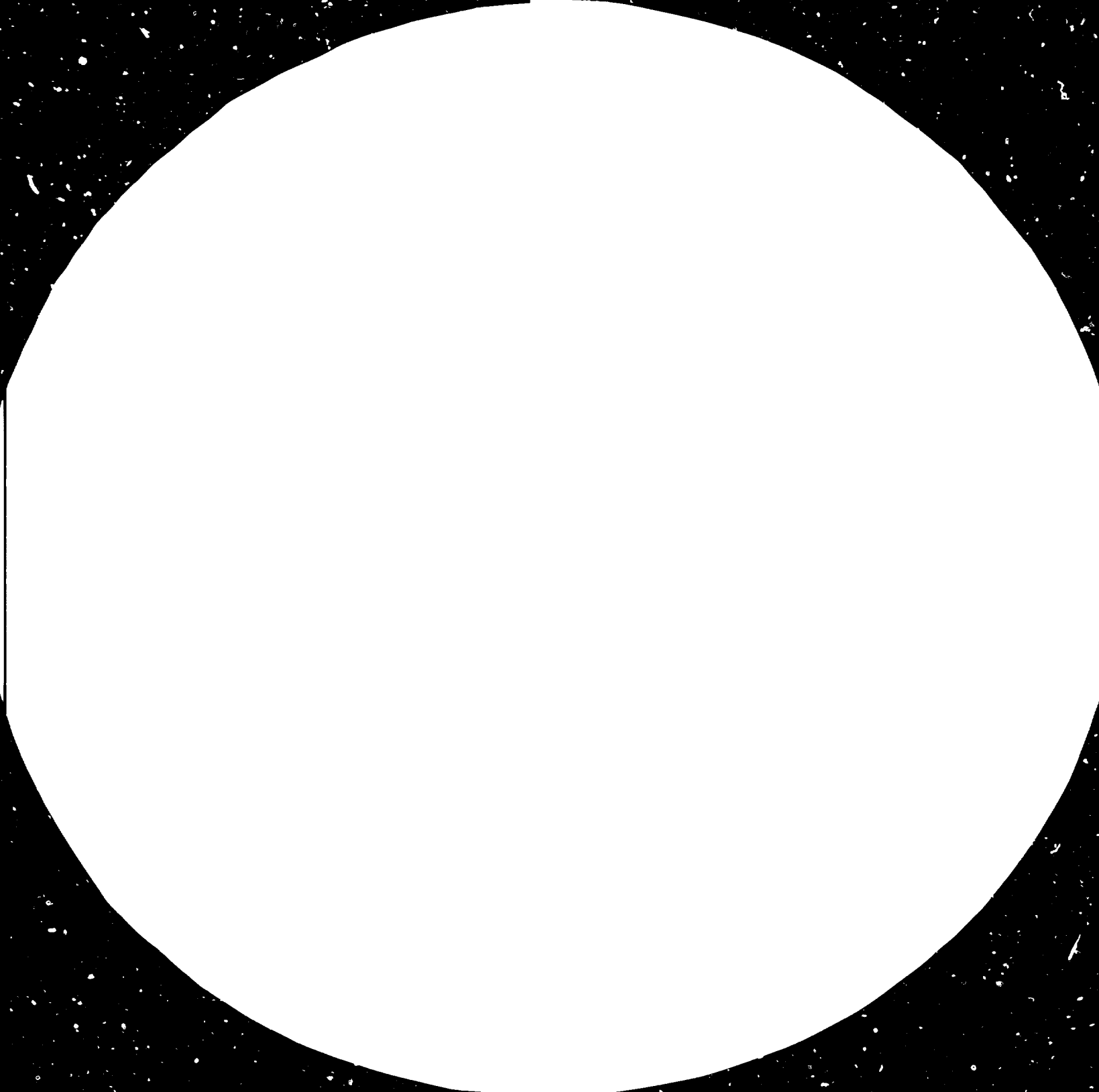


1. Debris + clayey earth
2. Rock rubble
3. Clay core
4. Sandy gravel layer
5. Hydraulically colmated stone heaps

Fig 12

Typical barrage section - No.1

(Source: see Ref. 310)





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25

32

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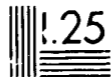
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barrage is to be calculated on the basis of seismic forces.

Several intermediate filter-dams (without sealing) are suggested to be built in a direction of right angles to the longitudinal center-line of the valley so as to increase the efficiency of clarification of return water. By this construction a stagnant back-water will originate uphill before the filterdam with a suitable settling surface and red mud can settle on the terraces formed by the dams.

The disposal area is surrounded by the barrage (on the lowest part of the valley and also on the highest part, if the slope of the valley-bottom is moderate) and sideways by the original, natural valley-sides. A big volume capacity for the disposal area can be formed without increasing the valley-sides crosswise, if dikes are built on both longitudinal sides of the valley following the highest contour-lines, or terrace-like, using the topographic circumstances. As regards construction, these dikes could be built up to a height of 8 to 10 m from sandy-clayey earth excavated from the bottom of the disposal area in a way that the lower one-third of the dike should be formed by the cut from the bottom layers and the upper two-third from the excavated earth. As a consequence of this construction the volume capacity of the original valley could be enlarged. If the original, natural bottom-layers had a suitable impermeability as a natural sealing, the dikes, of course, may not be built from this material. Further construction and heightening of the dikes can be built either from the granules of red mud of minimum 60 micron size separated by hydrocyclones (if these fractions are in a significant quantity) or from building materials, mentioned previously, available from the region.

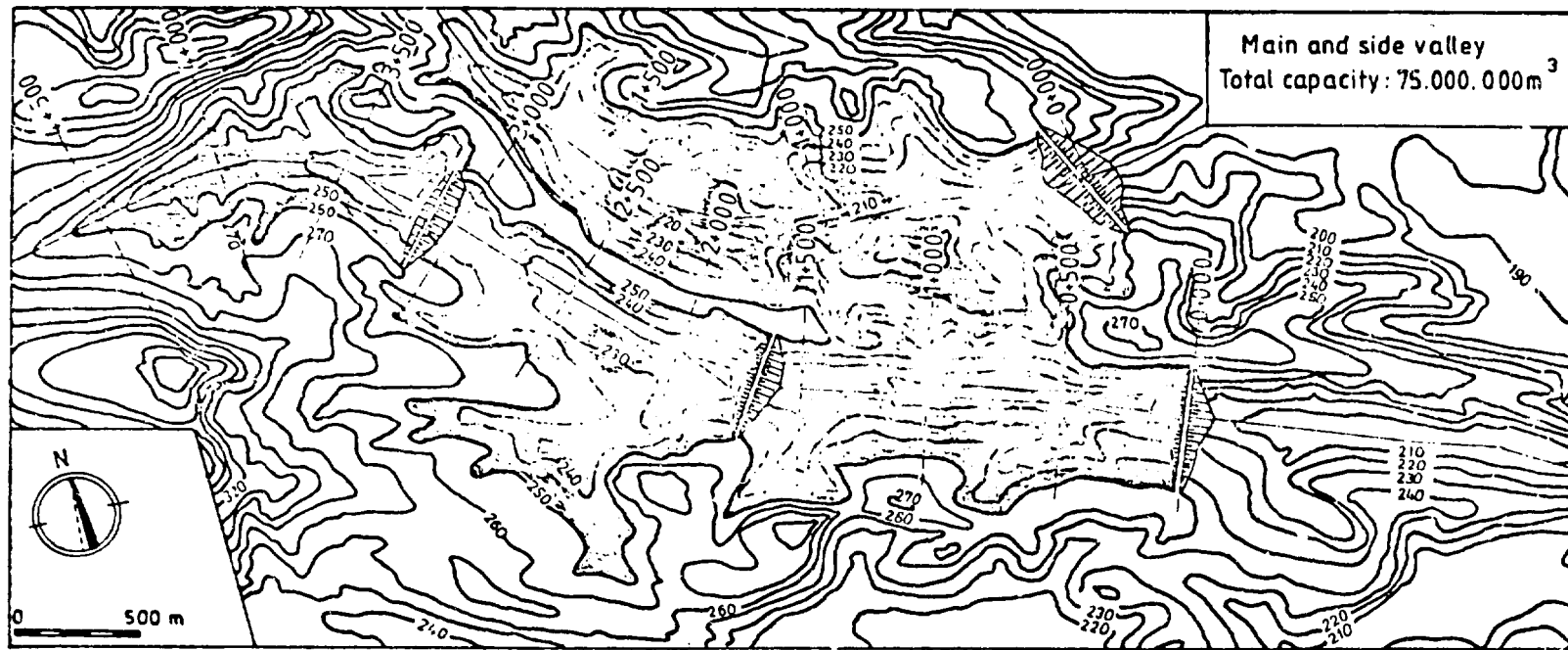
The barrage built on the lowest part of the disposal area is to be constructed in all cases from stones and rubble with sealing layer and it will gather water filtered and leaked through the unsealed intermediate filter-dam. An example is shown on Fig. 13.

A barrage construction was built in Salindres, where 170,000 tpy red mud is to be disposed. Stone and rubble were used as building material of the barrage and dikes quarried from the top of a rocky hill near the disposal area. Ash from the power station mixed with gypsum was used as sealing material of the barrage. The final capacity of the disposal area was calculated for 20 years. The final height of disposal will be 15 m at the barrage.

Calculating the dimensions of the barrage (and dikes) various data are to be taken into account as follows:

- red mud production per year
- water balance of the alumina plant
- transport water in the slurry arriving at the disposal area
- envisaged quantity of return water depending on solid content of mud, rainfall, evaporation, seepage, adhesive water of mud, etc.
- pressure of fluid tailing even in seismic region, where also the already consolidated, settled mud can flow again as a consequence of seismic vibration giving a surplus dynamic pressure
- data of soil and hydrogeological investigations as mentioned before.

As a consequence of the permanent hydrostatic pressure the body of the barrage would be wetted sooner or later.



Full dike construction 1:2000
Level of barrage: 260 and 250

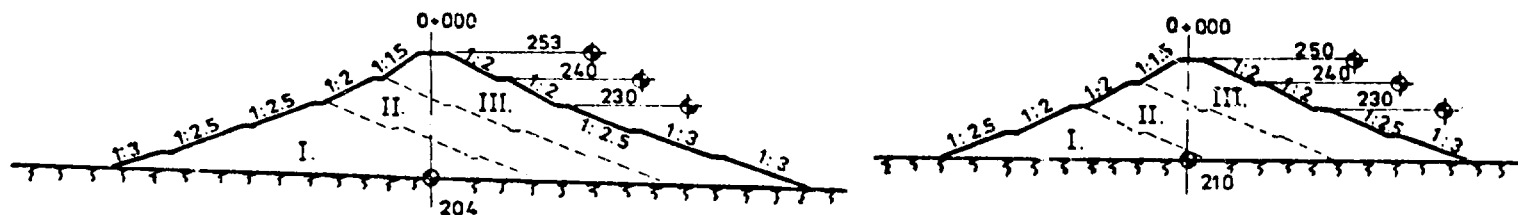


Fig 13

Reč mud disposal with barrage 4th phase of construction and disposal

(Source: see Ref. 31C)

Therefore, the slope of the barrage-embankment is to be moderated. Hydrodynamic forces emerge in consequence of changes in water level, therefore, a drainage is to be built on the foundation level and accidentally also in the body of the barrage. Impermeability can be ensured by a sealing layer constructed on the slope of the embankment (front-sealing), see Fig. 14.

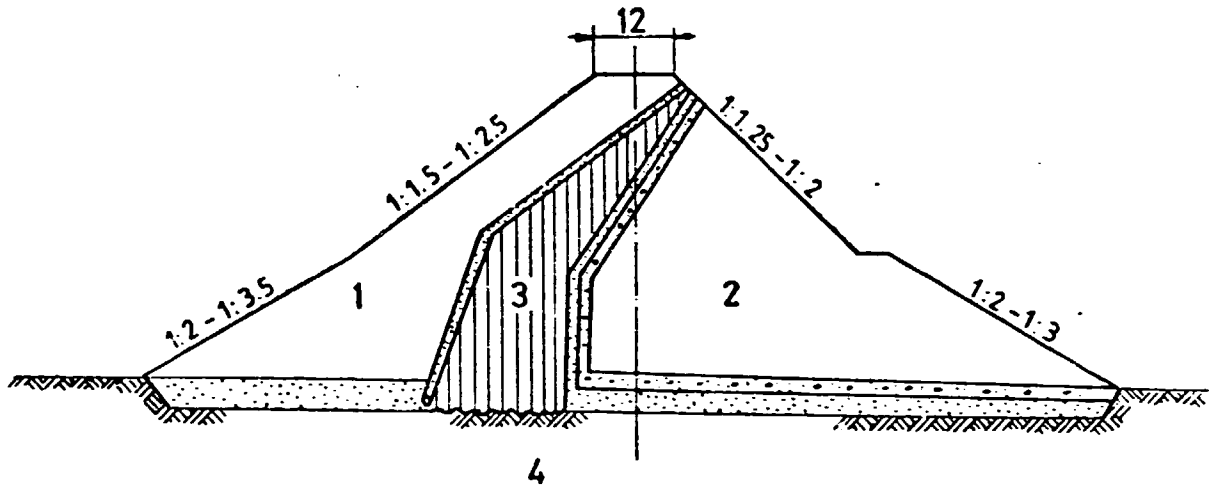
Dust emissions

One of the possible nuisance problems caused by residue ponds is the generation of caustic aerosols, and in the case of dried out ponds, fugitive dust. There are various methods for treating the latter of which wetting, using dust suppressants like bitumen emulsions and revegetation are the most common and effective.

Stacking of red mud after filtration

The adoption of this method can be necessary in some conditions of the region where the disposal is to be sited:

- shortage of suitable area
- expensive, restricted land use
- scantiness in water supply consequently maximum economy required in water consumption
- horizontal and flat site area
- permeable soil
- especially severe regulations for environmental protection
- disposal area sited in the close neighbourhood of the alumina plant and
- recultivation is required.



1. Debris and clayey earth hydraulically colmated
2. Supporting stone heaps hydraulically colmated
3. Impermeable clay core
4. Load distributing layer
5. Clay layer of front sealing

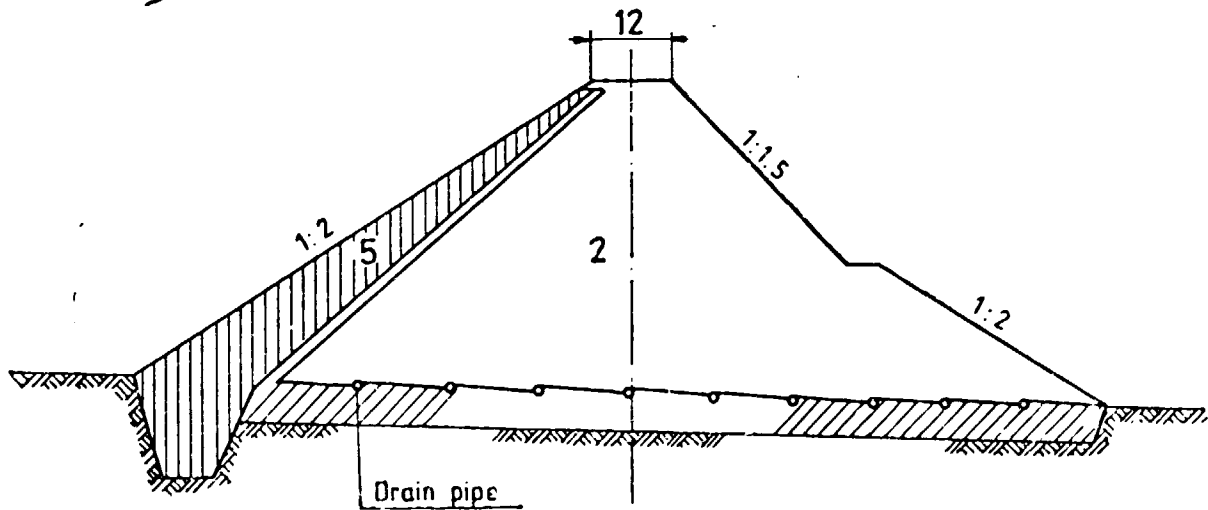


Fig 14

Typical inhomogeneous barrage section with
clay core or front sealing

(Source: see Ref. 310)

The filtered and washed red mud is treated mechanically by rapid agitation to decrease its viscosity from the original say 100 Pa.s to say 10 Pa.s. Then mud is pumped by piston or diaphragme pump from the plant to the disposal area generally without transport water. The adhesive moisture is about 45 per cent, volume weight of red mud about 1.15 ton/m^3 . If the transportation distance between the plant and the disposal area exceeds 2 km, mud viscosity must be reduced by adding water. The addition of 100 per cent of transport water virtually halves the yield value. To transport filtered red mud by pipeline over a distance of say 6 km by piston diaphragm pump will require the addition of approx. 50 per cent water and the water content of the slurry will then be about 63 per cent.

The disposal area is to be surrounded by dikes. Building materials excavated from the disposal area, or solidified or lime stabilized red mud can be used for the construction of the initial dikes. Dikes can be heightened from stabilized dry red mud gradually even up to 25 to 30 m. The soluble Na_2O -content of red mud has to be lower than 0.5 per cent. A clay or stabilized red mud layer is to be spread on the bottom. This layer is able to absorb a part of the water content of the red mud and a colmated impermeable layer will be formed by the fine size fraction of clay-content of red mud which will work as a sealing.

The advantages of this method:

- well-washed-and-filtered "dry" red mud does not contaminate the environment, consequently no special sealing is needed
- adhesive moisture of stabilized red mud can decrease to below 30 per cent by drying in air
- rainwater does not infiltrate into the stabilized mud. A part of rainwater evaporates, another part flows down without dissolving effect, because of

the high solid content of red mud. A surrounding ditch is to be built around the disposal area in order to lead off rainwater.

- after filling up the disposal area one can walk on the mud surface after 2 to 3 weeks and a tractor is able to move on it after 4 to 5 months. As a consequence, solidified mud can be used after certain time for recultivation and as building material for dikes of red mud disposal or other types of embankment constructions. The excavated disposal area can be filled again with red mud.
- four to five times more red mud can be stored on the same extent of disposal area than in the case of normal slurry transportation as a consequence of the lack of transport water, low volume weight and big height of possible mud storage.

Disadvantages:

- in normal conditions this method of disposal is by up to about 30 per cent more expensive than the cost of the "conservative" method because of the higher power requirement (filtration, mud transportation) and cost of special chemicals (plasticizers, stabilizers). In case of low filtration performance it may be even economically prohibitive. However, under special conditions (e.g. high acquisition cost of land etc. as mentioned beforehand in the first paragraph of this chapter) the adoption of this method can be the most economic one.

Pioneering work on dry red mud disposal was done by Geb. Giulini GmbH, Ludwigshafen FRG and developed further by VAW. Using alternative filling, drainage towers, filter beds and distribution of slurry by means of a circuit pipeline accelerated consolidation, and air drying of the stored red mud is achieved down to 29 per cent water content.

Other alumina plants operating with dry red mud disposal are: Martin Marietta, Virgin Islands and CBA, Brazil.

Dry red mud disposal system is under implementation in the following plants:

- San Ciprian, Spain
- Titograd, Yugoslavia
- Magyaróvár, Hungary
- Alunorte, Brazil

Disposal in excavation of mines no longer in use

Excavated mine areas no longer in use are to be recultivated. If the alumina plant and/or red mud disposal area can be sited in the neighbourhood of mines, a possibility emerges, for the preparation of recultivation as a very economical solution depending on some conditions since red mud can be disposed in the excavations.

In all cases preliminary tests and investigations are to be made and a co-operation is needed between the experts of the mine and the alumina plant in order to ensure the requirements of this type of red mud disposal if possible.

3.3.3 Disposal in water

The possibilities of disposal in water can be distributed into two main groups:

- disposal in rivers and
- marine disposal (in sea or in coastal artificial lagoons)

A couple of alumina plants discharged red mud into river as a simple solution, for instance Kaiser plants in Gramercy and Baton Rouge into Missisipi (USA) and Revere plant into Maggotty River (Jamaica). None of them proved a viable solution. Fish and other animals were killed,

water below the plant rendered unusable and finally discharging of red mud had to be abandoned as a consequence of disagreement of authorities. The only alumina plant discharging its red mud in river at present is the Fria plant at Kimbo, Guinea.

According to experience the disposal in river can not be suggested, considering

- the big quantity of other various wastes which generally load a river on an industrialized area
- the socio-economic impacts on the population
- the very poor settling properties of the fine granules of red mud in the permanent flow of the river
- the protection of fishing and angling and
- the mud contamination which makes unusable the sandy gravel of rivers as aggregate of concrete, etc.

Disposal of red mud in the sea seems to be the most simple method of disposal at first sight. It eliminates the majority of the problems associated with land disposal, as

- no arable land or industrial territory is occupied
- socio-economic impacts on the population are minimal
- recultivation of land is not necessary
- there is no dust formation, consequently air pollution is eliminated
- seepage of caustic liquors into aquifers is eliminated, too
- the pH of the liquid will be effectively neutralized by the precipitation of the hydroxide and carbonate ions as magnesium hydroxide and carbonate. (311,312,313)

The above advantages were the motives for some alumina plants to discharge red mud into the sea. Aluminium Pechiney (near Cassis, France), Aluminium de Grèce and some Japanese plants are still using this method, other plants, e.g. British Aluminium, Porto Marghera (Italy) plants abandoned it later because of the disagreement of authorities. Red mud slurry of the Porto Marghera plant was pumped into barges and discharged through the bottom into the deep sea.

Aluminium Pechiney (314) was authorized exceptionally in 1967 to discharge red mud into the Mediterranean Sea in the vicinity of Cassis, near Marseille, in form of slurry. Our team was acquainted with this system during their fact finding mission in Aix-en-Provence. The motive of Aluminium Pechiney was economy. Operation cost of marine disposal amounts only to one third of that of land disposal. The total red mud quantity pumped into the sea is nearly 1,000,000 tons per year, coming from two plants: Gardanne, sited at 54 km and La Barasse, sited at 7 km from the seashore. The end of the pipeline is at -300 m depth under sea level. Slurry continues its downward flow into a submarine trench of 1,700 m depth. The pipeline of \varnothing 100 mm is elevated successively at 200, 300 and 400 m high hills, when coming from Gardanne. In the last descending part of the pipeline vacuum is formed which contributed to the corrosion of the pipe in the beginning. Later on a diaphragm was installed on the lowest part of the pipeline and as the pipe was always filled up with slurry, no corrosion occurred. The part submerging into the sea is insulated electrically from the rest and provided with cathodic protection. The slurry entering the sea forms flocks of 2 cm diameter and its caustic soda content is neutralized due to

the magnesium chloride content of sea water. The pH-value of sea water does not change at 1 m distance from the slurry flow already. Although there is a beach in the vicinity of pipeline at Cassis, no complaints as regards contamination has been announced yet. Captain Cousteau took part in the engineering work and agreed originally but later had reservations. Pechiney admits that also other scientists keep to their reservations as regards marine disposal of red mud.

Aluminium de Grèce, St. Nicolas plant is discharging about 500,000 tons per year red mud in the Corinthian Gulf. Relevant technical data were at the disposal of the team. The soluble Na_2O content is 0.2 per cent and insoluble Na_2O content 4.0 per cent. Slurry discharged is $131.2 \text{ m}^3/\text{h}$ with 500 gpl solids content. It is pumped through a pipeline of $\varnothing 200 \text{ mm}$ into the sea to 2,500 m distance from the shore in the Bay of Astra Spitia. The pipeline has been operating for ten years without breakdown. The average slope of the sea bottom is about 5 per cent. At about - 300 m depth there is a long trench of 2.5 to 3 km^2 surface, the deepest point of which is at - 800 m. The slurry is pumped along the 120 m high coastal line to the - 100 m depth of the sea. From this point slurry flows freely into the trench. Two pipelines were laid in the sea but only one has been in operation since 1971. Slurry exempt of sand is collected in a stirred tank before pumping. The submarine trench and the point of outflow are monitored periodically from helicopters. No special effect of the waves or submarinal flows have been noticed. Fishing is going on undisturbed in the bay for the time being.

Some alumina plants in Japan are discharging red mud into the sea at a dumping area designated by the government. In the slurry, the approximate volume ratio of

red mud and water is 1:4. Slurry is poured into the sea at the depth of about 30 m below the sea surface with flexible hose from the disposal ship constructed for this new technique. According to the crew of the ship, yellowish coloration of the sea water due to red mud particles in suspension is seldom observable from the ship bridge, except in winter under a high wind or a gale.

A. Yositada Takenouti, Hiroo Natsume and Tatsuo Miyata carried out laboratory and field investigations in connection with this method on the sinking and diffusions of discharged red mud in oceanic water (315). The conclusions of their investigations were as follows:

- the slurry mixed from red mud and water in a ratio of 1:4, discharged into the sea through a flexible hose, flows downward with a sharp and clear boundary with the surrounding water, and a pycnocline does not exercise any decisive effect on the downward flow of this water with red mud,
- turbulent mixing at the boundary of the downward stream is very weak in spite of a large velocity gradient, and only a small amount of red mud particles is released from the boundary,
- the red mud particles which are brought into suspension from the boundary are dispersed by turbulent diffusion, but the concentration of the particles is small during the discharge even very close to the boundary. The particles also precipitate and consequently disappear from the layer above and in the pycnocline.

Biological effects of marine disposal of red mud

Where red mud flows and settles on the sea-bottom, it kills, of course, the stationary species of the fauna and as a mud-like, strange material generally can not be a part of the natural sea-bottom, first of all on rocky seabed. Concerning investigations in connection with other biological effects some results are introduced:

Bourcier and Zibrowius studied effects of red mud discharge on the biota of the sea at Cassis from a depth of -300 m and down to -1,800 m (3.16).

The benthic fauna had not been visibly altered since the previous surveys done before the red mud discharge. Many species were found feeding in and upon the red mud deposits without detriment. Fish behaving normally were observed in the vicinity of the discharge pipe. Invertebrates, however, were smothered along the center-line of the canyon.

Vitiello and Vivies (3.16) demonstrated that red mud in the canyon could support viable populations of meiobenthos. The data provide no evidence of a toxic effect.

No effect on fisheries were noted during a discharge period from 1966 to 1972 in the Bristol Channel when red mud was pumped from a special vessel. Blackman and Wilson reported on studies with settled and suspended red mud similar to that discharged into the Bristol Channel. Bivalves and soles (*Solea* sp.) were not affected by 50 to 100 mg red mud per cm². Mussels absorbed red mud into the digestive tract and were heavily covered externally but cleaned themselves in clean water after two days. However, 72 hour exposure of the armed bullhead (*Agonus cataphractus*) to the same type of red mud produced a mortality of 20 per cent.

In the studies reported by Dethlefsan, however, red mud discharged at 100 to 400 m away from caged cod, 58.8 per cent of cods suspended 4 m, and 13.6 per cent 10 m above the bottom had died after 5 days exposure. Other experiments reported that the metabolic rate of shrimp was depressed after 17 hour exposure to 10 gpl red mud.

Others demonstrated mortalities in herring embryos at a concentration as low as 1 ml red mud per liter. Kaiser evaluating the effect of German red mud on cultures of algae noticed that continuous additions can lead to extinction of algal cultures.

As a conclusion of these contradictory findings it seems reasonable to cite V.G. Hill's (Jamaica) main points of view concerning marine disposal such as

- the possible effects of marine disposal must meet the requirements concerning the aquatic life of the sea, particularly fish, tourism, aesthetics of the environment and public opinion and the regulations of the authorities, respectively. Submarine areas used for high-sea fishing and where fish spawn, must not be used at all
- the discharged red mud must be totally harmless to the marine life and with content of bio-accumulatable metal content less than the marine background level
- the discharged red mud must settle rapidly and this sediment and any material precipitated by reaction with the seawater must not resurface or otherwise adversely affect the marine environment under any conditions which may occur in the locality
- the discharged liquid must completely be mixed with seawater
- all installations must meet standards for marine constructions, for the protection of pipeline and

auxillary installations both on land and at sea
- continuing arrangements for monitoring of the installations for corrosion, leaks, equipment failures and changes in marine life in the vicinity of the installation. The monitoring must not only include instrumental observation but also regular observations by divers.

The method of the coastline red mud disposal in artificial lagoons ca. offer good possibilities having some advantages comparing with both land and marine disposal. The occupied area does not decrease the land territory; even after filling the disposal area it can be recultivated if it is properly executed. On the other hand some disadvantages and difficulties of the "real" marine disposal can be prevented.

This disposal method incorporates the separation of the mud solids in artificial coastal lagoons, so that they do not enter the sea. The dike of the lagoon is somewhat permeable to permit the equilibration of water level with side and further, the stone used to construct the dikes must be capable to withstand the maximum wave action on the seaward side. On the landward side of the dikes, a sand filter-layer should prevent the mud solids from filtering into the sea.

In the Gove Alumina Plant, Australia this method was elaborated on the basis of some experiences collected during the first operation period. Thickened red mud slurry from the plant is pumped to the artificial lagoons using seawater as the transporting medium, theoretically in sufficient quantity in order to precipitate the caustic soda in the slurry as magnesium hydroxide in the ponds (317).

The sea around the discharge point of the liquor was

carefully monitored by establishing biological sampling lines before operation started. This showed, that initially pollution was unacceptably widespread. The construction of a security pond, however, and the neutralization of discharged liquor to less than a pH of 9.3 by the addition of excess seawater stopped the pollution and the marine area affected was rapidly recovering.

This example demonstrates the need for adequate design in the marine disposal of red mud.

In Porto Vesme, Italy red mud is filtered, then neutralized with seawater. The slurry containing about 40 per cent solids is pumped to a colmation basin where drying out occurs by evaporation.

3.4 Recultivation of red mud disposal areas

The industrial development is occupying cultivated and natural vegetation areas from nature and agriculture ever again. In case of an alumina plant the situation is especially disadvantageous. The extent of red mud disposal area grows permanently related to the plant area and after an operation of 10 to 20 years the area occupied by red mud will be five to tenfold larger than that of the plant. Furthermore an extension in alumina production means only relatively smaller extension in plant area; contrary to this, the necessary extension of the disposal area is about in direct ratio to that of the alumina production.

According to the common knowledge, recultivation of red mud disposal is insolvable because red mud of most disposal areas no longer in use is not able to solidify and, therefore, one can not work on its surface, especially with mechanized agricultural technology. However, the situation is only the consequence of the bad construction and the lack of the suitable disposal technology of the red mud area in

the case of most alumina plants, because the original effort was only to construct a simple and cheap red mud disposal.

In this Study conceptions were expounded how to construct various disposal areas considering local conditions, bauxite and red mud quality, alumina technology process, environmental protection and last but not least requirements and possibilities for recultivation. Dewatering of red mud area is the most important task also from the viewpoint of recultivation. On the surface of a disposal area dried up as required, walking, even movement of engines and so preliminary work of revegetation (e.g. spreading out of humus layer) are made possible.

A much more difficult problem is the recultivation of the present disposal areas which are already filled and are no longer in use. Several experiments were made and some vegetation programmes are in progress. Results are already used in practice as well. As a consequence of these experiences complex engineering work could be made for the construction of red mud disposal considering efficiency, economy, transportation, disposal, water recycling, revegetation, recultivation and first of all ecology.

Revegetation of red mud disposal area without mechanization and application of fertile soil and fertilizers respectively is a problem not easy to solve because of several limiting factors affecting plant growth on red mud, such as high pH values, very high sodium chloride content and complete absence of nutrients in this biologically sterile material. In the followings several interesting experiments and results are reviewed. The conclusion is in all cases that some nutritive material is necessary by all means to promote plant growth.

D. Hinz and H.P.Doetling (317) began experimentation in Gove, Australia first with pot and container trials to evaluate the behaviour of tropical pastures and native plant spec-

ies. Direct sowing or planting into unleached red mud, excavated from the top-layers of the disposal area were not successful. On the other hand, with a lateritic soil cover of 3 to 7 cm thickness on the red mud, germination and survival of species under test improved. The roots of tolerant species penetrated the red mud. On the basis of pot trials, field trials were initiated, established directly on a red mud disposal area. Red mud surface was top dressed up to 10 cm depth with the same lateritic soil as used in the pot trials. Rates of fertilizing were also the same as before. Plants lived without irrigation and their growth was conditioned by natural rainfall. Various plants species were tested step by step. As a first phase grass-species (Graminaceae) were grown successfully. The *Chloris guyana* and *Sporobolus virginicus* penetrated the red mud with roots into a depth of 10 to 20 cm. Legume-species, such as *Tylosanthes humilis*, *Dolichos labla* and *Calapogonium mucunoides* were also well established. Native tree-species, such as *Acacia leptocarpa*, *Acacia holosericea* and *Eucalyptus albe* survived the dry season of 5 months and were outstanding with growth increase of 30 to 40 cm during one year. In the second phase a combination of grass-and legume-species were established together with *Acacia leptocarpa* seeds to promote also the early tree growth. Fortunately it was observed that the growth of this grass-legume and *Acacia*-tree combination is more vigorous than that of each species on its own. Dry matter yield of the harvest was almost twice so much after one year than the one without combination. As a result of further experimentation through selection, elimination and combination trials, a red mud area of 30 hectares no longer in use was planted in 1978 with stabile and maintenance free vegetation combined from various native and introduced grass-legume and tree-species. All these species are tolerant

to the high salt and alkaline soil content and able to ameliorate the soil and develop into natural bushland within the near future (3.18).

Very successful experimental cultivation of different vegetables (i.e. cabbages, zucchini and marrows) and a variety of cereal crops have been established on rehabilitated mud lake in the Kwinana Alumina Plant by Alcoa of Australia. Red mud was disposed of on a sealed mud lake and the concentration of lake water averaged 12 gpl of soda as Na_2CO_3 in the liquor phase.

While dumping the red mud the sand settled at the feeding points and the mud flew to the centre of the lake. The supernatant liquor was recycled into the process. The red mud settled to appr. 60 per cent solids by weight.

After the disposal had been completed, red mud was allowed to dry. In order to decrease the water content of the settled mud and at the same time to recover caustic soda from the pond, a de-liquoring system (called eductor system) was used. When leaching of mud by rainwater was sufficient, the rehabilitation procedures could be commenced.

The techniques developed and experienced by Alcoa of Australia for rehabilitation are (3.19):

- The surface has to be graded to evenly distribute the sand-sized particles and to provide access of vehicles to the entire surface area.
- A surface drainage system has to be installed to assist in leaching of salts from the surface layer.
- Where good quality topsoil is present on residue disposal sites it has to be removed prior to pond construction, stockpiled and used as a topdressing.
- Ripping to a depth of 0.5 m has to be carried out in rows at one to two metre centres using bulldozer.

This will also assist in the leaching of surface salts.

- Organic matter in the form of sawdust, fowl manure or sewage sludge has to be applied at the rate of 50 cubic metres per hectare and harrowed into the surface layer.
- Superphosphate with trace elements, sulphate of potash and ammonium nitrate has to be applied at 400 kg/ha, 200 kg/ha and 100 kg/ha, respectively.
- Cereal Rye grass and Wimmera Rye grass have to be sown at 40 kg/ha and 15 kg/ha respectively and at the same time 100 kg/ha of superphosphate has to be drilled in.
- Subsequently, maintenance dressings of fertilizers has to be applied as needed.
- After two years the vegetation has to be converted to legume pasture using medick, subterranean clover.
- Pasture has to be maintained by the grazing of livestock.

At Queensland Alumina Plant a section of the filled red mud pond was revegetated. About 12 inches of top-soil was spread on the area of the abandoned and dried out pond. Superphosphate, sulphate of ammonia and zinc sulphate were added as fertilizers, while Rhodes, Siratro and green couch (Agropyron-species) seeds were used to grass the area. Trial planting of trees is now in progress.

The Hungarian Universities for Horticulture and Agriculture resp. have been dealing with recultivation problems since 1972. Native brome-grass (Bromus species) and several tree-species such as tamarisk, oak, acacia and silver-tree (Eleagnus angustifolia) were tested at the Ajka Alumina Plant. The results were successful (320).

Inundation of the disposal surface by fecal sewage sludge proved to be a good idea to promote plant growing. Disposal area of passable surface could be covered with a humus-layer for planting vegetation. According to a Swiss licence a much cheaper process called Verdyol-Hydrosa can be used without humus-layer when a mixture from grass and legume seeds, nutritive materials and stimulators are spread out on the original disposal surface by water-gun. Seeds are able to germinate in the ameliorated circumstances and so the first phase of vegetation can be established preventing dust formation from the dried surface of red mud. Another advantage of this system is that it can also be used for revegetation of unpassable disposal areas.

Recultivation tests were performed at the Almásfüzitő Alumina Plant, too. Grass species (brome grass, dactylis, fescue grass and reed grass) sown in top soil gave about 5 t/h.year of dry hay or 300 to 500 kg of seed without any irrigation.

In the "in situ" experiments of Ch. Tommann and J. Portier in the Provencale area (France) the species exhibiting the best development were atriplex, tamarisk and the Aleppo pine.

3.5 Utilization of bauxite residue *

Red mud constitutes the major environmental problem of the alumina production. It can, however, be considered a complex secondary raw material at the same time as it contains valuable components (e.g. Fe_2O_3 , Al_2O_3 , Na_2O , V_2O_5 , TiO_2 , rare earth elements etc.

Researchers have been concerned themselves for a long time with the idea of utilizing red mud. Industrially established processes, however, can not be referred to, because the high moisture content (40 to 50 per cent) of red mud renders pyrometallurgic processing difficult, and separation of iron from aluminium brings about problems with the hydrometallurgic method. The thixotropic feature and extremely fine grain size of the mud and the interwoven state of individual mineral phases are also disadvantageous.

Several processes have been established for processing red mud, no practical realization, however, could be found so far. Most of the processes consider only the standpoints of the aluminium industry and only recently elaborated methods concern several industry branches.

From the point of view of red mud utilization the processes can be grouped as follows:

- Processes utilizing red mud completely
- Processes utilizing certain constituents of red mud
- Processes utilizing red mud as an alumina plant end product.

3.5.1 Complex utilization of bauxite residue

Two groups can be formed:

- red mud processing by complex methods,
- processes applying red mud as an additive.

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3.5.1.1 Complex methods for processing red mud

Smelting of red mud

Red mud smelting has been attempted in low-shaft furnace, blast furnace and electric furnace in the course of which pig iron or ferrosilicon and slag have been produced. The slag has been used for the production of cement or alumina. The Ti- and V-content of red mud has also been reduced along with the iron thus a special quality pig iron ("VANTIT" of vanadium and titanium content) could be produced. Smelting of red mud, however, is not an economic process. Red mud can be considered only as a low-iron (10 to 40 per cent) ore resulting in low yield and high specific energy (coke) consumption.

The Na_2O -content (3 to 10 per cent) of red mud is similarly unfavourable causing operating troubles, i.e. corrosion and quick wear of lining of the blast furnace.

Technologies producing self-desintegrating Ca-aluminate slag, molten iron and cement

The semi-plant scale technology for producing iron, alumina and cement from red mud was worked out in the Soviet Union.

According to one method red mud is reduced at $1,000^\circ\text{C}$ in a rotary kiln and then melted at $1,450^\circ\text{C}$ in another one. In order to produce self-desintegrating slag, sufficient amount of lime (stone) is added in the course of preparing the charge. Alumina is leached from the slag by sodium carbonate solution, then carbonated to precipitate and the residue is used for cement production (see Fig.15).

Disadvantage of the process is that part of the iron has to be separated magnetically from the slag.

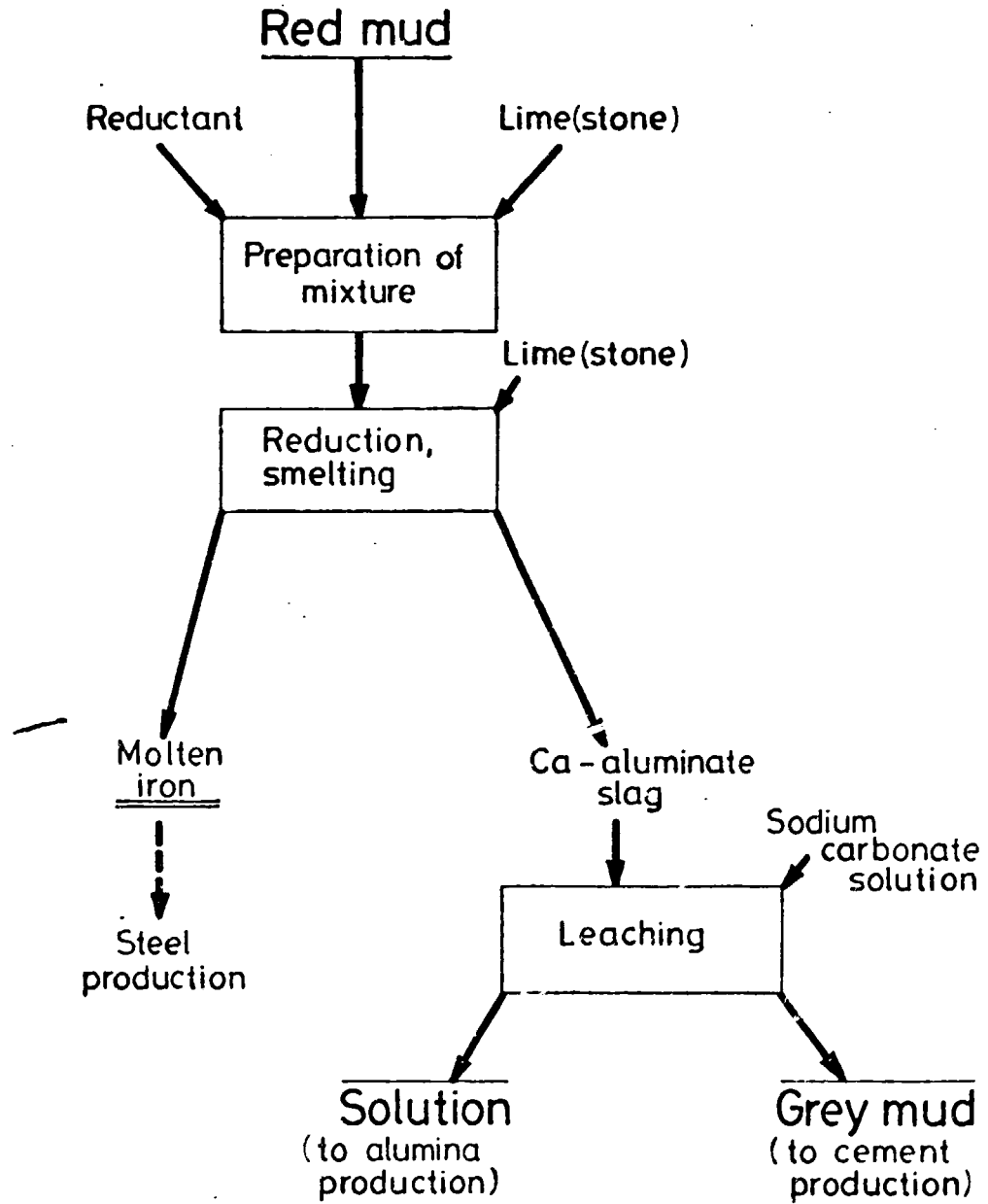


Fig 15

Production of molten iron (steel), alumina and cement from red mud
(Soviet processes)

(Source: see Ref. 321)

According to the other method only reduction of red mud is performed in rotary kiln, smelting takes place in electric furnace. Preparation of the charge is done similarly as outlined above. The products are the same as with the previous process, but magnetic separation of the products is not necessary. In both cases if the slag is cooled slowly (at a rate of 4 to 6 °C/min) it will become self-desintegrating in consequence of the phase transformation of $\beta\text{-}2\text{CaO}\cdot\text{SiO}_2$ into $\gamma\text{-}2\text{CaO}\cdot\text{SiO}_2$ of higher specific volume, thus the expensive crushing can be left out of the procedures and the material can be leached directly.

Only muds containing little or moderate amounts (less than 8 per cent) of Na_2O can be processed safely by this processes. Namely the slag will become self-desintegrating if not only slow cooling is performed but the Na_2O -content is kept below 1 per cent too (90 per cent of caustic volatilizes in the presence of lime and coke). Na_2O is incorporated namely in the crystal lattice of $\beta\text{-}2\text{CaO}\cdot\text{SiO}_2$ and stabilizing the same, it prevents the phase transformation which would give rise to self-desintegration.

The above methods render possible the recovery of 95 per cent of the Fe_2O_3 -content and 70 per cent of the Al_2O_3 -content of red mud without leaving any residue. Here, too, the so-called grey mud is used for the production of cement.

According to verbal communication of Soviet experts both processes are economic: were the red mud produced by UAZ and BAZ Soviet alumina plants processed this way, this would result in a profit of Rbl 15 millions compared with the method of producing iron, alumina and cement in separate plants individually.

The processing of high Na_2O containing red muds is rendered possible by a Hungarian process combining the Soviet methods with causticization i.e. the preventive

recovery of the Na_2O -content of red mud. This method proved good on a semi-plant scale. By this way 70 per cent of the Na_2O -content may be recovered in the alumina plant in form of sodium aluminate solution (see Fig. 16).

Production of iron lumps, alumina and cement from red mud
Modified series combined process

This process has already been tried in full plant scale. The operation was elaborated in Hungary. According to the process red mud is treated in rotary kiln by the Krupp-Renn method in presence of a reducing agent and lime. Iron lumps agglomerate to 1 to 5 mm size in the viscous non molten slag at $1,300^\circ\text{C}$. The iron is magnetically separated from the slag. The latter is then crushed and ground. Soda and limestone are added and the mixture is sintered at about $1,200^\circ\text{C}$. The Al_2O_3 and Na_2O -content are leached out from the sinter at a yield of 85 per cent. The iron recovery realized in the lumps comes to 84 per cent (see Fig. 17).

Disadvantage of the process lies in the high (about 1 per cent) sulfur and phosphorus content of the iron lumps, the two-stage heat treatment and high investment costs due mainly to magnetic separators. Thus the economy of process is only marginal due to the high energy prices at the present.

The recovery of iron, alumina and rare earth from red mud
and the production of fertilizers

This method was worked out in Yugoslavia for the utilization of red mud by melting it in electric furnace to gain iron and slag. Iron, containing also V and Ti is of "VANTIT grade. The slag is treated with H_2SO_4 , then filtered.

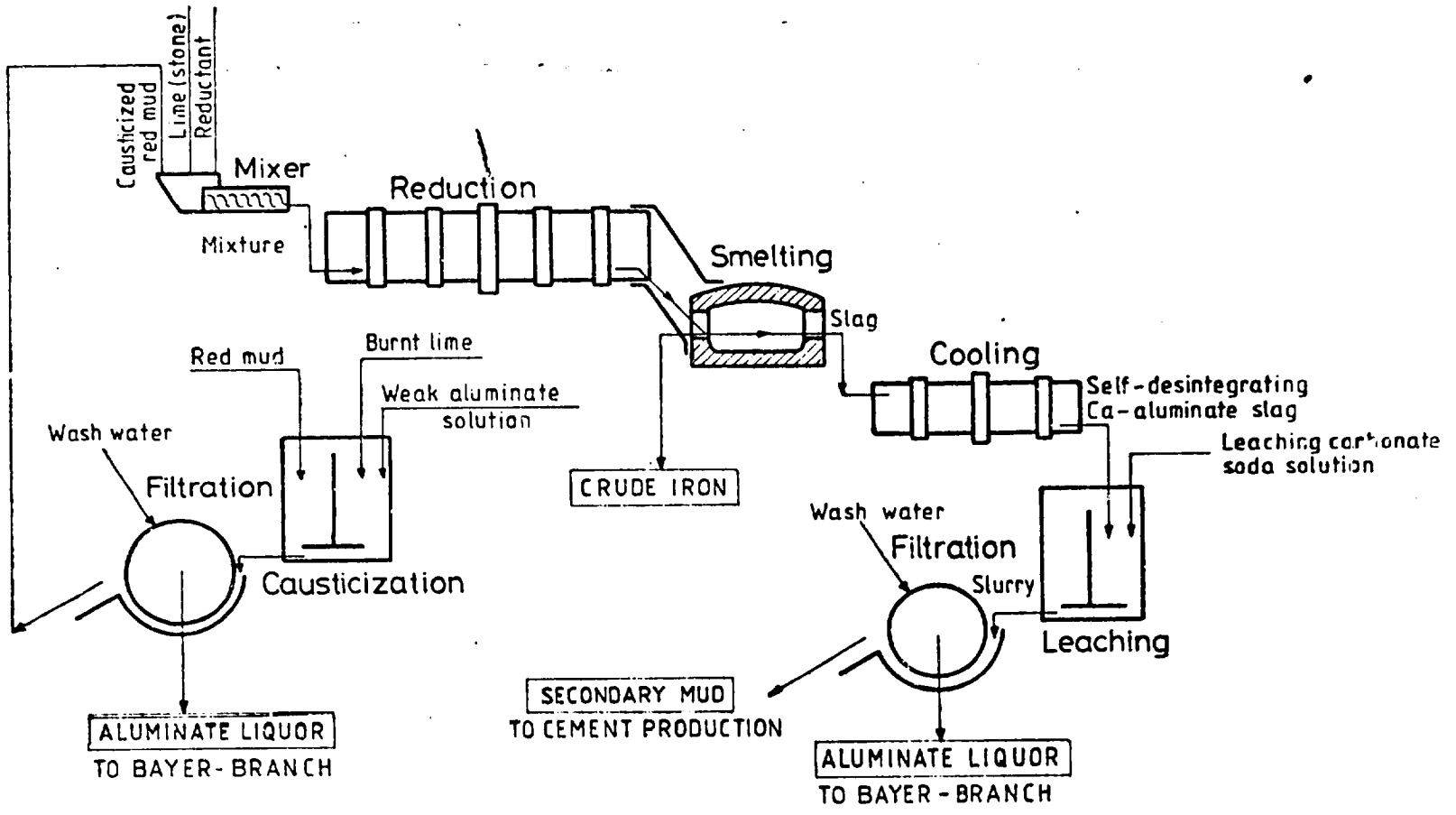
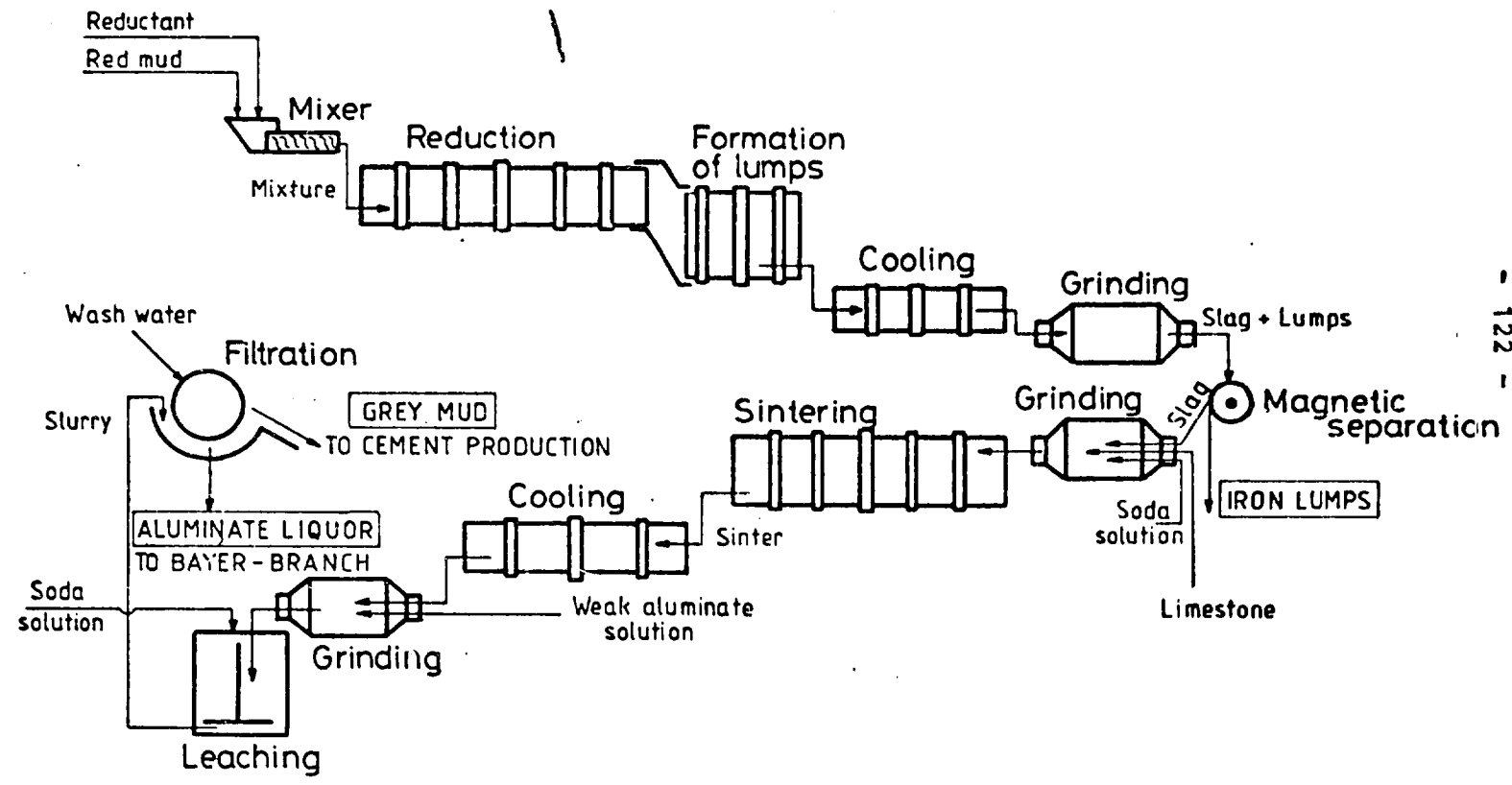


Fig 16

Reductive smelting of causticized red mud
Flow-sheet

(Source: see Ref. 322)

Fig 17
 Modified series combined process flow-sheet
 (Hungarian process)



(Source: see Ref. 323)

"PELOFOS" grade fertilizer can be obtained from the solid residue, whereas Ti, Zr, Th, U, La, Sc, Y, etc. can be obtained from the solution by extraction with kerosan.

3.5.1.2 Application of red mud as an additive

Application of red mud for iron metallurgical purposes

Red mud as additive has been used for the smelting of other iron ores processed in the Krupp-Renn kilns in Germany and Poland.

When red mud was added to the charge of the blast furnace, it was experienced that specific consumption figures worsened. Nevertheless, there are also advantages of the addition of red mud. If red mud filtered at 5 to 10 per cent of moisture content by press-filter is mixed with fines of ores, the capacity of the sintering belts can be increased (324).

Utilization of red mud for cement production

Cement - depending on its grade - contains higher or lower amounts of Fe_2O_3 . In the conventional cement production the necessary amount of Fe_2O_3 is charged by the addition of 1 to 2 per cent of pyrite sinter. Red mud obtained in the Bayer process is suitable for the replacement of pyrite sinter. A Japanese firm filters red mud at 30 per cent of moisture content and uses this material for the cement production at a rate of 30 to 45 kg red mud per ton of cement. Red mud filtration cost (4 \$/t alumina) is more favourable than that calculated for disposing red mud into the sea.

Successful experiments for the replacement of pyrite sinter by red mud have also been made in Hungary. On qualifying the tests it was established, that no particular problem occurred with the application of red mud and a portland cement of grade 500 and aluminate module 1 could be obtained. Owing to higher proportion of the molten phase of the mixture grindability is rather poor and tendency to formation of incrustations in the kiln is high. In spite of all there is no setback of such kind of utilization of red mud.

The situation is more favourable if red mud obtained by the sinter process is used for processing in the cement industry. This contains far more CaO and less Fe_2O_3 and Na_2O than Bayer mud, thus could be used in larger proportion for the cement industry. For the production of 1 ton cement 400 to 500 kg mud of the sinter process may be charged as compared to some percentage of Bayer-mud.

The raw material may be reduced by 18 per cent if the red mud from the sinter process is used, thus oil consumption can be reduced by 10 per cent and as a final result the cost of cement production is less by 15 per cent than that of the conventional one. Addition of red mud does not require other technological equipment than used in the cement factories. This induced China to expand the capacity of a cement factory from 600,000 tpy to 1,100,000 tpy on the basis of using red mud as additive.

Red mud may also be suitable to produce swelling cement. Mixing red mud and flue dust, granulating and heat-treating the mixture in rotating kiln, high-strength (450 kp/cm^2) swelling cement can be produced (325).

Application of red mud as building and construction material

The technique of manufacturing bricks from red mud was worked out first in the Federal German Republic. The method

has been adopted for several years in a brick factory. The strength of the bricks is reported to surpass that of the bricks made of the conventional raw material, thus it can also be used to construct high buildings. Transportation of red mud, however, caused some problems. Tauber and collaborators also produced good quality bricks by mixing red mud and clay slate and baking the same (326).

Red mud can also be used for the production of light building construction material and heat insulating material (327).

Utilization of red mud for soil amelioration and road building purposes

Red mud can also be used for the amelioration of the arable soil. Though the tests were successful the transportation costs of red mud, however, do not render this kind of application possible.

Red mud could be well utilized as filling material at the road construction operations and the production of bituminous pastes. VAW (GFR) co-operating with the Building Material Research Institute constructed 30,000 m² of such experimental road (328).

Utilization of red mud for other purposes

Gas purifying paste, known as Lux-paste, had also been made of red mud (329).

The firm Giulini (GFR) worked out the production of flocculant from red mud for water clarification purposes. The compound known as "ferri-floc" consists mainly of iron- and aluminium-sulfates, positive charge high molecule metal-hydroxo complex compounds, which pick up the negative charge molecules of the contaminating material and separate them from the water.

After acid treatment red mud can be used as filler in the rubber industry (330).

Pigments can be produced by treating high titania red muds and successful research work is in progress on the production of adsorbents, absorbents, catalysts, etc. by the use of red mud (327).

3.5.2 Extraction of certain mineral values from bauxite residues

3.5.2.1 Recovery of the iron content of red mud by physical beneficiation

The recovery of the Fe_2O_3 -content of red mud by magnetic separation is not a promising method. The capability for dressing is namely basically determined by the textural features of the material. As some phases of the red mud are fairly interwoven they are hardly separable from each other. The high field strength wet magnetic separators bid better prospects (331).

Processes are also known for the exclusive recovery of iron from the mud in the form of magnetic iron oxide or sponge iron. Industrial realization of the process, however, is not known yet (332).

Some researchers produce molten iron suitable for steel production from the red mud without utilizing the slag (see Fig. 18.).

3.5.2.2 Process utilizing the Na_2O - (and Al_2O_3)-content of red mud

The most common method enabling the recovery of 70 per cent of the Na_2O -content of red mud is the so-called "mud

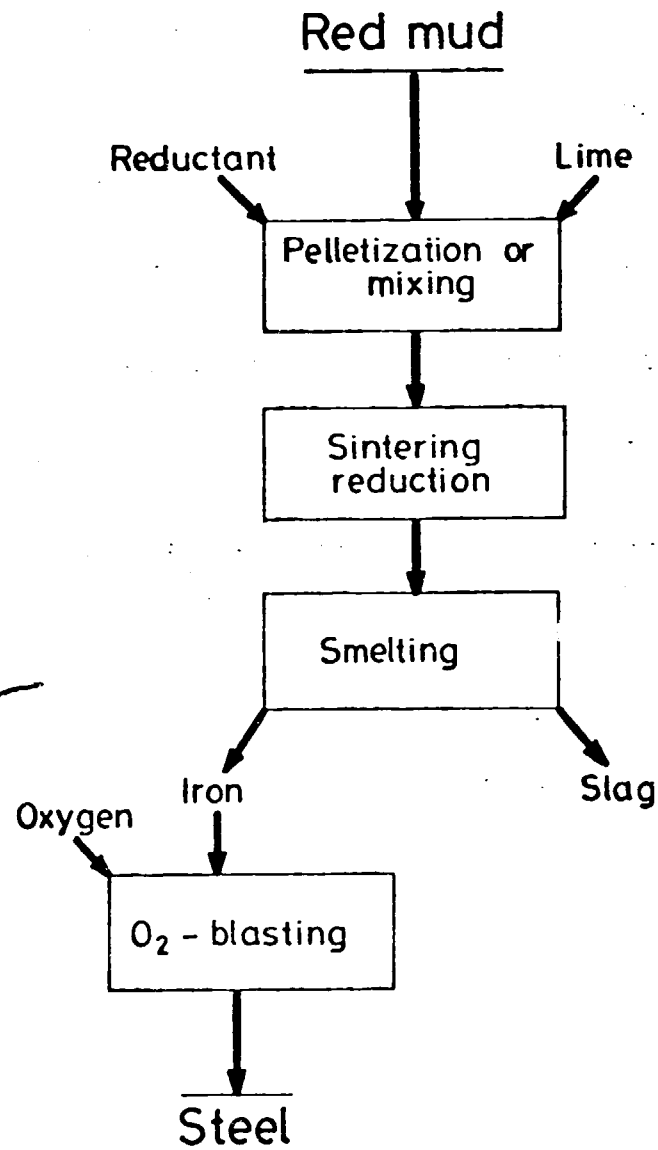


Fig 18

Production of steel from red mud
(USA and GFR processes)

(Source: see Ref. 333)

causticization" converting Na-Al-hydrosilicate content of the mud into Ca-Al-hydrosilicate by stirring the slurry and adding 3 mols of CaO per mol of Na₂O at 90 °C, meanwhile NaOH is released. The weak solution of about 30 gpl Na₂O concentration can be recycled to the process liquor of the alumina plant.

A number of Soviet investigators dealt with the recovery of Na₂O- and Al₂O₃-content of red mud by means of aluminate liquor and caustic soda solutions (334).

According to the method known as Bayer hydrochemical process Na₂O- and Al₂O₃-content of red mud can be almost completely recovered by the use of high molar ratio, high concentration aluminate liquor in the presence of lime at 280 °C and the residue can be further processed as iron ore. Problems arise, however, with the separation of the liquid and the mud phase and the separation of crystalline solid Na-aluminate content (335).

The so-called "biochemical processes" can, after all, be ranged with the acid methods because they operate in sulfuric acid or acetic acid medium.

3.5.2.3 Other methods for processing red mud

Several processes deal with the sintering of red mud with various additives, then leaching it to recover its Na₂O- and Al₂O₃-content. Out of them only the so-called series combined process has been realized on the plant-scale.

With the hydrometallurgic processes red mud is treated with various acids, caustic liquors or other compounds and the individual metals are recovered by fractionated crystallization, precipitation, ion-exchange methods or their combination (336).

It should be similarly noted, that for a long time ago the recovery of V-, Ti- and rare earth element content of the red mud has been dealt with. Several successful laboratory tests, but no industrial realization are reported in the literature (337, 338).

A Hungarian method has been elaborated for the preliminary removal of the iron content of bauxites. The ore is treated with NH_4Cl at about 330°C , NH_4Cl dissociates into NH_3 and HCl and the latter reacts with the Fe_2O_3 -content of bauxite. Resulting iron chlorides partly volatilize, partly get retained in the ore treated.

Iron chlorides can be leached out by water and separated by filtration and washing from the residue containing about 5 per cent Fe_2O_3 .

The volatilized iron chlorides and NH_3 are absorbed in water. NH_3 reacts with iron chlorides to form iron hydroxide precipitate. The resulting NH_4Cl -solution is evaporated, NH_4Cl crystallized and recycled to the bauxite handling procedure.

The deironized bauxite - depending on its grade - can either be directed to the Bayer process or to the chlorination process. In the first case the mud resulting after the Bayer process will contain only little amount (8 to 10 per cent) of iron, and will consist mainly of Na-Al-hydrosilicates. This "white mud" can be causticized and major portion (about 70 per cent) of its Na_2O -content recovered, however, the lime sintering of the mud can also be performed to recover about 85 per cent of its Na_2O - and Al_2O_3 -content. The final mud consisting of Ca-Al-hydro-silicate or di-calcium silicate can be utilized for cement production. Abbreviated process flow diagram can be seen in Fig. 19. No red mud is produced in the course of the process, which could contaminate the environment, moreover,

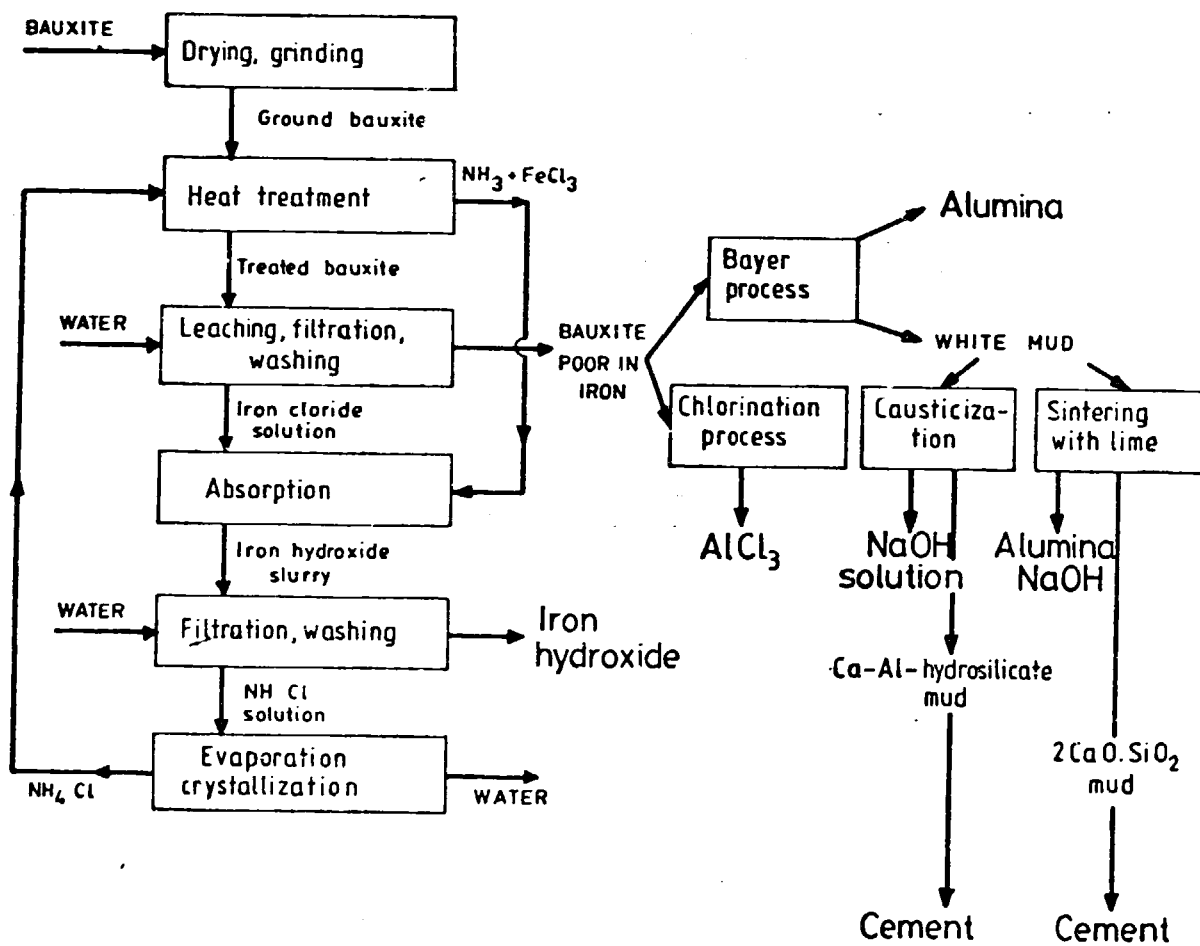


Fig 19

Preliminary elimination of iron from bauxites
(Hungarian process)

(Source: see Ref. 339)

the process is free from any waste product and at the same time it renders the production of iron, caustic soda, alumina and cement possible.

3.5.3 Process utilizing red mud as an alumina plant end product

According to a Hungarian patent (F.Puskás No. 171820) a mixture can be produced, in which the rate of dry red mud relative to the dry weight of the mixture is 50 to 90 per cent. This mixture can be baked to give high strength heat insulating bricks, heat insulating water-pipes, building bricks, wall covering tiles, roof tiles, low weight building materials (specific weight 1 t/m^3 , that of gravel 1.8 t/m^3), brickwork of foundries, surfacing material.

By proper selection of quantity, quality, grain size of the additives and of the manufacturing technology; outer, inner chemical and physical properties, technical characteristics of the end products may be influenced optionally. Frostresisting ceramics may also be produced.

On the basis of the patent total quantity of red mud could be processed to valuable ceramic and other products in the majority of countries.

Red mud is not transportable in original state, however, if the mixtures are produced in the alumina plant they can be transported to the ceramic factory. Red mud is available free of charge, thus extraction of other ores used at present to produce ceramics might be saved.

A further advantage is that baking is made at relatively low temperatures, 950 to $1,150 \text{ }^\circ\text{C}$.

Additives are, in majority, wastes or refuses of other industry branches constituting environmental problems themselves at present.

Additives may be: flotation refuse of ore dressing, sand washing sludge, waste of silicate industry plants or their dust, mining refuse of igneous rocks, oil shale slag, refuse of perlit grinding, dust of perlit swelling, mining and dressing refuse of noble minerals, ash and flue dust of power plants, loess, dolomite, diatomaceous earth, household and industrial scrap glass, zeolite, quartz sand, sandy illite refuse, etc.

Certain additives can be added before filtration of red mud to the slurry improving filtration performance and raising the strength of red mud in dry stacking and enabling its revegetation.

Taking into account the above the way of looking to the red mud has to be changed. It can not be regarded as a waste, but a valuable product of the alumina plant.

UNIDO studies demonstrated, that the process is feasible with Jamaican and Indian bauxites, too.

Table 9.

REVIEW OF THE UTILIZATION OF RED MUD

Mode of utilization	Investment costs	Operating costs
In case of utilizing red mud, it ceases to be a source of environmental pollutant		
A. UTILIZATION OF RED MUD AS INDUSTRIAL RAW MATERIAL		
a) complex utilization of red mud		
- smelting of red mud	- uneconomically too high at present	- energy consumption too high at present
- production of iron, alumina, cement	- it is more economical in the Soviet Union	as if products were separately produced
- production of iron lumps, alumina, cement	- high	- high
- production of iron, alumina, fertilizer, rare earths	- no information	- no information
b) utilization as additive		
- for iron metallurgy purposes	-	- iron metallurgy costs can be reduced
- for cement production	- similar to the convent. cement product.	- 15 % less than at conventional cement pr.
- for building and construction material	- similar quality products than those produced from conventional materials	
- other purposes	- road construction, flocculant, filler for rubber industry, etc.: economy depends on local conditions	
c) utilization of individual constituents of red mud	- no industrial realization so far	
B. UTILIZATION OF RED MUD FOR AGRICULTURAL PURPOSES		
- soil amelioration purposes	-	- realizable depending on transport costs
- plantation	-	- searching for adequate plants and species
C. UTILIZATION OF RED MUD AS ALUMINA PLANT'S PRODUCT		

3.6 Economic aspects and evaluation of the environmental compatibility

Ecologists and entrepreneurs of the industrial plants do not make secret of the fact, that proper adjustment to the environment considerably affects the realization costs of a new project. Environmental protection costs money. It is, however, indisputable that this kind of investment would be returned to the entirety of society in the long run. These problems weigh on industrial undertakers because these extra costs diminish return on investment. (e.g. cost level of air pollution control was estimated at about \$ 13 per capita in the United States between 1970 and 1974 but yearly excess costs due to air pollution came to \$ 65 per capita at the same time.)

Resolution of this discrepancy can only be achieved by thorough projection of environmental compatibility, through consideration economic goals in the long run economically, with maximum recovery of reusable materials and by keeping in mind the benefit resulting from the prevention of negative environmental impacts.

In order to treat red mud disposal as demanded by modern regulations and standards not only the risk involved in red mud storage has to be considered, but possibilities enabling its prevention at the lowest expenditure have also to be determined at the given place and time.

Red mud disposal and storage does not usually represent a decisive cost element within the production cost of alumina. According to our estimation the cost of red mud disposal and storage on land comes to \$ 0.5 to 1.5 per ton of alumina, i.e. roughly less than 1 per cent of the total production cost of the alumina.

However the economy of red mud disposal and utilization has to be analysed on a much broader basis, since new projects imply increasing risk due to world-wide social, economic and energy problems and at the same time even adequate profitability is difficult to be guaranteed due to steadily increasing operation costs.

According to our present knowledge, the main source of pollution caused by red mud impoundment on land is its contaminated liquor content. The seepage of the contaminated water has to be prevented in order to avoid the hazard to living organisms and to prevent bioaccumulation. This activity should not be restricted to the proper insulation of the impoundment basins, however, even natural flooding or earthquake has to be taken into account. Another source of pollution can be the dusting of red mud impoundment areas, which has to be diminished/stopped by periodic wetting or revegetation.

The general aspects of the environmental compatibility are usually outlined by state or local authorities' regulations. Attention is drawn to the fact, that, apart from restrictions, instructions and regulations, nearly in every country of the world economic policy allowances and subsidies are granted to promote the solution of ecological problems. Such allowances may provide encouraging possibilities.

To reduce investment cost of red mud disposal a number of possible solutions have to be investigated. Stress should be laid upon the proper selection of the disposal area, use of local inexpensive construction materials for building the dikes and insulation of the basins. Another beneficial aspect which should be made use of is the recycling of reusable liquor to the plant.

Depending on local circumstances the value of land suitable for storing red mud can vary in the range of 0.02-0.15 $\$/m^2$, though several alumina plants got hold of suitable areas free of charge or at nominal cost.

Investment costs of red mud impoundment areas related to 1 m³ of storing capacity range as follows:

- \$ 0.3-0.4 in case of using cost free construction material (including consolidated red mud itself)
- \$ 0.8-1.2 in case of using natural material (soil, rock) including exploitation and transportation costs
- \$ 30 in case of using purchased industrial products (cement, bitumen, asphalt).

The establishment costs of the impoundment area would be increased by the cost of drainage system required for the recovery of the liquor, though these costs are returned.

Other costs of red mud storage such as the transportation of mud to the area and the costs of various operations required there, have similarly to be taken into account.

It is important that during the overall optimization of the plant technology the interrelations between the impoundment area and the selected technological solutions be also taken into account.

Pollution control tasks can be very different from country to country, site to site and they should be determined in accordance with the local natural, social and economic environment.

Tasks range from the regular observation (analysis of air and water samples), prevention of leakages, recirculation of liquor, dust control etc. up to the rehabilitation of the area.

A minimum requirement today is the establishment of testing wells around the red mud impoundment area. Their establishment cost is \$ 1,000 to 10,000 per well depending on soil conditions. Operating cost of regular inspection amounts to about \$ 0.01 per ton alumina.

The final requirement is the rehabilitation of the area. In case replantation with the existing vegetation of the surrounding area is performed, estimated cost of grassing comes to \$ 0.5-0.6/m² (e.g. by the Verdyol-Hydröse method), the cost of covering with arable soil and afforestation comes to \$ 1.0-4.0/m².

The problem of marine disposal, however, cannot be settled merely upon the basis of economy. Based on the feature of deepsea tests the problem calls for further investigations to decide, whether or not red mud actually influences the biological balance after a long period in the vicinity of the disposal area.

It should be mentioned that any disposal of red mud should be made public to establish proper public feeling. It is known that public opinion still increasingly responds on environmental protection problems so no expenditure should be saved in order to make known the actual state, the measures taken and to be taken, the problems solved and to be solved, so as not to make doubtful the results achieved by unmotivated excitement. The activity of Alcoa of Australia was found to be exemplary as regards both environmental protection and information of public reaction.

Most effective and complete solution of the environmental problems related to red mud would be its utilization, as a result of which red mud would cease to further be a source of pollution. Possibilities of red mud utilization were dealt with in Chapter 3.4.

Unfortunately the majority of recommendations for the utilization of red mud are not attractive for the users under the present economic conditions. A way of utilization which could be considered perspective is transforming red mud to an economically produceable product and using it for the production of e.g. multi-purpose heavy ceramic wares.

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4. ENVIRONMENTAL ASPECTS OF ALUMINIUM ELECTROLYSIS*

4.1. Pollution effects of the aluminium smelter technology

Modern aluminium production consists of two independent steps. In the first step the mineral found in nature is converted into pure aluminium oxide. In the second step aluminium is obtained from the oxide by electrolytic method (4.1). The industrial method of electrolytic aluminium production was patented by Hall and Herault separately in 1886. It is based on the electrolysis of aluminium oxide dissolved in melt cryolite (Na_3AlF_6) bath. The electrolysis is carried out at 940-980 C^o. Aluminium deposits at the cathode and rests on the bottom of the pot. Oxygen developed at the carbon anodes oxidizes the carbon. The electrolysis cells can be characterized by the type of the applied carbon anode. The way to collect the pollutants arising during the electrolysis is also determined by the arrangement and structure of the carbon anodes, since most of the arising gas leaves along the perimeter of the anodes.

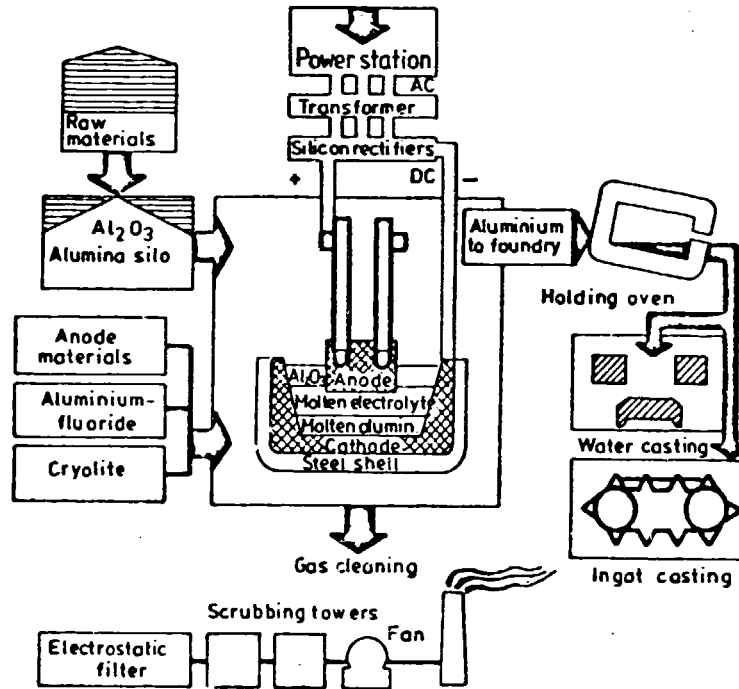
Two fundamental types of pots are used in aluminium smelter technology (4.2):

1. Pots with Wöderberg anode
 - a) vertical stud
 - b) horizontal stud
2. Pots with prebaked anode
 - a) center worked
 - b) side worked

The flowsheet of a Typical smelter with prebaked anodes is shown on Fig 20. The pots are placed into potrooms and connected in series. The structure of each pot is the same.

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Fig 20. Flow sheet of a typical smelter utilizing prebaked anodes.



Source: see ref 4.1.

Aluminium smelting releases a great number and amount of different pollutants. The emission sources are the pots themselves - in accordance with the technology.

The emitted pollutants are the following (43 to 48):

- carbon monoxide, since the oxygen released from alumina reacts with the carbon anode,
- sulphur dioxide, originating from the sulphur content of the pitch coke and tar used for the preparation of anodes,
- fluor compounds (HF from the hydrolysis of the fluor salts, NaF and AlF_3 from the vaporization from the electrolyte, CF_4 and a small amount of free fluorine gas),
- solid pollutants (fluor salts, alumina powder, soot, etc),
- polyaromatic hydrocarbons from anode combustion.

Among the emissions from the pots the fluorine compounds have attracted most attention. It is well known that they influence the health of the operating personnel and cause serious injuries to vegetation even at very small gas concentrations. From the economic point of view the loss of fluorine compounds is also undesired because of material loss and corrosion problems.

The composition of the waste gases from the electrolysis cells depends heavily on the type of anodes used. The waste gas from Söderberg type pots contains no less than 2 to 3 kgs of tar products per ton of aluminium produced, while prebaked anode type pots do not emit tar products in significant quantity. The total fluorine consumption lies between 20 and 50 kg per ton of aluminium produced for both types of pots and approximately half of this quantity is removed in the waste gas from the cell. Sulphur emission constitutes 5 to 15 kg sulphur equivalent per ton of aluminium produced.

The concentration of polyaromatic hydrocarbons in the potroom air varies between 3 and 3000 $\mu\text{g}/\text{m}^3$ air for Söderberg pots.

Recently several studies have been carried out concerning the effect of exposure to polyaromatic hydrocarbons, which are potential carcinogen agents. No evidence of a consistent excess risk of lung cancer was found in aluminium industry. However, cancer of other organs (pancreas, lymph, glands and kidneys) occurs more frequently than normal. (4.9)

4.2. Characterisation of the processing operation causing pollution

In the course of aluminium electrolysis concentrated (spot like) air pollution is caused by solid and gaseous materials leaving through the chimneys. Distributed (diffuse) air pollution is caused by all the pollutants leaving from cells to the potroom then through the holes of the potroom to the atmosphere.

Concentrated emission can be measured with confidence while the distributed one cannot be measured directly. Material balance calculations and emission measurements can provide only rough estimates of distributed emission.

4.2.1. Unloading and storage of raw material

The air pollutant is solid: alumina. The alumina used as raw material for aluminium electrolysis is transported in closed containers and unloaded into alumina silos. In the course of the unloading operation a small overpressure is formed. Cyclons or bag filters are used to separate the evolving powder. The degree of air pollution is influenced by the

type, efficiency and technical state of the separator.

4.2.2. Electrolysis

The air pollutants are solid: dust (alumina, fluor compounds) and gaseous: CO, SO₂, fluorides. The gas caught by the exhausting system causes concentrated air pollution. Distributed pollution is caused by the gases not caught by the exhaust system but leaving through the holes of the potroom roof into the atmosphere. Air pollution takes place continuously. The amount of carbon monoxide leaving the cell depends on the way of exhausting the anode gas. In case of pots with vertical stud anode a built-in burner can convert the significant part of the carbon monoxide into carbon dioxide which is less pollutant. The amount of SO₂ evolving depends on the sulphur content of the anode mass and on the amount of anode mass used. A great part of the fluoride content of the electrolyte bath is vaporized. One part of the fluor reacts with the carbon content of the electrodes and forms gaseous or sublimating compounds. Another part of the fluor forms hydrogen fluoride with the hydrogen bound to the pitch constituents of the anode mass. The electrolysis cells are under depression. Depression rises the fluor containing dust. In addition to that the alumina powder emerges heat and dusting is caused also by thermal convection. The degree of air pollution depends on the type of the cell, on the way of exhausting and on the operating conditions of the electrolysis.

In the course of electrolysis the alumina concentration in the bath is decreasing and an anode effect takes place. At an anode effect the pot voltage is increased up to 5-10 times. A gas cushion is formed around the anode which

insulates it from the bath. The result is a well visible arc discharge. The composition of the gas is changed and the CO content can reach upto 90 %. Also 1-2 % of carbon tetra fluoride can be detected. Hence, the degree of air pollution depends on the frequency and duration of the anode effects as well.

4.2.3. Alumina feeding, crust breaking

The air pollutants are solid: dust and gaseous: CO, HF and hydrocarbons. In case of lacking or not sufficiently operating of the exhausting system the alumina feeding operation is a distributed source of air pollution. In case of sufficient exhausting it can be considered a concentrated source.

The alumina is put on the crust of the electrolyte from the alumina feeding platform truck by pneumatic way. Here the alumina is preheated then by breaking the crust it is dropped into the electrolyte. The operation is accompanied by a significant dust formation. Breaking the crust gives free way for the gases (CO, HF, etc.) to escape. The degree of air pollution depends on the frequency, duration and way of alumina feeding and crust breaking. The efficiency of exhaust highly influences the degree of air pollution.

4.2.4. Aluminium tapping

The air pollutants are solid: soot and gaseous; CO, SO₂, tar derivatives. The molten aluminium is tapped into special vacuum tanks periodically every day or second day. Metal tapping is not accompanied by particular air pollution. Care must be taken, however, to ensure a given level of the metal remaining in the pot. After the metal level was decreased, the anode

must be lowered by 8-10 cm in some minutes to keep the necessary distance. (The distance between the bottom of the anodes and the surface of the aluminium layer is controlled to ensure heat balance.) In Söderberg type cells this operation frequently leads to the flowing of the anode mass accompanied by green fire. The phenomenon results a significant amount of air pollutants originated from pitch distillation (CO, SO₂, tar derivatives, soot).

The degree of air pollution depends on the frequency of the flowing of the anode mass, on the amount of sulphur burning out from the anode mass, on the amount of the vaporized tar derivatives and on the efficiency of gas exhausting system.

4.3. Biological effects of pollution caused by aluminium smelters (4.10 to 4.13)

4.3.1. The effects of fluorides on vegetation

It is established that gaseous fluoride compounds are amongst the most toxic pollutants. Experiments show serious damage of vegetation at 0.001 ppm HF concentration of the air. The fruits, first of all the cherry, the plum, the apple, the pear, the nut and the grape, are very sensitive to the fluoride compounds. Some forest trees, like different types of pine, beach, poplar, oak and chestnut are also very sensitive. An important factor influencing the toxicity of the fluoride compounds is the type of soil. It is a general experience that on alkali type soils shades are less serious than on acidic type soils. Calciferous soils can fairly well compensate a moderate level of fluoride pollution and in a similar way lime containing fertilizers can also reduce pollution effects.

The physiological mechanism of fluoride poisoning has not been discovered in details. It is known, however, that the fluoride compounds effect metabolism processes. Solid fluoride taken through the roots happens to be less harmful than gaseous uptake ingested by the leaves of the plant.

4.3.2. The effects of fluorides on health condition

Fluoride is a normal constituent of body tissue and ingestion from trace amounts in water is desirable. Continued exposure to abnormal level of fluorides leads to dental and/or skeletal fluorosis. Dental fluorosis introduces permanent defects into the teeth, especially during childhood. Dental fluorosis of animals may lead to grooving and pitting of the teeth.

Skeletal fluorosis can be detected by X-ray examinations. In severely affected animals it can lead to stiff laborious gait and difficulty in rising.

In aluminium industry the above mentioned forms of fluorosis are seldom encountered. Bronchitis is, however, frequently met among workers in aluminium smelters.

According to some studies on the effects of fluoride on personnel it was found that new employees frequently develop headache, nausea, irritation of conjunctiva and respiratory passages. The symptoms are usually cleared in several days. Continuous exposure to potroom conditions (3-10 mgF/24 hr) caused 13 % incidence of cough and X-ray detectable abnormalities were found in one quarter of the potroom personnel.

Fluoride uptake must be closely monitored by regular tests of urine samples of the workers. Average urinary con-

centration of under 5 mg F per litre corresponds to a daily intake of 5 mg F. At a daily intake of 5-8 mg F osteosclerosis does not occur yet. Higher average intake is considered dangerous.

4.4. Threshold limits for fluoride emission (4.26)

In several countries administrative restrictions have been introduced to control air pollution caused by fluoride compounds. There are at least three types of restrictions: threshold limit values, air quality standards and emission restrictions.

The threshold limit value is the maximum acceptable fluoride content for continuous exposure for eight hours per day. Its aim is to save the health of the personnel of the smelter. The threshold limit value is usually expressed separately for hydrogen fluoride (0.5-2 mgF/m³ air) and for total fluoride amount (1-2.5 mg F/m³ air).

Air quality standards impose restriction on the average concentration of hydrogen fluoride or total fluoride compounds on a one day base. Typical limit values are 0.001-0.01 mgF/m³ air. Air quality standards impose indirect restrictions on fluoride emission.

Emission restrictions concern emitted pollutant flux expressed in kg F/hr. Such limits are imposed in a few countries only.

4.5. Technological possibilities to reduce emission levels

The gravest air pollution problem caused by aluminium smelters is that gases containing fluoride can escape to the

atmosphere. The emission takes place partly through the potroom air (distributed source) and partly through the chimneys of the exhausting facilities (concentrated source). The distributed source is hardly controllable clearly. In order to reduce the pollutant emission to some prescribed value it is necessary to increase the exhaust and fluorine collecting efficiency. The exhausted gases can be treated by effective scrubbing facilities. There are two fundamental technologies for gas treatment: the wet and the dry scrubbing one.

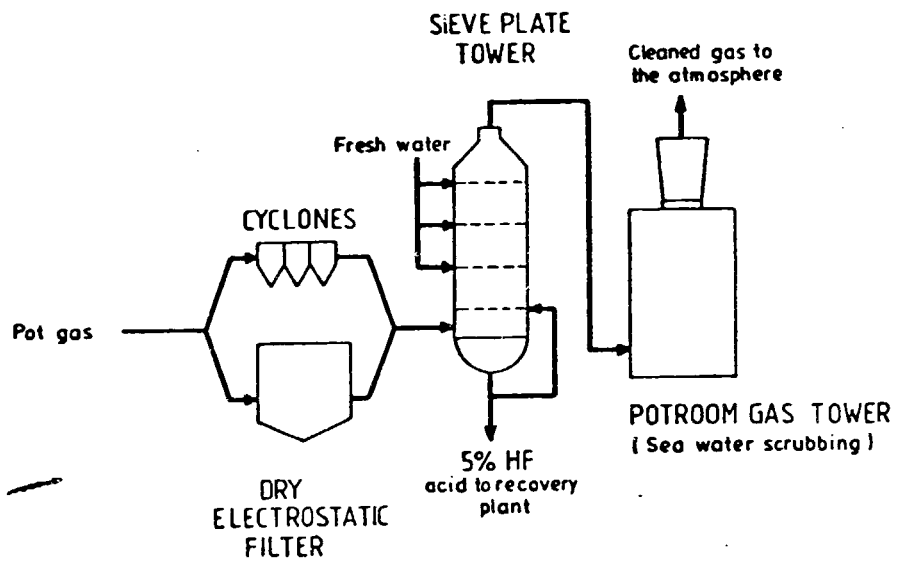
The basic principle of the wet technology is that the waste gases are led through a wash liquor (water or alkaline wash) in order to capture the fluor containing impurities. The wash liquor must be regenerated by recovering the fluoride from it.

The basic principle of the dry technology is to lead the waste gases through an alumina layer which adsorbs the fluoride compounds. The treated alumina can be directly fed into the electrolysing cell.

4.5.1. Wet scrubbing gas treatment technique (4.14-4.18)

The flow sheet of a typical wet scrubbing system is shown on Fig 21. The pot gas is led through cyclones and/or electrostatic filters to remove dust and tar, then it enters the scrubbing tower with sieve plates. The washing liquor flows in countercurrent direction and leaves for the HF recovering operation. The gas from the sieve plate tower is fed into a second tower where scrubbing is accomplished by sea water. Here most of the SO_2 content of the gas is absorbed. The scrubbing water is discharged without any recovery into the sea.

Fig 21.: Flow sheet of a typical wet scrubbing system.



Source: see ref 4.1.

The solution of 5 % HF obtained in the sieve plate tower can be recovered by alumina to aluminium fluoride.

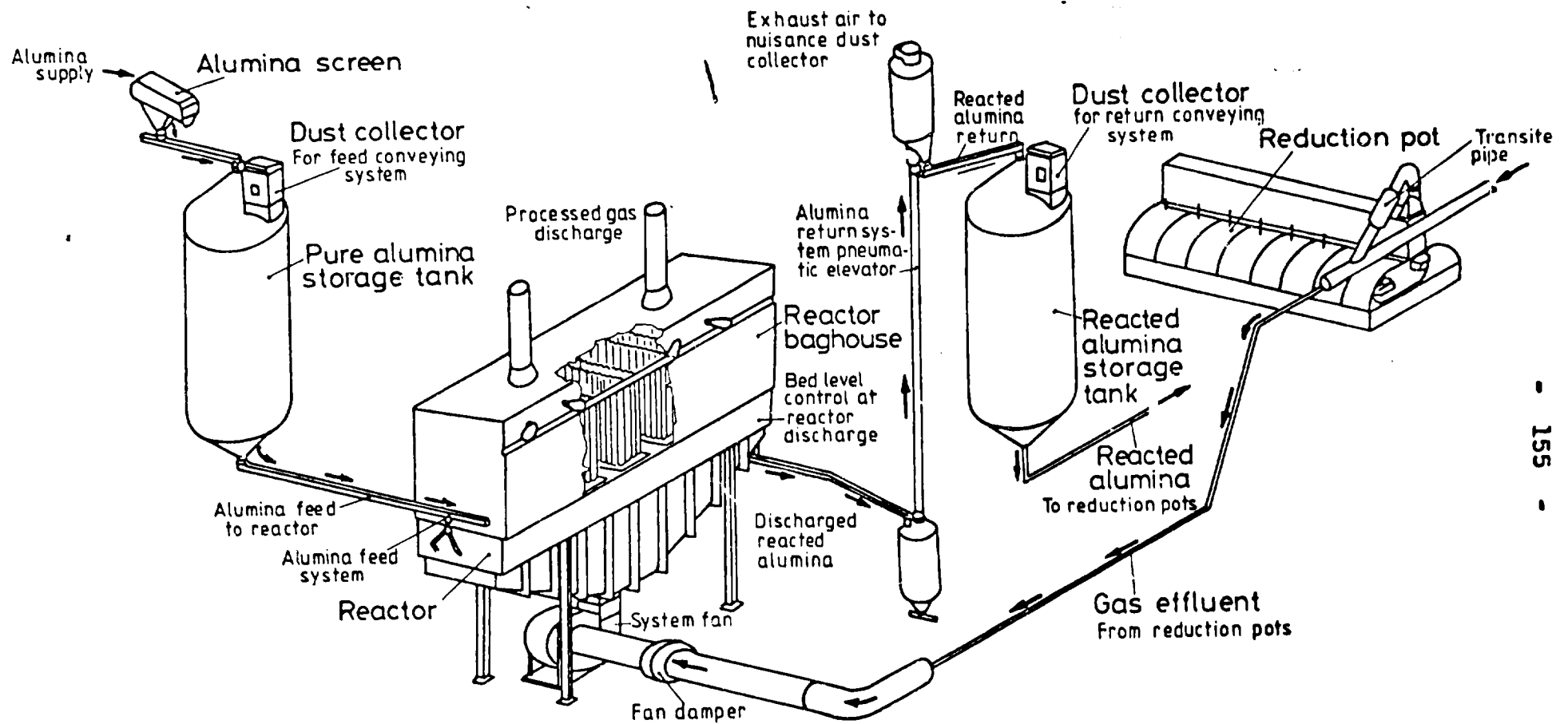
The advantage of the wet technology is that the impurities are not recirculated into the pots hence the metal purity is not affected by the gas treatment. Serious corrosion problems, however, make dry scrubbing technique more attractive.

4.5.2. Gas treatment by dry scrubbing (4.19-4.25)

Dry scrubbing is based on the physical and chemical sorption of HF on alumina. The sorption is carried out at low temperatures (about 100 °C). The flow sheet of a typical dry scrubbing facility is shown on Fig 22. In this ALCOA 398 procedure the exhausted gases from the pots are led through an alumina layer placed on a perforated sheet. The alumina is fluidized. In the upper part of the fluidizing reactor bag filters are placed to capture the alumina entrained by the gas stream. The fluor separating efficiency can reach 99.0 %. Approximately fifty per cent of the alumina to be electrolysed is used for the gas treatment. The treated alumina is fed into the pots. While being preheated on the crust the sorbed gas is converted into aluminium fluoride..

Dry scrubbing is very simple and cost efficient technology. It is particularly suitable at cells having prebaked anodes where tar vapours are not taken into account either. There are, however, some disadvantages of the technique. Preheating is not entirely satisfactory for recent automated break-and-feed design. Volatile impurities apart from the fluorides are continuously recirculated and consequently accumulated in the bath destroying the quality of the produced metal. The requirement of high real surface area makes necessary to use alumina of

Fig 22.: Fume treatment system of ALCOA



Source: see ref 4.20.

a higher portion of γ - Al_2O_3 , while α - Al_2O_3 would be preferable for its better dissolution characteristics in the electrolyte.

4.6. Ecological aspects of erecting new plants (4.27)

When designing new plants it is highly desirable to avoid distributed pollution sources. All pollutants not separated must leave through concentrated sources. This makes possible effective monitoring and further improvements if needed. Therefore special emphasis must be taken to exhaust and fluor collecting efficiency.

In case of new plant design or reconstruction the separator facilities must be selected to minimize the pollutant emission within the framework of the technico-economic possibilities.

Since air quality depends not only on emission levels but on several other factors as well, a detailed study of the meteorological and air pollution situation of the district must be carried out.

When locating new plants the following meteorological parameters must be taken into account: wind direction, wind rate, wind frequency, quantity of precipitation, etc. In addition to the meteorological factors the following parameters characterizing the air pollution situation of the district must be considered: recent level of emission, other existing and designed industrial sites, existing and designed residential areas, territorial and topographic relations influencing the binding and propagation of the pollutants, possible protecting effect of the vegetation, etc.

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5. ENVIRONMENTAL ANALYTICAL CHEMISTRY IN THE ALUMINA AND ALUMINIUM INDUSTRY

The presence of ecotoxic materials in the aqueous, atmospheric and biological ecosystems is proved by the data of different analytical methods. To evaluate properly the presence of these materials a special branch of the analytical chemistry has been developed in the last two decades. The features of these analytical methods used in the field of environmental protection are as follows:

1. Very low levels of concentration of different inorganic, organic and organometallic substances should be investigated.
2. Special sampling methods should be elaborated for the low concentration, for the evaluation of the average value and of the local distribution of harmful materials.
3. The correlation of the analytical results and different specific data eg. meteorological, geographical, etc. should be taken into consideration in the final report.
4. Different specific sampling, analytical and evaluation methods are necessary to monitor the environmental effects of different technological processes.
5. Disregarding the soil analysis, the matrix effects can be neglected, because the samples are generally coming from either the polluted air or the diluted aqueous solutions.

The techniques generally applied for the trace analysis of the environmental samples are atomic absorption spectroscopy (AAS), atomic emission spectroscopy with inductively coupled plasma source (ICPAES), stripping voltammetry (SV) or the combination of the latter method with differential pulse polarography (SVDP), liquid and gas chromatography

(LC, GC) generally combined with mass spectrometry (LCMS, GCMS) and ultravioletvisible or infrared spectrophotometry (UVS, IRS).

Recently, much attention has been paid to the specific instruments applied for solving certain analytical problems of environmental protection (1,3,4) (eg. the specific IR gas detectors, or the FLUCHECK gas analyzer, etc.)

In the field of alumina and aluminium industry the soil, water and the air can be polluted by the industrial production.

Strictly speaking, the ore exploration and bauxite mining activity do not cause any pollution, however they have other impacts on the environment. The elimination of these effects is discussed in Part 1.

In the alumina production the red mud of significant sodiumsalt content can pollute soil and water. The air is also polluted by certain particulate matter like bauxite, red mud and alumina dust, furthermore, by some products of the electric power station.

However, the main source of air pollution is the electrolysis; the gaseous byproduct formed in the smelters contain some fluoride, sulphide and carcinogenic organic compounds. The dust emission of smelters is considerable also.

The first step of the quantitative evaluation of pollutants is sampling, either a continuous monitoring system or laboratory methods are used.

5.1. Sampling of different materials for environmental analysis.

The sampling process in case of soil or water is quite well known from the common analytical practice.

An important peculiarity of the environmental analysis is the proper selection of the quantity of sample. It depends on the detection capability of the particular analytical technique and on the concentration level of the contaminant to be determined. Since the high and the low concentration values of impurities change in time covered, the duration of sampling from flow water is a significant factor to obtain the representative average value.

The collection of accurate and precise atmospheric samples of particulate matter is much more difficult as their sizes, densities and concentration fluctuate. Different collection devices are used in this field based on sedimentation, filtration, dry and wet impingement, electrostatic and thermal precipitation. For the selection of the appropriate device a good collection is summarized in A. C. Stern's book (5.1).

To examine the source of dust pollution, only the isokinetic sampling system can be applied. The stack sampling test is not a highly reliable method, and its possible sources of error are discussed in several publications (5.2.). The applied sampling method, the sampling location, number of sampling points, duration of sampling at each point and total sampling duration must be specially considered for each case of sampling. The overall test should be as long as possible (2-6 hours) to cover one or more cycles for cyclic processes.

The procedure used for sampling a gas or mixture of gases in a duct or stack differs from the sampling of particulate matter. The strict conditions of the isokinetic sampling procedures are not required.

There is nevertheless the problem of selecting the proper collecting device which will enable reliable quantitative analysis. The rates of gaseous sampling are generally much lower than in case of particulate matter sampling, ranging approximately from 1 to 5 liters/min. Several different methods are available for collecting the gaseous constituents from gas streams. Selection of the appropriate method depends upon temperature, humidity and the gaseous constituent being analyzed.

The most frequently used devices are the liquid absorption with wet scrubbers (impingers), solid absorption, freez-out units, etc.

From the special aspects of alumina and aluminium industry the next sampling processes are generally applied:

1. Sampling of soil near red mud lakes.
2. Sampling of particulate matter near the alumina and aluminium factory (bauxite, red mud, alumina, cryolyte, sodium fluoride, etc.)
3. Sampling of water in different industrial waste water tubes (for pH, sodium, cyanide, etc.)
4. Stack sampling in power plants, calcining ovens and in aluminium smelters.

5.2. Analysis, detection.

As it was summarized in the previous, the soil and water samples can be analysed for sodium, fluoride and cyanide content,

moreover, the pH value can be measured.

After the adequate sampling the cyanide and sodium content can be extracted. After separation, the sodium content can be measured by flame photometric or AAS method or, together with the cyanide and fluoride ions, by ionselective electrodes. The details of these methods can be found in the literature. The pH value can be measured in a suspension of the soil or in case of higher alkaline concentration it can be titrated.

The water samples can be analysed by the same methods without any pretreatment.

The different components of particulate matter can be determined by several routine analytical methods (eg. AAS or ES methods) after the morphological classification of the particles by certain microscopic techniques. These methods can be eliminated if the scanning electron microscope is used. In that case both the morphology and the chemical composition can be investigated because the SEM instruments are generally built together with an energy dispersive X-ray analyzer (EDXRA).

The different waste gases and ambient air are investigated for the determination of SO_2 , CO, CO_2 , fluoride and organic compounds.

The determination of the gaseous constituents of waste gases and of ambient air is performed from the scrubber solutions in the form of the absorbed ions. Due to the different concentration levels and sampling times, the concentration of the different constituents can vary significantly. Therefore, the absorber solutions can be analyzed by different methods. The actual procedure is selected with

regard to its detection capacity precision, fastness, etc. Such methods are the very accurate titrimetric methods or the potentiometry with ionselective electrodes or some others having been previously mentioned.

5.3. Source monitoring

The monitoring of pollutant concentration or of total mass flow of pollutant emission from stationary sources is a major problem of plant owners, control agencies and instrument manufacturers. To fulfill the regulatory requirements and to control the environmental pollution, the industrial establishment needs to keep a record of process operation and contaminant emissions. Instrument manufacturers need guidelines on performance requirements in order to provide appropriate instrumentation.

On-site monitoring provides data about one source of pollutant continuously. In the alumina production the monitoring of the pH-value and sodium content of out-flow waste water and the particulate matter, the SO₂ emission of power plants have special significance. In the aluminium smelters the monitoring of fluoride, SO₂, CO, CO₂ and organic materials of stack gas are the primary tasks.

The typical performance of monitoring system for pollutant emission from stationary source are as follows (6): error less than 20 %, calibration error less than 5 %, zero drift (24 hours) less than 4 %, response time less than 15 minutes.

The monitor systems contain the automatic sampling devices, the detector units and the data handling systems.

The particulate matter emission is measured by optical, electromechanical, electrical and nuclear techniques. Monitoring of gas emission is mainly performed by IR and UV - visible, electrical conductivity, coulometric, potentiometric and gas chromatographic detectors.

To monitor waters, potentiometric and conductometric analytical monitors are widely used in the aluminium industry.

Monitoring of the emitted gaseous components of the aluminium production is realized by IR detectors as well as by potentiometric monitors (eg. FLUCHECK).

The instrumentation used for monitoring environmental pollution in alumina and aluminium industry are summarized in Table 10.

Table 10: Instrumentation used for monitoring environmental pollution of alumina and aluminium industry.

Task	Instrumentation	Producer
Water quality	Industrial pH sensor	Beckman, Radelkis
pH, Na, con-	Industrial pNa sensor	ALUTERV-FKI
ductivity	Conductivity meter	ALUTERV-FKI
Particulate matter		VASKUT
Ambient air, gas		
SO ₂	SO ₂ analyzers, FLUCHECK analyzer	Antechnika, Casella ALUTERV-FKI
CO, CO ₂	IR analyzers	Antechnika, Foxboro, Hiteka
F	FLUCHECK analyzer	ALUTERV-FKI

The calibration and the standard used are of primary importance at every instrumental method.

5.4. Data handling and evaluation

The data of the emission sources of pollutant are regularly given by the laboratories or monitor units, and should be evaluated by the research and control personnel. The geographical and meteorological data are also required for the preparation of an appropriate report about the emission into the environment (Emission inventory).

A detailed report provides the possibility to make different modelling for the development of a suitable emission control strategy.

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