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Letter of transmittal to the Executive Director of UNIDO

We have the honour to submit herewith the report of a group of experts on the aluminium industry, Alumina production from various ores. This report was prepared during our meeting, 10-16 November 1967, at the headquarters of the United Nations Industrial Development Organization, Vienna.

The group elected Mr. G. Dobos, Doctor of Science, Managing Director of the Hungarian Aluminium Corporation, Magyar Aluminiumipari Troszt, XIII Poszony ut 56, Budapest, Hungary, as its Chairman, and Mr. P. Dayal, Doctor of Philosophy (Metallurgy), Development Officer (Metals), Directorate General of Technical Development, India and Mr. B. Siahaan, Engineer, Chief of the Indonesian Aluminium Project, Indonesia, as its Rapporteurs. The other members of the group were:

Mr. S.I. Beneslavsky	Doctor of Science on Minerology, Chief of the laboratory of the aluminium-magnesium institute of the Soviet Union, Moscow, Union of Soviet Socialist Republics
Mr. S. Moment	Consulting Industrial Economist 2916 S.E. Woodstock Boulevard Portland, Oregon 97202 United States
Mr. Ed. Nachtigall	Doctor, Engineer, Dozent, Director of the aluminium reduction plant "Vereinigte Metallwerke AG", Austria Parkstrasse, Braunau am Inn, Austria
Mr. G. Popov	Consulting Engineer, Head of the Research Laboratory, Argentina, Hipólito Yrigoyen, Buenos Aires, Argentina

Mr. J.H. Reimers	Head of the Metallurgical Consulting Company 260, Church Street Oakville, Ontario, Canada
Mr. J. Vosyka	Engineer, scientific worker in an aluminium plant, Czechoslovakia ZSNP, Ziar nad Hronom, Czechoslovakia

Mr. M. Maurakh and Mr. B. Crowston, staff members of UNIDO, were assigned to the group as Technical Secretaries to assist in its work.

The terms of reference given to us were to present papers on alumina production from various ores with particular reference to the needs of developing countries, to discuss these papers and to prepare a report conteining conclusions and recommendations.

In submitting this report we have acted in a personal capacity, not as official representatives of the organizations of the Governments to which we belong.

(G. DOBOS) (JAN H. REIMERS)

(B. Siahaan) (USA)

(J. Vosyka)

(P. DAYAL)

Note: This report summarizes the papers presented and the discussion that took place at the First Meeting of an Expert Consulting Group on the Aluminium Industry.

Copies of the individual papers listed in annex 1 of this report are available upon request from the Metallurgical Industries Section, UNIDO, Rathausplatz 2, 1010 Vienna, Austria.

INTRODUCTION

1. The United Nations Industrial Development Organization has made plans for a series of expert group meetings on the aluminium industry. The purpose of these meetings is to examine the present technological and economic status of aluminium production and make recommendations for the development and improvement of the aluminium industry in developing countries, and to assist UNIDO's technical assistance activities in this field. This report covers the first meeting of a group of experts on the aluminium industry and examines the production of alumina from various ores. Further meetings of groups of experts will be held in the future to cover other aspects of aluminium production.

2. The aluminium industry dates back to the beginning of the twentieth century. Early aluminium producing plants were located in the United States and Western Europe; they were fully integrated and operated with local ores and bauxites and used local hydroelectric power. The production of aluminium increased during the Second World War. Rapid expansion was continued in post-war years but the reserves of high quality bauxite in Western Europe and to a lesser extent in the United States were insufficient to satisfy an increased demand for aluminium products. New supplies of bauxite were found in tropical regions which are now mainly developing countries. These areas supply approximately 70 per cent of the world's bauxite; over 90 per cent of the world's aluminium, however, is still produced in developed countries.

3. Interest in aluminium is now universal. In recent years aluminium industries have sprung up in a number of developing countries and many other countries have examined the possibility of establishing an aluminium industry. The first section of this report assesses the present state of alumina and aluminium production in the world and in developing countries. The second section examines the reserves and requirements of aluminium ores. Practically all of the world's aluminium is obtained from bauxite. However, the Union of Soviet Socialist Republics has successfully produced aluminium from other aluminium-bearing ores on a commercial scale. The third and fourth sections examine the present technology and future potential of the conventional method of processing bauxite to alumina by the Bayer process.

4. The treatment of low-quality bauxites with alumina to silica molar weight ratios less than 8 and other complex alumina-bearing ores are examined in the fifth section of the report. Treatment by the sinter method, parallel Bayer-sinter process, combination method, desilication process, electrothermic reduction, acid process, Ponomarev method and the high-pressure tube autoclave digestion are described.

CONCLUSIONS

5. Aluminium has shown a faster consumption increase in recent years than all other common metals; in 1966 approximately 7 million metric tons were produced. The expected average growth rate is on the order of 6 to 9 per cent per year. On the basis of the lower figure world production of primary metal should be 12 million metric tons in 1975 and nearly 16 million metric tons in 1980.

6. Practically all of the world's aluminium is produced from bauxite by the Bayer process. It is now possible to treat efficiently a large variety of bauxite qualities including mixed bauxites.

7. Most of the world's bauxite reserves and a large proportion of the world's undeveloped water power are located in the tropical and sub-tropical belt, mostly in developing countries. Natural conditions, therefore, exist for establishing alumina and aluminium reduction plants in many of these countries. The advent of cheap nuclear power could in the long term, however, provide new possibilities for economic aluminium reduction plants in industrially developed countries with bauxite deposits but no hydroelectric power.

8. Major aluminium companies usually think in terms of alumina plants with a capacity of at least 400,000 metric tons and aluminium reduction plants with capacities of at least 100,000 metric tons. The capacity of the smallest alumina plant built in the United States during the last two decades was 330,000 metric tons per year. Minimum capacities of alumina plants connected with mining of a bauxite deposit, for example, in Australia, Surinam, Jamaica and West Africa during this period was about 200,000 metric tons per year.

9. In recent years, aluminium has been produced by direct reduction from aluminium compounds in electric resistance arc furnaces in relatively small-scale pilot plants. These direct reduction processes do not present a threat to conventional alumina and aluminium reduction plants within the foreseeable future.

10. Bauxite is the most important raw material for alumina production at present; the world's bauxite reserves in the foreseeable future should reach not less than 25 billion (25×10^9) tons. This will satisfy the world's

demand for aluminium for hundreds of years. The greatest increase of bauxite reserves may be expected on the African and Asian continents. Some countries are located in "bauxiteless" zones, however, and this might necessitate their processing aluminium-containing ores other than bauxite.

11. The most important non-bauxite aluminium ores are nepheline sodas. Extraction of alumina from these ores is carried out in the Union of Soviet Socialist Republics on an industrial scale. Aluminite is used as a raw material for alumina production in Mexico, the United States and the Union of Soviet Socialist Republics. Clay-type ores are also used for Al-Si alloys by the electrothermic method.

12. The Bayer alumina producing process which in its basic principle remained substantially unaltered for nearly one hundred years, has attained a considerably high technical level. The equipment used has been improved and modern control methods have been introduced.

13. Further knowledge of bauxite properties and its practical utilization, stepping up of mineral composition determinations, research with a view to mechanism of chemical processes, further development of thermal techniques, enlargement of the utilization of high-capacity equipment, improvement of the efficiency of countercurrent processes as well as modern automation and increasing the degree of computer control used, may result in further improvement of the economic efficiency of production.

14. Low-grade bauxites containing more than 7 per cent silica cannot be treated by the Bayer process. Modified versions of this process, however, such as the sinter, parallel Bayer and sinter, combination and desilication processes can be used to treat sub-marginal quality bauxites. The techno-economic indexes of these methods are not as high as those of the Bayer method although they have improved significantly during recent years.

15. The factors which have chiefly controlled the creation of the alumina industry in the developing countries and which would also assist in their expansion are: the availability of adequate long-term supply of bauxite; the need of large aluminium enterprises in the developed countries to import alumina, and their willingness to provide the finance and know-how and secure necessary markets; and the provision of suitable terms and conditions by the developing countries.

RECOMMENDATIONS

It was recommended that developing countries should:

16. Consider, in addition to investigating and evaluating natural resources, market analysis, feasibility studies or clarification of financial possibilities, the following aspects which are characteristic of the aluminium industry

(a) The composition of the particular bauxite deposit which allows a preliminary consideration of the possible technological variants to be predicted, for example, the optimal digestion conditions, the settling properties of the red mud obtained, the possible elimination of certain impurities necessitates in the majority of cases pilot-plant examination of the ores before the properties of the corresponding plants could be assessed;

(b) The possibility of pilot-plant scale examination of the most important aluminium ore deposits either in the existing plants or creating in some countries new units with the aid of UNIDO;

17. Examine the processing of mixed ores (gibbsitic-boehmitic, boehmitic-diasporic types) which in individual cases necessitate the elaboration of technological modification of the Bayer process;

18. Assess whether the extraction of certain elements contained in bauxite may increase the over-all economy of the process. For example, production of vanadium, gallium and other technically valuable elements has been carried out in some countries. The utilization of the iron titanium fluorine and other useful components in the ore might also be considered in individual cases;

19. Examine the possible processing of lower quality bauxites by the application of series and parallel combined variants of the Bayer process. These ores are successfully treated by these methods in several countries;

20. Study the utilization of non-bauxite alumina-containing ores for the production of alumina from the technical and economic point of view. Attention could be focussed on the experience of the Union of Soviet Socialist Republics in processing such complex ores (nepheline, alunite, different clays);

21. Present their proposals for developing the aluminium industry to the United Nations Industrial Development Organization who will ascertain whether the necessary technical assistance through the Technical Assistance Funds, Special Funds or the Special Industrial Service Fund is to be granted.

It was recommended that developed countries should:

22. Make provision for technical education and training of personnel of the developing countries in the field of alumina and aluminium industry;

23. Establish and maintain contact with experts in the field of the aluminium industry of developing countries for the purpose of promoting their participation in the preparation and execution of new projects;

24. Make available to the Governments and firms of developing countries all books, pamphlets and other documents on aluminium production. Distribution should be made for public use in the developing countries;

25. Organization of further research work on low-quality bauxites and other complex aluminium-containing ores in order to make the processing of these more efficient and more economical.

It was recommended that UNIDO or the appropriate United Nations organizations should:

26. Arrange further regular meetings of a group of experts on the aluminium industry, possibly with a nucleus of permanent members, to solve problems or give concrete advice and suggestions to developing countries wishing to establish or develop bauxite, alumina or aluminium production. It is suggested that some of these meetings be organized in interested developing countries;

27. Organize in the near future an international meeting dealing with the problems of estimation of bauxite resources with a special view to the methodological aspects of such problems to make the evaluation of existing ore resources more accurate and further geological prospecting activity more efficient;

28. Undertake studies to evaluate technical indexes which allow an economic assessment of alumina production from bauxites and other complex bearing ores;

29. Organize in some interested developing countries installation of specialized laboratories dealing with bauxite analysis and laboratory scale technological tests, taking in view the possibility of utilization of the facilities of existing universities and institutions. (This may be of interest to a number of developing countries with bauxite deposits);

30. Arrange the systematic preparation and distribution of UNIDO documents dealing with problems concerning the development of bauxite mining, alumina and aluminium production, marketing and fields of application of aluminium products in these countries;

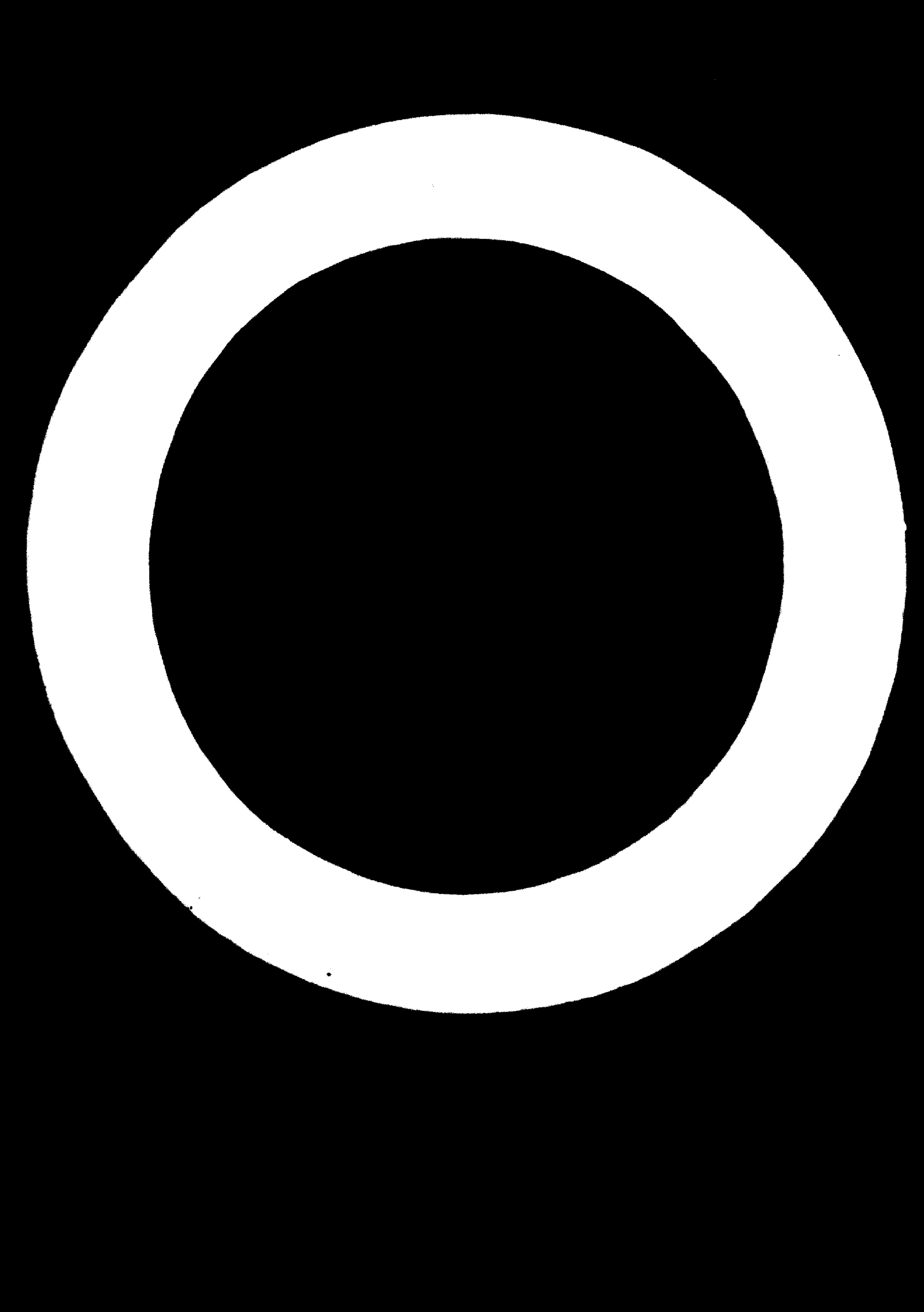
31. Organize market analysis of possible outlets of alumina and aluminium products of the developing countries on national, regional and interregional levels and carry out feasibility studies on the installation of alumina and aluminium plants on the initiative of interested countries;

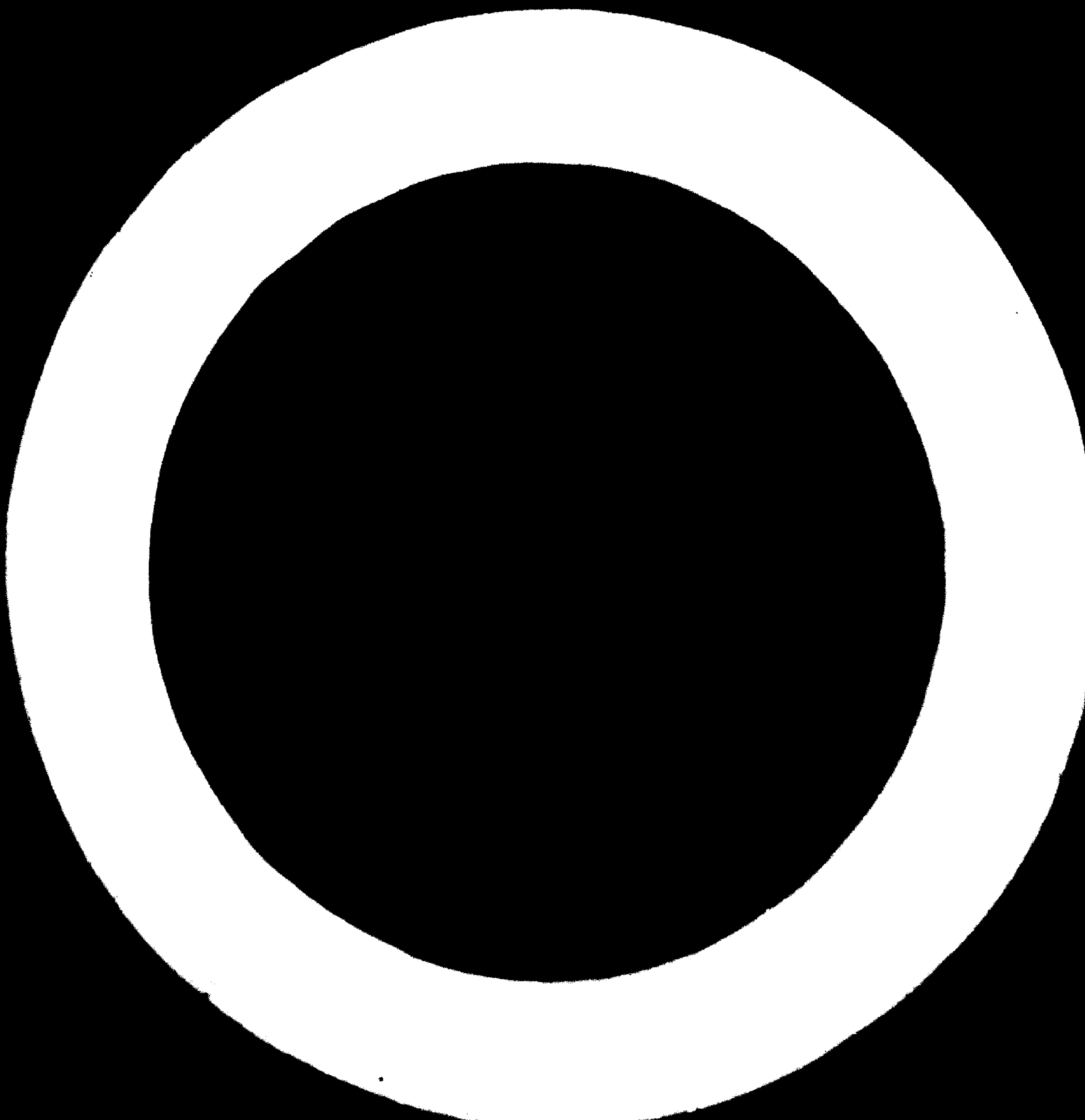
32. Organize short seminars at regular intervals for leading government officials and developing countries wishing to establish an aluminium industry. These seminars would aim to inform these executives of the basic problems of the establishment and development of an aluminium industry;

33. Increase the fellowship programme through technical assistance activities of the United Nations;

34. Examine the necessity of creating a permanent special course or studies in developing countries dealing with the problems of the alumina and aluminium industry;

35. Study the necessity for the preparation, analysis and compilation of a compendium of the mining codes of the developing countries in order to facilitate successful execution of bauxite mining projects in these countries.





I. PRESENT STATE OF ALUMINA AND ALUMINIUM PRODUCTION IN THE WORLD AND IN THE DEVELOPING COUNTRIES

Present situation and future outlook

36. The latest available statistics of world production of bauxite and aluminium, together with details of exports and imports of these materials are shown in tables 1 to 6. Statistics for alumina are not available for many countries because alumina is an intermediary product which is often not shown separately; however, the latest available tables showing world alumina exports and imports are shown in tables 7 and 8.

37. Most alumina plants are located in the main aluminium metal producing countries, rather than in bauxite producing countries. This has, of course, historical reasons since the alumina industry first grew up in the old established aluminium producing countries, and this situation has been perpetuated by the tariff protection afforded by these countries against alumina imports, and also probably to some extent by the major aluminium companies' reluctance to invest the large sums required in the bauxite producing countries.

38. The present situation is that developing countries with bauxite deposits are still exporting most of their bauxite in unprocessed form. This is illustrated by table 9 showing 1960 production figures for bauxite, alumina and aluminium, taken from "Bauxite, Alumina and Aluminium", published in 1962 by the United Kingdom's Overseas Geological Surveys. The figures are, unfortunately, not up-to-date because alumina production figures are not normally published in all countries. Since 1960, several alumina plants have been built in developing countries, in St. Croix in the Virgin Islands (this is, however, administratively United States territory), Surinam, Guyana, Brazil, India and China (Taiwan); the plant in Guinea has reached a production of more than 500,000 tons per year and a large alumina plant with a capacity of nearly 1 million tons per year will be built in Jamaica. At the same time, however, considerable expansion of alumina production facilities has taken place in industrially advanced countries such as the United States and Japan who import their bauxite and in Australia where some of the world's largest bauxite deposits have been discovered in the course of the last ten years.

The general trend appears to be towards locating new alumina production facilities near bauxite sources, that is, to a considerable extent in developing countries.

39. Table 9 shows an even more striking concentration of aluminium reduction capacity in the industrially advanced countries. Substantial aluminium reduction facilities, however, have been added since 1960 in Surinam, Mexico, Brazil, China (Taiwan) and India.

40. Aluminium has shown a faster consumption increase in recent years than all other common metals. In 1966, 7 million metric tons were produced. The expected average growth rate is on the order of 6 per cent per year. This basic world production of primary metal should be 12 million metric tons in 1975 and nearly 16 million tons in 1980.

Main economic factors affecting present production

41. The main factors affecting the economics of alumina and aluminium production are discussed below.

Bauxite and other alumina raw materials

42. Bauxite is and will be, as far ahead as one can see, by far the main raw material for aluminium production. Bauxite is the result of tropical surface weathering of aluminous rocks and is, therefore, found mainly in the tropical and warm zones of the earth. It is, therefore, deficient in many of the industrially advanced countries with large aluminium industries such as the United States, the Soviet Union, the Federal Republic of Germany, Great Britain, Japan and Canada.

43. Practically all of the world's alumina is produced from bauxite by the Bayer process. The only non-bauxite raw material which is used today on a large scale is nepheline, a sodium-potassium-aluminium silicate containing approximately 34 per cent Al_2O_3. It is obtained as a by-product from the beneficiation of apatite mined on a large scale on the Kola Peninsula. This nepheline is used for the production of alumina in the Soviet Union, whereby potash is obtained as a by-product.

44. The Bayer process has been greatly improved in recent years and will certainly produce most of the world's alumina requirements for many years to come. Continuous digestion has become standard practice for all types of bauxite, and continuous precipitation is also being widely adopted. It is now possible to treat efficiently a large variety of bauxite qualities, including "mixed bauxites". Fuel consumption has been greatly reduced as the

result of improved heat exchanger efficiency. Plant capacity has been increased by using sodium hydroxide instead of sodium carbonate.

Auxiliary raw materials

45. The main auxiliary raw materials in aluminium production are fluorides (cryolite and aluminium fluoride) and anode materials, low ash coke and pitch.

46. The only known large natural cryolite deposit at Ivigtut in Greenland is practically exhausted. Most present and all future fluoride requirements will, therefore, be based on processing fluorspar (calcium fluoride) of which there exist large deposits in the world, for example in Newfoundland, Mexico, France, Spain, Sweden, China, South Africa and the Soviet Union. Present reserves are estimated to be sufficient to supply the demand for the next twenty years.

47. Practically all the low ash coke used as anode material is petrol coke, of which there are adequate supplies today. Petroleum coke could, however, become a bottleneck if the aluminium industry grows faster than petroleum refining; substitutes may, therefore, acquire importance in the future.

Electric power

48. Electric power is the most important economic factor in aluminium production. Electrolytic aluminium reduction on an economic scale requires large quantities of cheap power.

49. Power from coal, lignite, natural gas and in particular from hydroelectric power developments, is used for aluminium production. Of these power sources, natural gas requires the lowest investment per kilowatt installed, but fuel cost is usually comparatively high. Hydroelectric developments, on the other hand, usually require the highest investment but are very cheap to operate. Amortization and interest on capital always form a large proportion of the power cost.

Labour

50. With rising living standards, labour cost becomes an increasingly important economic factor in the aluminium industry. Labour requirements for bauxite mining have been greatly reduced in recent years by extensive use of modern mechanical equipment such as bulldozers, draglines, large trucks and in particular enormous rotary bucket excavators which have been in use for some years now in Surinam and Guyana. Bayer alumina plant operating labour

requirements have been reduced by the adoption of large units and the now almost universal changeover to continuous operations.

51. Ocean freight costs are being greatly reduced by using large bulk carriers; at the same time, mechanical loading and unloading equipment is lowering terminal costs. Overland rail freight charges, on the other hand, show in most countries a tendency to increase.

52. The result of this is that it has become economical for the major aluminium producers to bring in bauxite or alumina from distant sources, using large bulk carriers.

Plant size

53. Major aluminium companies usually think in terms of alumina plants with a capacity of at least 300,000 tons and aluminium reduction plants with a capacity of at least 100,000 tons. The minimum plant size for a self-contained alumina plant is 250,000 metric tons per year in North America and 150,000 tons per year in Japan and Europe. An alumina plant connected with mining of a bauxite deposit (for example in Australia, Surinam, Jamaica or West Africa) is about 200,000 metric tons per year. The economy of an alumina plant improves with increasing capacity up to about 660,000 tons Al_2O_3 per year, which is the largest unit size in operation today. A larger plant will, therefore, consist of two or more parallel production units, and further cost savings become less marked.

New direct reduction processes

54. During recent years, aluminium has been produced by direct reduction from aluminium compounds in electric resistance ore furnaces in relatively small-scale pilot plants. These direct reduction processes do not present a threat to conventional alumina and aluminium reduction plants within the foreseeable future. The advent of cheap nuclear power could, however, in the long term provide new possibilities for economic aluminium reduction plants in industrially developed countries with bauxite deposits but no hydroelectric power.

Structure of the aluminium industry

55. The aluminium industry has always been characterized by vertical integration. This trend became even more pronounced in recent years and therefore independent bauxite, alumina, aluminium reduction or aluminium producers have difficulties in selling their products unless they own their own finishing capacity. Contrary to this trend, however, has been the recent emergence of several independent aluminium fabricators in the United States.

56. At the same time, the leading aluminium companies, which were originally national in character, have gradually extended their interest to all countries of the world where foreign companies are allowed to operate.

57. A large proportion of the aluminium industry in non-centrally planned economies from bauxite mining to the marketing of finished aluminium products, is now controlled by comparatively few companies.

58. Developing countries wishing to develop their alumina or aluminium industry have the choice of obtaining "know-how" from the large companies in the market economics of the world or from the state-controlled aluminium producers in nations with centrally planned economies. As a result of this policy, the major companies have considerable "know-how".

Recent trends in aluminium technology

59. The aluminium industry is a young and aggressive industry. It spends large amounts on research and industrial development. This has resulted in continuous improvement of the present production methods as well as great efforts to develop basically new processes.

Bauxite exploration and mining

60. All major aluminium companies as well as government agencies have intensified exploration for bauxite in recent years, utilizing modern exploration techniques. Bauxite mining, carried on an ever-increasing scale, has adopted the modern mass handling methods used, for example, for open pit coal and lignite mining, such as huge rotary excavators and moveable draglines using light-weight aluminium trestles.

Alumina production

61. Research is mostly directed towards improvement of the conventional Bayer process and its adaption to the newly found "mixed" bauxites. To a lesser degree, research is directed towards the utilization of other raw materials than bauxite; this, however, is a major field of research in the Union of Soviet Socialist Republics.

Aluminium reduction

62. Research is mostly directed towards larger cells and also towards greater output from a given size of cell. This has lead to reduced power consumption, coke consumption and electrolyte consumption. Reduced labour requirement has been obtained through mechanization and control including computerized operations and new materials of construction to improve cell life.

Aluminium fabrication and finishing

63. New fabrication techniques being developed, particularly in North America and Western Europe, will create significant changes in fabrication technology in industrially developed countries in the coming years. Among these developments can be mentioned continuous casting of sheets, recently adopted for a large new rolling mill in Norway, rolling and extrusion of aluminium pellets and powder, explosion forming, new strip and rod casting methods, new alloys and surface finishing techniques.

II. ALUMINIUM ORES, RESERVES AND REQUIREMENTS

Reserves of bauxite ores

64. The average content of aluminium on the earth's crust is 7.45 per cent according to USSR academician Fersman's estimation. This content is almost twice as much as that of iron (4.16 per cent) which is the most used metal at present.

65. More than 300 minerals are known to have aluminium content higher than the average content of the earth's crust. Only a few of them, however, have significance for industry.

66. Practically all the aluminium produced in the world is from bauxite. Bauxite is a rock which mainly consists of aluminium and iron hydroxides, together with a small quantity of an impurity of aqueous alumo-silicates, mostly of kaolinite and of titanium and calcium oxide minerals as well as small amounts of impurities of other elements such as Mg, Cr, V, P, S etc. The chemical and petrographical composition of bauxite depends on the concentration of different minerals contained in it. Furthermore, it is possible to say that bauxite is an economical rather than petrographical notion, because the requirements for bauxite are not definable by objective mineralogical factors, but they depend on the level of bauxite technological processing, on economical conditions of bauxite deposits, on a country's bauxite demand, on bauxite availability, and on other factors. World bauxite reserves as well as bauxite reserves of separate countries are not well estimated. This very important question has never been submitted to any consideration. However, figures given in available documents do not differ considerably because authors have used common sources. Large parts of the world's resources of bauxite are located in the tropical and sub-tropical developing countries. Taking into account that the same countries have a large reserve of underdeveloped water power, it can be concluded that there are good possibilities for establishing and creating an aluminium industry in many of these countries.

67. An evaluation of possibilities for discovering new bauxite deposits during the near future in the world and particularly in the developing countries

may be sufficiently optimistic. According to various sources, the total resources of bauxites available for mining run from 10 x 10^9 to 25 x 10^9 tons and more. The experts believe that taking into account a decrease of the requirements for bauxite as a result of improvement of the technology of its processing, the world's bauxite reserves in the near future should not reach less than 25 x 10^9 tons.

68. The greatest increase of bauxite reserves may be expected on the African continent, where about 50 per cent of all bauxite ore is concentrated at present. It is quite possible that the reserves of this part of the world can be doubled, as a result of intensive geological surveys.

69. A reliable prediction can be made with respect to discovering bauxites in Asia. The islands of Indonesia, the territory of China, Cambodia, Laos, India and others have practically not been investigated. In the future one may expect in this part of the world not a doubling, but a far greater increase of the bauxite reserves.

70. The possibilities of an increase of the bauxite reserves in Europe are probably more limited, but they do exist in old bauxite-bearing regions and particularly in new areas in Yugoslavia, Greece and Turkey.

Requirements for bauxite ores

Bayer process

71. According to the bauxite requirements which exist in various countries, the best grade contents at present (for the dry per cent) are:

	Per cent		Per cent
Al_2O_3	50 min	CaO	1 max
SiO_2	3 max	S	0.5 max
Fe_2O_3	2-15	P_2O_5	0.2 max

72. For alumina production by the classic Bayer method the above grade of bauxite is now used. However, as a result of continuous improvement of the technology the maximum content of Al_2O_3 in bauxite being economically processed is progressively decreasing.

Other processes

73. For alumina production by other methods (sintering, combined) the grade of bauxite can be lower. Developing the technology of extracting Al_2O_3 from bauxite by methods other than Bayer's, one will allow change in decreasing the Al_2O_3 content and in increasing the content of SiO_2 and Fe_2O_3. For example, aluminium ores with a content of Al_2O_3, 43 to 45 per cent, of SiO_2 10 to 15 per cent and FeO_3 18 to 20 per cent can be used for processing by sintering methods. Unfortunately, the techno-economic indices of sintering and combined methods are not as high as the ones gained through Bayer's method, although they have been improved significantly during recent years.

Extraction of valuable compounds

74. Bauxite type ores very often contain valuable metals and elements other than aluminium. Processing of these ores with either the Bayer or other methods and extracting of a range of valuable compounds has a great economic importance for developing countries. Such ores are noted below:

(a) Ores with an intermediate composition between bauxites and iron ores. Ores of these types are known in Turkey (Al_2O_3 : 10 - 12%; Fe_2O_3 : 70 - 80%), in the United Arab Republic (Al_2O_3 : 5 - 10%; Fe_2O_3 : 80 - 85%), in the Union of Soviet Socialist Republics (Al_2O_3 : 20 - 30%; Fe_2O_3 : 55 - 70%) in Guinea and others. These ores can be utilized as a complex range of materials for iron and alumina production.

(b) Ores with a heightened content of titanium. Such ores are known in India (Al_2O_3 : 56 - 60%; SiO_2 : 0.3 - 7.0% and TiO_2 up to 10%).

(c) Ores with a heightened content of vanadium (France, Hungary, USSR), chromium (Hungary, USSR), gallium (France, USSR). Undoubtedly the same kind of ores exist in many developing countries. During processing of these ores valuable metals are concentrated into intermediate products: red muds, solutions etc., from which they can be extracted more easily.

Reserves and requirements of non-bauxite ores

75. The irregularity of distribution of bauxite on the earth should not limit the development of the aluminium industry in countries that are located in "bauxiteless" zones. There are two possibilities for such countries: to import bauxite or alumina from other countries or to utilize domestic, local

aluminium-containing raw materials other than bauxite. However, the natural wish of such countries to be economically independent will push them often to select the second way. The additional factor which is favourable for the utilization of many non-bauxite ores is the possibility of producing not only alumina but other valuable by-products, the price of which can reach 90 per cent of the price of the produced alumina.

Nephelines

76. The most important non-bauxite ore is the nepheline rocks extraction of alumina which exists in the Union of Soviet Socialist Republics on an industrial scale. The experience of the USSR shows that the process can be profitable, if the nepheline rocks contain not less than 27 per cent of Al_2O_3 and not less than 14 to 18 per cent alkalies. Iron oxide is a component, the content of which should be limited by 5 per cent. Silicon modulus (Al_2O_3/SiO_2) should be less than 3.0 and the alkaline modulus (R_2O/Al_2O_3) should be more than 0.7. Nepheline rocks are known to be in Korea, in the United Arab Republic, Brazil, Finland, Canada and some other countries.

Clay-type ores

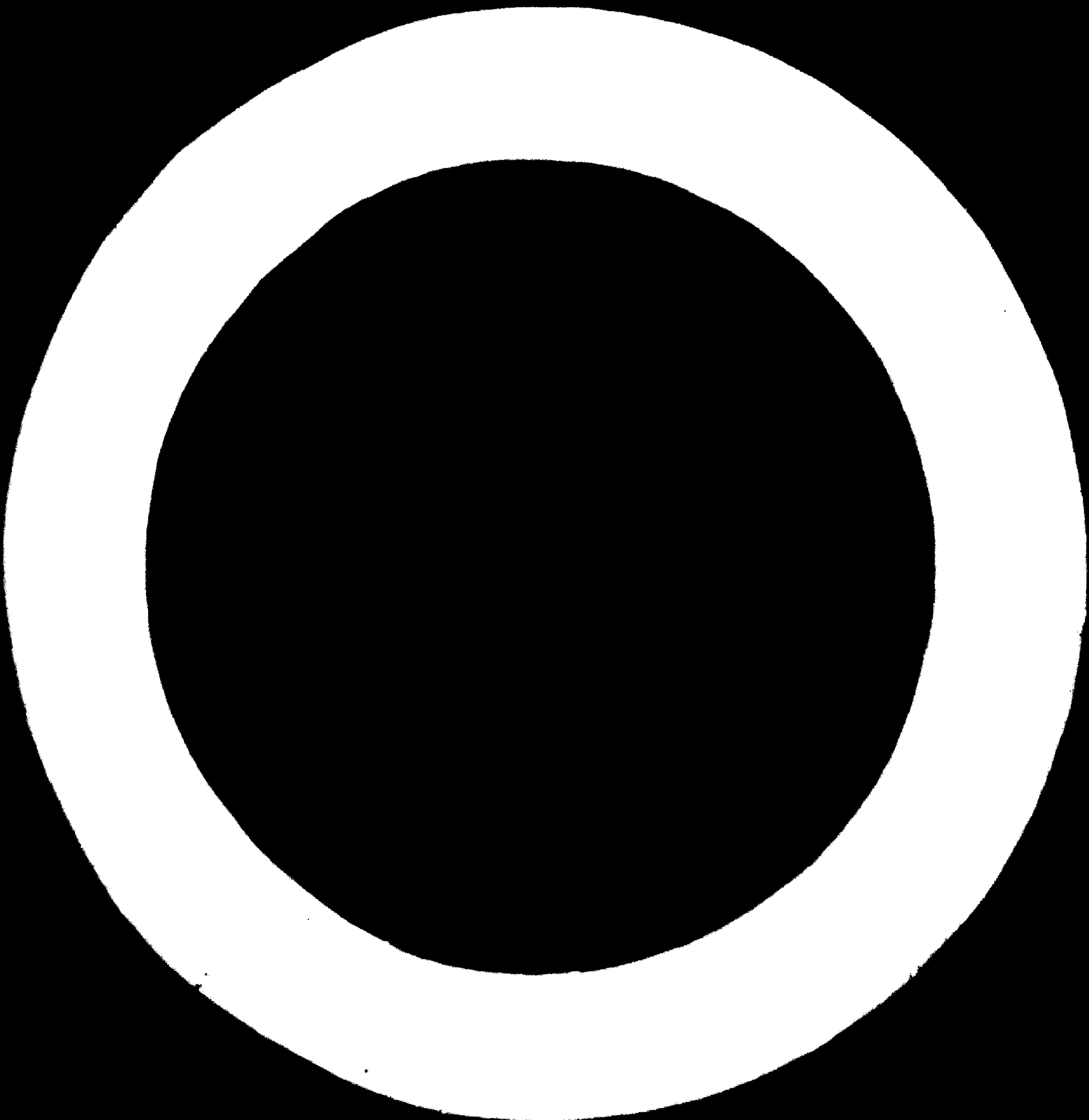
77. Clay-type ores (such as kaolinite, halloystite, anhydrous and alumosilicates) are used for aluminium-silicon alloys production by the electrothermic method, which was investigated on an industrial scale in the USSR. Kaolinite should be beneficiated for obtaining a concentrate with 35% min. Al_2O_3; 47% max TiO_2; 0.8% max. (CaO plus MgO) and 0.5% max. (Na_2O plus K_2O). In addition to the above method of processing clay-type ores, sintering with limestone and the acid methods can be used for alumina production.

Alunite

78. Alunite may also be used as a raw material for alumina production. Mexico, the United States and the Union of Soviet Socialist Republics have industrial experience in processing alunite ores. Alunite deposits are known in Southeastern China (210 - 280.10^6 tons) United States (5.10^6 tons) Puerto Rico (280.10^6 tons) USSR and Australia.

Pickeringite

79. One expert has mentioned the pickeringite deposits in Argentina. This mineral contains 11.9 per cent Al_2O_3 and is based on sulphates of Al and Mg. Processing of the pickeringite ores may be very simple since the mineral dissolves in water at room temperature. The volume of deposits, technology and the economy of processing require further investigations.



III. CONVENTIONAL PRODUCTION OF ALUMINA FROM BAUXITE BY THE BAYER PROCESS

Principle of the Bayer method

80. At present over 90 per cent of the world's alumina is produced on the basis of the Bayer process which has been known for about eighty years. This process is based on the realization of K.I. Bayer that the reaction

$$Al/OH/_3 \text{ plus } NaOH \text{ plus aq } \quad NaAlO_2 \text{ plus aq} \ldots$$

is reversible. The dissolution reaction is endothermal (11 - 12 Mcal/mol Al_2O_3). By means of temperature and NaOH-concentration variation the reaction can be lead in one direction or another.

81. As known, the Bayer process consists of the alkaline digestion of bauxites mostly under pressure, wherein the alumina is extracted from the bauxite, the separation of the alumina-enriched liquors from the residues of digestion (red mud); the decomposition of the cooled and diluted aluminate liquor and the precipitation of aluminium-hydrate; and finally the calcination of the hydrate. After the precipitation of the hydrate, the spent liquor is recycled in the digestion phase, the excess of water removed by evaporation.

Difference in practice

82. The basic principles elaborated by Bayer have not changed substantially but the process itself, in keeping with the general advance of techniques, underwent a considerable development, especially within the last twenty-five years. As a matter of fact, the Bayer process lead itself to the processing of high-quality bauxites. However, if combined with additional technological processes, the processing of bauxites with higher silica content and of some other alumina-containing ores may be undertaken. According to the trihydratic ($Al/OH/_3$) or monohydratic (AlO/OH) character of the processed bauxite,

two characteristic variants of the process are known. One is often called the American process and the other the European process. Technological flowsheets of these two processes are practically identical, and only temperatures and concentration-ratios differ substantially. Within the two characteristic variants, several different solutions have been developed regarding the individual technological procedures, taking into consideration the raw material situation, price conditions, technical level and other circumstances given.

Techno-economic indices

83. The production of alumina, if examined from the point of view of the manufacture of aluminium as a metallurgical process, may be considered to be a chemical enrichment, its object being to eliminate accompanying contaminations from Al_2O_3 in the bauxite and to render it suitable for metallurgical processing. As an enriching process it may first of all be characterized by its efficiency (Al_2O_3 recovery), further by the specific use of reagents and fuel required for the process as well as the extent of specific capital investment. Efficiency of the process and specific utilization of reagents as well as the extent of the necessary first investment is determined by the technical level of realization of the process. Fuel consumption, however, is determined first of all by this latter factor.

84. Essentially, the Bayer process is a solvent-circulating circuit, fuel consumption of which is determined by the extent of temperature differences produced and the efficiency of countercurrent heat recovery; the efficiency of the process being determined by the efficiency of working of the mud and hydrate solution.

New developments

85. Countercurrent heat recovery can be realized effectively by the use of continuously operating equipment only. This is the reason for endeavouring to render some of the operations of the process continuous which has proved to be highly successful in recent years. Another important condition to render the process economic is the choice of high-capacity equipment units, as well as a better approach and conservation of the technological optimum, which is efficiently backed by automation and quite recently by the use of a computer.

Improvements in operation

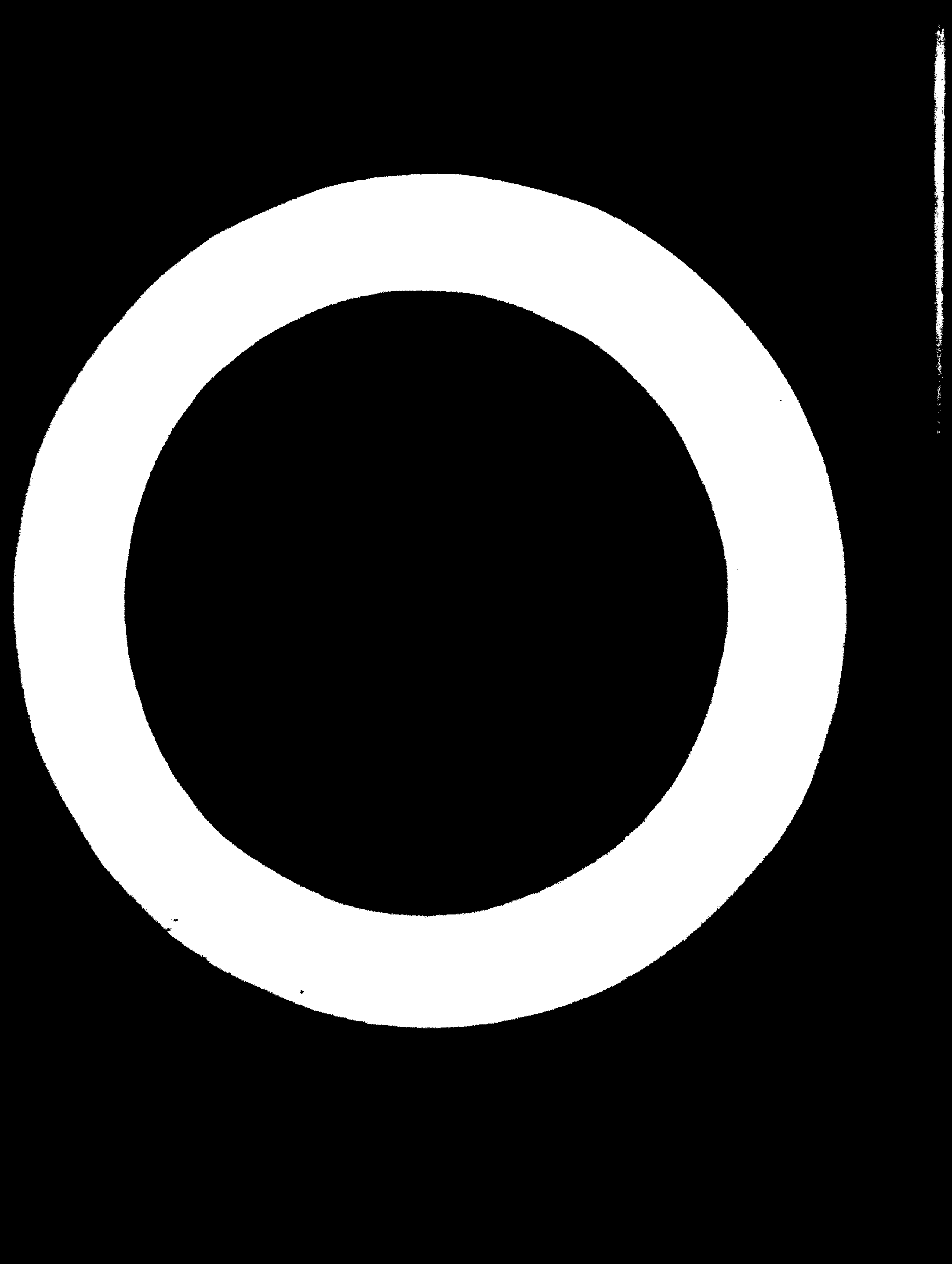
86. In the course of recent years, the recovery as well as reagent and heat consumption values characterizing the process have shown very considerable improvement. This applies especially to those plants where modern technology has been introduced, in spite of the fact that the bauxite quality, especially in Europe, has gradually deteriorated on a parallel with the decrease of reserves. It may be observed that the effect of bauxite quality on the efficiency of the proc ss and its techno-economic characteristics is steadily decreasing. This, however, does not apply to specific consumption of bauxite and caustic soda. This tendency may be ascribed to the considerable development of the process and its gradual "accommodation" to the quality of bauxite. At present, predominantly in Europe, processing of such bauxite qualities is considered to be economic by the Bayer process, which previously appeared to be utilizable only by applying the sinter or combined processes.

87. The development of the process is characterized by the undermentioned values, published by Ginsberg:

Table 1

Specific consumptions applying to one metric ton of alumina

	SiO_2 content %	Bauxite (dry) t	Caustic soda NaOH kg	Steam t	Electricity kWh	Heat mill. cal.	Working plant	Hours total
Prior to 1930	3	2.2	85	8	325	2.8	14	28
At present in modern plants	5-7	2.5	120	3.5 and approx. 2 resp.	240	1.3	3	8



IV. RECENT TECHNOLOGICAL IMPROVEMENT OF THE BAYER PROCESS

88. Among the recent directions of the further development of the Bayer method, the following seem to merit attention: deeper knowledge of the process chemistry; new types of equipment used for practical carrying out of the Bayer technology; automation; and possible modifications of the Bayer process with a view to processing poorer or complex ores.

Problems of process chemistry of the Bayer process

General considerations

89. Taking into consideration the ever deeper knowledge of process chemistry and the development of investigation methods, it may be expected that on the basis of laboratory investigations more and more accurate conclusions will be drawn as to the expected technological behaviour of bauxites, and this will pave the way for further improvements of the technological process. The effect of mineral modifications of aluminium hydroxide and of silica and titanium oxide on digestion chemistry may already be considered as cleared. Iron oxide modifications have first of all an influence on red mud settling, appreciation of which should not be neglected. As regards elimination of other impurities, industrial solutions are already available at present. Furthermore, recuperation of valuable elements (Fe, V, Ga, F etc.) on an industrial scale is also solved. Decomposition kinetics which in the recent past was still considered to be a "difficult art" may be set in equations.

Digestion conditions

90. Digestion temperature and composition of digesting liquor may be selected on the basis of equilibrium solubility of the different aluminium oxide forms, but it is obviously necessary to take into consideration the behaviour of accompanying components also.

91. When digesting boehmite-containing bauxites, a higher temperature is necessary in order to attain adequate working at digesting temperatures ranging between 220 to 250°C. Equilibrium data of diasporic bauxites, as compared to gibbsitic and boehmitic ores, are far from being fully cleared up. By an adequate modification of the Bayer process and with the addition of about 4 per cent lime to the bauxite, diasporic ores can also be processed at the usual digesting temperatures although for approaching molar ratios attained at digestion of boehmitic bauxites, digesting liquor of a higher Na_2O concentration is necessary. According to experimental measurements diasporic bauxites may be digested without any lime addition at a higher digesting temperature than the usual one of 280°C. This very fact may be of considerable importance at an eventual realization of tube-digestion on an industrial scale.

Bauxites with high iron contents

92. Fe_2O_3 content of bauxites varies between extraordinarily broad limits (2 to 30 per cent). Although after digestion iron minerals can invariably be traced in the red mud, their role is still rather significant. At the processing of bauxites with high Fe_2O_3 content, the specific quantity of red mud is quite considerable, thus requiring surplus equipment and more washing-water. In addition, certain iron minerals, especially goethite, deteriorate the sedimentation rate of the mud, thus causing surplus costs as well.

93. Red mud of bauxites having a high Fe_2O_3 content may be taken into consideration as iron ores as well, especially in countries that are poor in iron ores, along with the simultaneous recovery of the Na_2O and Al_2O_3 contents of red mud.

Treatment of digesting liquors

94. Among the accompanying elements, a considerable fraction of vanadium, phosphorus, fluorine and gallium dissolves in the digesting liquor, as do sulphates. Concentrated in the liquor circuit, these components cause technological troubles as well as soda losses. Contents in organic substances of bauxites belong among the detrimental contaminations that are easily soluble in the digesting liquor, enriched in the circuit, and may cause difficulties at the salt separation and evaporation. On account of the relatively high organic substance contents of Hungarian bauxites, considerable work was carried on in Hungary, but with the introduction of intensive salt separation the problems thus arising were essentially eliminated. Among the elements mentioned, recovery of the valuable vanadium and gallium contents has been solved on an industrial level.

95. In processing ores with high organic material content, special solutions should be foreseen, if necessary, for the elimination of these impurities (e.g. treatment of one part of the spent liquor with charcoal).

Equipment used for carrying out the Bayer technology

Development of equipment used

96. Alumina plant equipment was developed in general from equipment that had already been used previously in other industrial branches. It was only in the last decades that attention was focussed on some special requirements of the alumina plants. Consequently, some development principles such as continuity, high capacity, open-air siting, decrease of "cold" reserves and elimination of dead space are identical with those applied in connexion with equipment used in some other branches of the chemical industry. However, in recent years more and more equipment has been developed especially for the alumina industry.

For bauxite preparation

97. At present high capacity wet grinding ball-mills are almost exclusively used, operating in either closed or open circuits. Elimination of the adherent moisture of bauxite by means of drying is justified generally only if it yields a decrease of transportation costs. Introduction of autogenous milling seems to be an up-to-date means of development and successful tests are already being undertaken.

For digestion

98. The trend of development was at first aimed at continuity which rendered multi-stage flashing possible and accordingly application of heat recovery. Following this, increase of digestion temperature was more and more brought into the limelight and in the near future introduction of digestion at a temperature exceeding 250°C may solve the problem.

99. There are possibilities for development in the field of pre-heaters, autoclaves (decrease of scales, elimination of dead space, increase of heat transfer etc.) as well as on that of the decrease of flashing tank volume (by means of better steam selection, self stirring and other means).

Settling, washing and filtration

100. Settling: development of settling tanks points again towards using one-chamber equipment by means of which good settling and a better compression of red mud can be attained than in the case of multi-chamber equipment. In alumina plants equipment of a large size, having a diameter amounting to 30 to 36 m with flat or conical bottom and lateral or central mud discharge, is sited in the open air.

101. Washing and filtration: a method frequently used for washing of red mud is filtration. On the basis of economic considerations one has to determine whether multi-stage settling and/or one or more stage filtration should be chosen. In general, filtration of red muds is rather difficult. On the other hand, however, the mud of some bauxite types can be filtered with relatively good results. Bearing in mind the fact that filtration of red mud improves with the decrease of liquor-phase concentration, it appears to be serving the purpose to effect red-mud washing first by means of settling and then by filtering the mud which has been partly washed.

102. Neither the drum filters nor the traditional pressure filters guarantee a treatable and transportable non-adhering red mud. It is well known that red muds are able to be treated with a moisture content below 30 per cent. This can be attained by means of drying after filtration.

103. This problem is adequately solved by the AJKO-type air cushion pressure filter developed in Hungary. This operates automatically, requires no drying and guarantees the necessary moisture content below 30 per cent by means of mechanic pressure following the filtration. Filter cakes of red mud thus obtained may be stored in thick layers in prismatic form, but they may also be directly transported to the possible site of utilization.

104. According to experience acquired, in the case of vacuum filters one filtering stage substitutes approximately two washing stages, and in the case of filtration with a low moisture content, three washing stages.

Decomposition

105. At present decomposition is carried out in the majority of cases in air-lift agitated tanks sited in the open air, energy consumption of which is considerably lower than that of mechanically agitated tanks. They can also be connected in series without any further difficulty. Additional saving may be expected from propeller-agitators. Here, development points towards an increase of tank sizes (2,000 to 3,000 m^3).

106. The technological solution according to which only hydrate quantity in line with the production is carried further from one tank into the other,

while the other part of the hydrate remains in the slurry tank as constant seed, merits attention. By this procedure filtration of seed, being rather costly and requiring extensive equipment, can be eliminated. For hydrate filtration, disc filters requiring small space have become more and more popular. At present they are made with 240 m^2 filtering surface, operating costs of which are considerably lower than that of the drum filters.

Evaporation

107. Evaporation was initially carried out by equipment adapted from other industrial branches, especially from the caustic soda industry. However, evaporation of alumina plant liquors is connected with special problems. With direct current equipment an increased silica separation results due to low concentration and high temperature prevailing in the first body. The low temperature and high concentration reigning in the last bodies favours, first of all, soda separation. One possible solution is to use countercurrent or mixed equipment and to apply self-evaporation of the evaporated thick liquor by a maximum utilization of the flashed steam. Such modern-type equipment operates with low specific steam, that is to say without maintenance and thus no spare equipment is needed. In this equipment distribution of temperature and concentration is such that in the course of evaporation, neither silica nor sodium carbonate are precipitated in noteworthy quantities. In the course of size development of this equipment, bodies having a heating surface of 1,400 m^2 are already in use. The question of salt separation, which has formerly caused considerable problems, has been solved by the introduction of self-discharge centrifuges.

Calcination

108. The development of calcining equipment was first of all reflected in the increase of size, and at present generally 75 to 110 m long furnaces are operating in alumina plants. There are two interesting trends of development: the preliminary drying of the hydrate, allowing for a uniform production to be turned out with low energy consumption; and the introduction of dust cyclones, using the heat of flue gases for hydrate pre-heating and that of alumina for recuperation. In addition, in this case shorter furnaces may be used with a rather advantageous specific energy (capacity 900 t/day, fuel oil requirement 110 kg/t).

109. Numerous experiments were carried out in view of fluid bed calcination of the alumina, but such equipment is not yet operating on an industrial scale. On the other hand, fluidization may very well be used for recuperating alumina heat and for the transport of alumina.

Automation

110. Endeavours made all over the world permit us to conclude that the problem of continuous, automatic analysis of liquors of different concentrations occurring in the Bayer process, will finally be solved in the near future. This is of decisive importance both from the point of view of automation as well as optimization.

Computer control of alumina plants

111. Conception of cumputer-controlled alumina plants has already reached such a stage that its general acceptance may be expected within a few years. This possibility may be ascribed to the following factors:

(a) Substantial development in measuring and analyzing instruments. Accuracy and speed of such instruments is at present already sufficient to enable them to be connected to process-controlling computers;

(b) Both mathematical and statistical methods, application of which has been made possible by computers, are able to furnish suitable flow-equations;

(c) In the majority of plants, part-procedures are automized and their connexion to a central computer system can easily be realized.

In practice, off-line type computer controlling is being introduced in several important alumina plants. The basis of the mathematical model necesary for computer controlling is given by material and heat balances of alumina plants as well as by economic programmes.

Present state of Bayer technology

112. Summarizing the above, we can state that the Bayer alumina-producing process which in its basic principle remained substantially unaltered for nearly one hundred years, has attained a considerably high technical level in study of the processes, as well as the improvement of the equipment used and the introduction of modern controlling methods. In addition, further knowledge of the bauxite properties and its practical utilization, stepping up of mineral composition determinations, research with a view to the mechanism of chemical processes, further development of thermal techniques, enlargement of the utilization of high capacity equipment, improvement of the efficiency of countercurrent processes as well as modern automation and the popularization of computer controlling, may result in further improvement of the economic efficiency of production.

ID/WG.11/10

ALUMINA PRODUCTION FROM VARIOUS ORES

Report of the First Meeting
of an Expert Consulting Group
on the Aluminium Industry

Vienna, 10 – 16 November 1967

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

V. SPECIAL METHODS FOR PRODUCING ALUMINA FROM LOW-GRADE BAUXITES AND COMPLEX ORES

113. Several methods have been used to separate alumina from low-grade bauxite ores. Brief descriptions of the main methods are given below.

Possible modifications of the Bayer process for treatment of low-grade bauxites

114. The ratio of weight of Al_2O_3/SiO_2 in bauxite is a good indicator of the commercial value of the ore. Low-grade bauxites have Al_2O_3/SiO_2 weight ratios less than 8; ratios of 5 to 6 are considered critical. Processing ores with high silica content results in high reagent and heat consumption and necessitates increased investment costs. A number of techniques may be used for treatment of low-grade bauxites, but to a great extent modified versions of the Bayer method are still used. Some of the various techniques used are described below.

Sinter process

115. Most low-grade bauxites can be treated by the classical sinter method which works as a self-reliant circuit. Bauxite and limestone, together with soda liquor, are milled to a size 175 mesh. The composition is two parts limestone to one part silica, one part Na_2O to one part Al_2O_3, and one part Na_2O to one part Fe_2O_3. The slurry obtained is then sintered at 1200°C to 1300°C. The silica is precipitated in the form of dicalcium silicate. The desilicanized alumina hydrate is filtered off and added to the Bayer circuit before the stage of decomposition.

116. The efficiency of the process depends on the bauxite character; the alumina yields decrease with decreasing silica modulus compared to the Bayer process. The heat consumption during the sintering process represents the

highest energy consumption among the technologies for low-grade bauxites. Characteristic data for the classical sintering process follow.

Table 2

Characteristic data for the sintering process

	Silica modulus			$\frac{\text{Free } Al_2O_3}{\text{Free } SiO_2}$		
	8	7	6	5	4	3
Al_2O_3 yield %	86	85	84	83	81.5	80
Na_2O conc. kg/t Al_2O_3	83	87	91	100	120	140
Sinter t/t Al_2O_3	3.8	3.9	4.0	4.1	4.5	4.9
Heat for sinter mil. kcal	4.95	5.1	5.2	5.3	5.8	6.4
Heat for wet line mil. kcal	2.5	2.5	2.5	2.5	2.5	2.5
Total mil. kcal/t Al_2O_3	7.45	7.6	7.7	7.8	8.3	8.9

117. This method has the following advantages: possibility of partial utilization of low-grade bauxite for the alumina production; compensation for the alkali losses of the Bayer branch by soda instead of caustic; possibility of the recovery of the alkali content from the separated materials in the Bayer branch salts and elimination of the organic material content of these.

118. Disadvantage of this method is the low proportion of low-grade bauxite that can be used in this case and the comparatively low alumina extraction efficiency in the Bayer plant.

The parallel Bayer-sinter process

119. The parallel Bayer-sinter process is used for bauxites containing a mixture of high-quality bauxite and a small proportion of low-quality bauxites. This process consists of two parallel lines, the Bayer and the sinter line. The Bayer is used for good quality bauxite (85% of the total) and the sinter line (15%) for low-quality bauxite. The parallel Bayer-sinter process as a whole is simpler than the Bayer and sinter line working together, particularly when calcined soda is cheaper and soda more easily obtainable than caustic. This technique is also useful for treatment of bauxites with relatively high carbonate and organic matter.

The combination method

120. In cases of processing exclusively high silica bauxite by the Bayer process, the series-combined technique is the only method possible. In this case the red mud of the Bayer branch is washed, filtered and dried and then sintered with lime and soda. The sinter produced is leached in ball-mills and the aluminate liquor obtained is decomposed together with the liquor froe the Bayer branch. This variant produces a relatively higher alumina extraction efficiency, lower soda losses, but the lime sode sintering of high iron oxide red muds seems to present a certain number of problems. A large number of these difficulties hav. been overcome, however, due to the research work realized in recent years in the Soviet Union.

121. The operating characteristics of the combination method are given below:

Table 3

Operating characteristics of the combination method

	Silica modulus					
	8	7	6	5	4	3
Alumina yields	94	93.5	93	91.5	90	88
Kg Na_2O/t Al_2O_3	45	48	52	58	75	90
Sinter bulk t/t Al_2O_3	1.2	1.3	1.4	1.6	2.0	2.4
Heat cons. total oil. kcal per ton Al_2O_3	4.1	4.2	4.3	4.5	5.1	5.7

The desilication process

122. The desilication process consists of three lines. The first processe. low-grade bauxite after roasting at 800 to 1050°C, followed by leaching with dilute caustic solution or aluminate liquor. In the second line the filtered cake of desilicated bauxite, which is now high-grade, is processed by the normal Bayer method. In the third line, soda is regenerated from the dissolved sodium silicate by adding lime. If the silica dissolves in sodium aluminate, sodium aluminate silicate is precipitated by the addition of sodalite mud.

123. The desilication method is the subject of a number of patents which recommend different alkali concentrations, temperatures and stirring times. The desilication method has not, however, been used for large-scale production.

Comparison of methods for treatment of low-grade bauxites

124. A comparison of operating characteristics of classical Bayer, parallel Bayer-sinter process, desilication process and combination method has been made by Hungarian specialists. The comparison was made for domestic bauxite with a silica modulus of 6.65 of the following analysis: Al_2O_3 51.7%, SiO_2 7.77%, Fe_2O_3 22.0%, TiO_2 2.5%. This comparison is therefore only relevant to the particular bauxite mentioned. With a different ore, a different set of values would of course be obtained.

Table 4

Comparison of methods for treatment of low-grade bauxites

Consumption per ton of alumina	Processing method				
	1B	2C	3P	4DS	5DL
Bauxite tons	2.95	2.32	2.57 0.32 a/	2.75	3.09
NaOH kg	139	-	-	103.5	97.7
Na_2CO_3 kg	-	71.5	170	-	-
CaO kg	196	129	120	-	100
$CaCO_3$ kg	-	972	153	430	-
Steam (70 ata) t	1.65	1.37	1.47	1.31	1.60
Steam (4 ata) t	1.25	1.62	1.50	2.07	2.40
Oil for roasting kg	-	-	-	102	1.52
Oil for sintering kg	-	216	78	71	-
Oil for Al_2O_3 calcination kg	113	113	113	113	113
Oil total kg	113	329	193	286	285
Electrical energy kWh	286	328	331	374	342
Alumina yields for plant %	78.7	92.2	80.4	84.5	75.2
Na_2O loss for plant kg	105.5	41.4	97.2	78.4	74.0

a/ To sinter line

1B - normal Bayer process
2C - combination method
3P - parallel Bayer-sinter process
4DS - desilication by aluminate solution and regeneration of soda by sintering
5DL - desilication by dilute alkali and wet regeneration of soda by lime

Other methods used for treating low-quality bauxites and complex ores

125. Several methods have been used to separate alumina from low-quality bauxites and other complex alumina ores. Brief descriptions of these processes are given.

Electrothermic extraction of alumina

126. Low-grade bauxite is crushed and melted in an electric arc furnace in the presence of coke and ferrosilicon. The alumina and ferrosilicon settle to the bottom of the furnace and are separated mechanically by crushing the cooled content. The product is brown corunde with maximum 96 to 97 per cent Al_2O_3 and Si and Fe both above 1 per cent.

127. To improve the process, a reducing agent is added in two steps in the patented Pechiney method. The reducing agent is added, 0.2 to 0.3% in excess of stoechiometric, and metallic impurities are precipitated by the addition of rust-free iron scrap. The electrothermic method has a maximum simplicity of equipment and it is little influenced by the ore character. The process can be operated with a small electric arc furnace of less than 1,000 kVA and a minimum of equipment if manpower is not expensive.

Consumption

Electric energy:	3300 - 4000 kWh/ton alumina
Electrode:	20 - 35 kg/ton alumina
Coke:	70 - 120 kg/ton alumina

Electrothermic reduction of white bauxite to alloy - 65 per cent Al - 35 per cent Si

128. In this process the white bauxite is totally reduced to an alumina (60 - 65%) silica (40 - 35%) alloy. White bauxite with Fe_2O_3 lower than 1.5 per cent is mixed with milled kaoline or quarzite and a reducing agent, high reactive and low ash washed lignite. These materials are briquetted with 0.85 to 0.9 parts of carbon, corresponding to the reactions $Al_2O_3 + 3C = 3CO + 2A$ and $SiO_2 + 2C = 2CO + Si$.

129. The intermediate alloy $Al_{65}Si_{35}$ is tapped, mixed with molten aluminium and impurities are crystallized and filtered.

Consumption per ton of alloy - 65% Al - 35% Si:

Electric energy	11,500 kWh/ton
Bauxite plus quarzite	3 t/t
Lignite	0.9 t/t
For 1 ton of final product foundry alloy	Al - 13% Si
Intermediate alloy	0.5 t/t
Aluminium	0.61 t/t
Electric energy	500 kWh/ton
By-product	0.21 t/t filtration wastes of composition: Si 16 - 36; Fe 5 - 10; Mn 7 - 17%

The acid process of alumina extraction

130. Many serious difficulties and problems are encountered with the various acid processes. The basic aluminium sulphate process, developed in Australia, should be mentioned. This process performs double-step counter-current leaching in dilute sulphuric acid at 130°C and 180°C. In the second step the aluminium sulphate is converted in the basic form by means of excess ore. A ferric sulphate is converted to ferrous by reduction with SO_2. The hydrolysis of basic aluminium sulphate follows and an intermediate product low in iron is obtained. Main problems are represented by the equipment for calcination. Cheap sulphur and energy sources are required. The method is unsuitable for ores containing alkali and alkali earth carbonates. White bauxites with low iron content are suitable for this method.

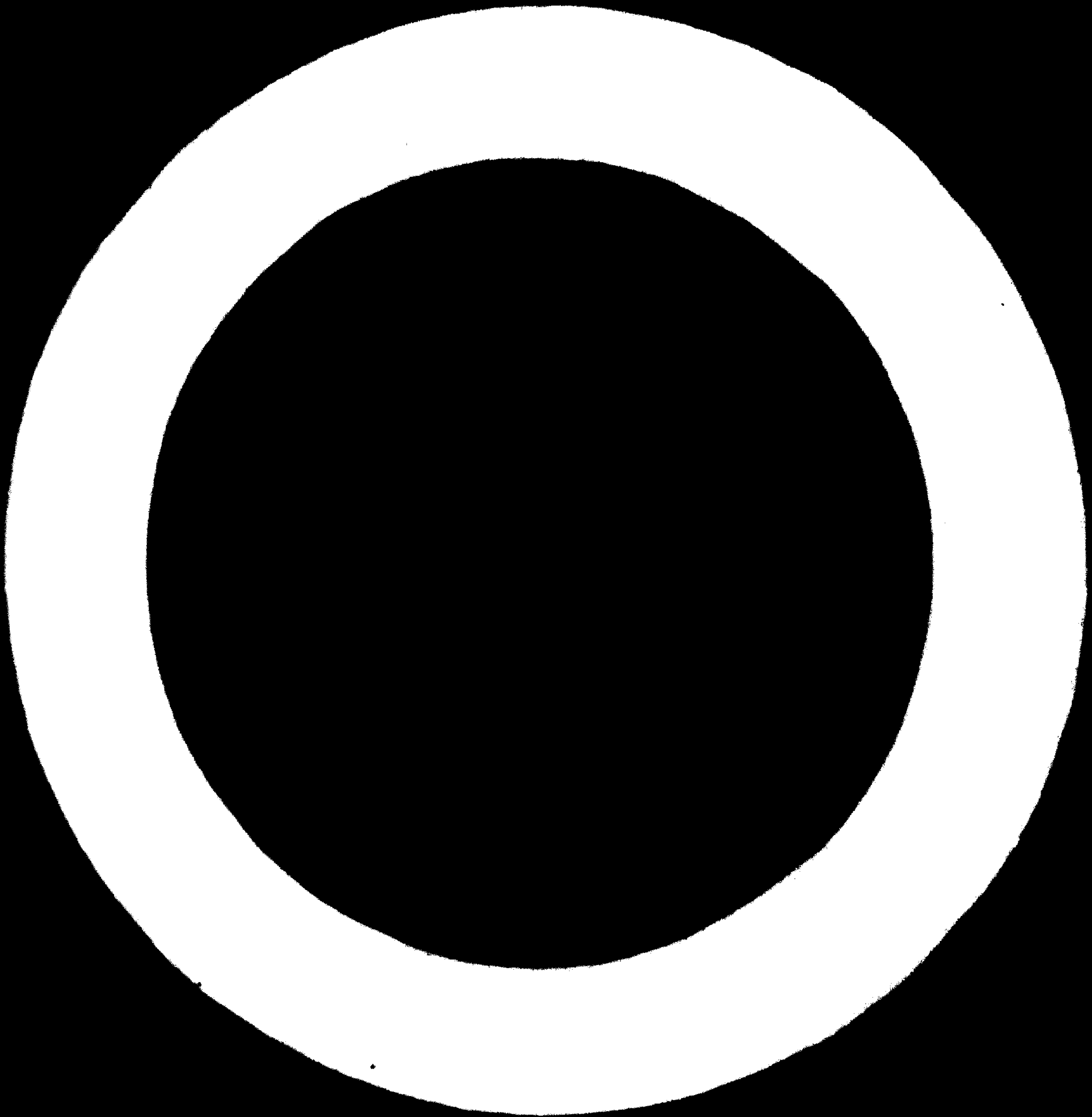
The Ponomarev method

131. The method was proposed especially for gibbsite bauxite with a high silica content. The bauxite is extracted with 450 to 550 gram Na_2O per litre at 100 to 130°C for five to ten minutes. Desilication of the aluminate liquor is obtained by addition of lime at 220 to 250°C in molar ratio CaO : SiO_2, 1:1 for ten to twenty minutes. The purified liquor is evaporated and sodium aluminate is crystallized. The solid sodium aluminate is dissolved in weak liquor and alumina trihydrate and precipitated by Bayer decomposition. More detailed characteristics of this method cannot be given, as data from large-scale processing is not available.

High-pressure tube autoclave digestion

132. This new method for treating low-grade bauxites is based on reaction velocity of dissolving alumina in caustic which increases exponentially with digestion temperature. At 290 to 320ºC the digestion times are only five to ten minutes. The tube autoclave construction is based on the pipe-style used in the oil refineries and high pressure pumps.

133. The high-pressure tube autoclave digestion has a number of significant advantages, especially for processing bauxites with high iron and silica content. The engineering technique of this new process, however, is not fully resolved.



VI. EXPERIENCE IN CREATING, EXPANSION AND IMPROVEMENT OF THE ALUMINA INDUSTRY IN DEVELOPING COUNTRIES

Location and capacity

134. The developing countries that have acquired alumina industries are: in Africa, Republic of Guinea; in Asia, India and the Republic of China; in South America, Brazil, Surinam (a colony of the Netherlands), and Guyana (formerly British Guyana and now an independent member of the British Commonwealth); in the Caribbean, only Jamaica and St. Croix in the Virgin Islands; and in Europe, Greece.

135. The developing countries, excluding St. Croix, had a total alumina capacity of 3.2 million short tons at the end of 1966 or about 19 per cent of the world capacity. According to the plans of expansion announced, the alumina capacity of these countries is likely to increase to 6.1 million tons or nearly 24 per cent of a world total of possibly 25.8 million short tons as given in table 5 below.

136. The bauxite reserve of these developing countries as in 1963 was estimated to be 2.3×10^9 (39 per cent) out of a total world commercial reserve of bauxite of 5.8×10^9 tons.

137. The production of bauxite in the developing countries has been between 70 to 80 per cent of the world production during the last ten years. Barely one fifth of this bauxite is converted into alumina in these countries and the rest is exported to the developed countries. There is thus a large scope for the expansion of the alumina industry of the developing countries.

Factors influencing creation

138. The factors that have controlled the creation of the alumina industry in the developing countries are: availability of adequate long-term supply of bauxite, domestic or imported; assured market for the alumina at a world

market price; availability of the investment capital; terms and conditions of arrangements with the aluminium enterprises to attract the industry; and political security of the investments in the alumina industry and dependability of the supply of alumina.

Table 5

Developing countries having an alumina capacity in 1966, and their projected capacity, 1970-1971
(in thousands of short tons)

		Approximate capacity end of 1966	Projected capacity 1970-1971
Caribbean area -	Jamaica	875	2,620
South America -	Brazil	68	133
	Guyana	385	385
	Surinam	880	1,110
Europe -	Greece	220	220
Asia -	India	151	963
	Republic of China	46	82 a/
Africa -	Republic of Guinea	577	577
	Total, developing countries	3,202	6,090
	World total	17,364	25,776
Per cent of world capacity in developing countries		18.5	23.6

a/ Expansion expected but information not yet available

Availability of supply

139. The decisions have not rested on the availability of trained personnel or such infrastructure as ports, housing and public services. These can be provided by the enterprises when not otherwise available. The decisions have not always required the existence of domestic bauxite resources because the ore can be imported to alumina plants that are well located as illustrated in the case of the Republic of China, St. Croix, and the location of large alumina capacity in developed countries lacking bauxite resources.

Market

140. When the market has been initially small, the low-capacity alumina plants have survived only through trade protection policies for the associated domestic aluminium industry as in the Republic of China, Brazil and India. Where industry has to depend on the export market, low-cost efficient alumina plants have been built.

Investment

141. Where the market for some individual enterprises could not support the most economical alumina development, the consortium or joint venture has been used to increase the total market and build a larger alumina plant.

Terms and conditions

142. The competition between developing countries has been important in guiding the decisions to invest in alumina capacity. The competition includes the kinds of terms and concessions granted regarding bauxite exploration and mining and tax and other incentives. The most important element of competition, however, is the kind of stability a country can offer, politically, legally and financially, as the environment in which an alumina enterprise must exist.

Supplying bauxite

143. The growing dependence of the developed countries upon imported bauxite has increased the incentive to locate alumina plants close to the ore in order to save transportation costs.

Future expansion

144. The above factors that govern the creation of an alumina industry in a developing country will also govern the expansion of the industry. In fact, in most of the developing countries that have large deposits of bauxite the alumina industry is expanding, conditions being favourable.

145. In Jamaica and Guinea the alumina industry is based on the use of lower grades of bauxite previously ignored or considered uneconomic. Although there is a general growing interest in the use of low-grade bauxite and other

aluminous ores, the trend is not yet established in view of the large resources of higher grade ore being developed in Guinea, Australia and in other countries.

146. During the implementation of the expansion of an alumina plant, the following technical points have to be taken into consideration: pilot plant study of available bauxite; design of the plant; availability of equipment; provisions of adequate space for future expansions and training of technical and operating personnel.

Pilot plant studies

147. Characteristics of bauxite such as its hardness, quantity of sandy material, settling properties of red mud, presence of organic materials vary from place to place. It has been experienced that data collected in laboratory scale tests do not present the designer with the entire picture, with the result that many problems arise during the operation of the plant after its erection. It is therefore necessary that before taking up the design of a new plant or expansion, composite samples of bauxite should be collected from the mines and their properties studied in a pilot plant.

Design of plant

148. The technical know-how, the engineering of the plant and the training of the local personnel will have to be provided by the alumina enterprise participating in the project. Costs for such facilities should be within reasonable limits.

Availability of equipment

149. In most of the developing countries the equipment of plants will have to be imported. Importation of equipment should be arranged from most economical sources within the limits of quality.

Expansion

150. In alumina plants that are initially designed for smaller capacities, adequate space should be provided for future expansion to raise the capacity to an economic size, particularly in the developing countries where land is not very expensive. Generally, the main units in an alumina plant achieve an output of 10 per cent or more than the rated capacity, if some balancing plants are added. Provision should therefore be kept for this aspect to have additional production involving limited additionel investment. This will further improve the economics of the project.

Annex 1

A. Titles of nine papers presented at the First Meeting of an Expert Consulting Group on the Aluminium Industry

ID/WG.11/1	The present status of alumina and aluminium production in the world and in the developing countries; prospect of developing an aluminium industry by J.H. Raimers, Canada
ID/WG.11/2	World reserves and requirements for aluminium raw materials by S.I. Benaslavsky, Union of Soviet Socialist Republics
ID/WG.11/3	Requirements for alumina for the production of aluminium in an Austrian aluminium reduction plant by E. Nachtigall, Austria
ID/WG.11/4	Development and prospects of the Bayer system of alumina production by G. Dobos, Hungary
ID/WG.11/5	Processing of aluminium ores with heightened content of Si and/or Fe by J. Vosyka, Czechoslovakia
ID/WG.11/6	Technological aspects of alumina production from complex ores by C. Popov, Argentina
ID/WG.11/7	Investment cost and economic scale of an aluminium plant in Indonesia by B. Siahaan, Indonesia
ID/WG.11/8	Experiences in creating an alumina industry in developing countries by S. Moment, United States
ID/WG.11/9	Experience in the expansion of alumina plants and industry in the developing countries by P. Dayal, India

B. Summaries of the papers presented at the First Meeting of an Expert Consulting Group on the Aluminium Industry

ID/WG.11/1 SUMMARY

The present status of alumina and aluminium production in the world and in the developing countries; prospect of developing an aluminium industry by J.H. Reimers, Canada

Most of the world's bauxite reserves and a large proportion of the world's undeveloped water power are located in the tropical and sub-tropical belts, mostly in developing countries. Natural conditions exist therefore for establishing alumina and aluminium reduction plants in many of these countries.

Aluminium is now a basic industry and competitive production units require large investments. Plants of economic size therefore produce much more than can be absorbed by the limited market of a country in the early stages of development. For these reasons outlets to world markets are necessary, and establishment of an aluminium industry is more easily achieved with the participation of one of the major aluminium companies.

The aluminium industry is vertically integrated and highly international in character. At the same time aluminium consumption shows one of the fastest growth rates for a major commodity. The major aluminium companies are therefore eager to develop new sources of alumina and primary metal, provided the projects are economically sound and provided the countries involved offer a secure economic and political climate for long-term investment.

The support of foreign governments and particularly of international agencies may be more acceptable to emerging countries, but governments usually attach political conditions to their offers and agencies have limited financing possibilities.

Developing countries can, within reason, apply pressure to have foreign companies interested in their bauxite process it locally. Australia, although not a developing country, has done so successfully. However, the terms made with foreign companies must be reasonable so that the projects are not killed in their infancy. The Australian Government's handling of their bauxite concessions should be carefully studied in this connexion.

The various aluminium producers have developed designs and practices that differ considerably, due to different conditions and also to some extent due to local traditions in the industry. It is, therefore, desirable to engage the services of independent advisers to evaluate and compare available technologies and recommend the selection most suitable for a particular project, before making a final choice. Each of the major aluminium companies usually thinks, at least officially, that it has the best technology; unbiased evaluation and advice should be sought therefore.

New direct reduction processes do not present a threat to conventional alumina and aluminium reduction plants within the foreseeable future. On the other hand, the advent of cheap nuclear power could within a few years provide new possibilities for economic aluminium reduction plants in industrially developed countries where the main aluminium markets are and will be for many years to come.

ID/WG.11/2 SUMMARY — World reserves and requirements for aluminium raw materials by S.I. Beneslavsky, Union of Soviet Socialist Republics

Aluminium is the most widely spread element of the earth crust that has industrial importance. Its percentage of the earth's crust is 7.45. At present bauxites are practically the only raw material from which aluminium is extracted. These rocks are relatively widely spread on the earth.

In many countries rocks characterized by considerable variations in their composition are regarded as bauxites. Bauxite is an economical rather than a petrographic notion. The absence of objective criteria for the definition of the term "bauxite" is the reason for various estimations of its total quantity throughout the earth and different calculations of its reserves. Two main types of bauxites are known: residual-homogenic autochtonous; and sedimentary-homogenic allochtonous.

At present the largest known bauxite reserves are on the African continent, in Australia, in the Caribbean basin and in the northern part of South America. On the whole, bauxites are open-mined for the aluminium industry. In the Union of Soviet Socialist Republics, and to a considerably lesser extent in the United States, Yugoslavia, France and Hungary, bauxite is mined from underground drill holes and pits.

The absence of a generally acknowledged definition of the term bauxite restricts the possibilities of an estimation of the quantity of bauxite

rocks in various regions, as well as accurate estimates of bauxite resources. Equatorial Africa, Australia, Central and South America, Hindustani peninsula have the greatest prospects for discovering surface deposits. The ancient epochs of bauxite formation and the "buried" deposits connected with them have been inadequately studied so that it is difficult to make a prediction of their resources.

The world aluminium industry applies on the whole the Bayer process, using temperatures of digestion. Bauxites that have a high silica content are processed by means of sintering. The many other patents on the extraction of aluminium oxide from bauxites have not found practical application.

The improvements of the technology of the extraction of Al_2O_3 from bauxites and the improvement of economical conditions in developing regions and new countries will permit a change in the minimum essential specifications for bauxites, decreasing their content of Al_2O_3 and increasing their content of SiO_2 and Fe_2O_3.

Bauxite reserves that meet the average world requirements may be estimated as 8×10^9 to 10×10^9 tons; the reserves of ores, suitable for processing to alumina, will constitute not less than 25×10^9 tons with the improvement of economic conditions and technology.

The irregular pattern of distribution of bauxite deposits throughout the world brought about by geological causes should not be permitted to hinder the development of the aluminium industry in countries that are in zones without bauxite.

For alumina production it is necessary to use nepheline and leucite syenites, kaoline clays and argillites and disthen rocks (andalusite, sillimanite).

A favourable factor for processing these rocks is the presence of alkaline (Na and K) which is used in the technological process and is a separate commercial product as well.

The spread of alumo-silicate alkaline rocks in the lithosphere is not large and is even less than that of bauxites; the greatest areas are in the northern hemisphere. Almost all nepheline rocks are utilized only in the Union of Soviet Socialist Republics. These rocks are at least spread in the countries of the southern hemisphere.

The reserves of alumo-containing alkaline rocks in zones that are perspective for their utilization may be estimated at several billion tons.

The specifications for this new type of raw material have not yet become stable. Conditionally, taking into account the regional economy in the Union of Soviet Socialist Republics, it is considered profitable to process rocks containing about 27 per cent Al_2O_3 and 14 to 18 per cent of alkalines.

For the production of aluminium-silicon alloys, it is rational to use ores in which the aluminium-to-silicon ratio is near to that required for the alloys (disthen, andalusite, sillimanite, kaolinite). These rocks are spread in the lithosphere to a far greater extent than the alkaline alumo-silicate rocks. They are known in regions of earliest formation where there are neither bauxites nor alkaline quartz-free eruptive rocks, as in the southern part of Africa and the northern regions of Europe and North America. Kaolinite clays are widely spread in different climatic zones of the earth.

The industrial production of alumo-silicon alloys and silumine from the kaolinite concentrate is organized in the Union of Soviet Socialist Republics where there are kaolinate reserves of many thousand million tons. The alumo-silicate alkali-free raw material (content in the concentrate) must meet the following requirements:

	Al_2O_3	SiO_2	Fe_2O_3
Disthen (sillimanite, andalusite) concentrate	> 56%	< 37.5%	< 0.5%
Kaolinite concentrate	> 36%	< 47 %	< 0.5%

For the utilization of alumo-silicates as raw materials for the production of alumo-silicon alloys, as well as aluminium, it is necessary to work out technical-economical efficient methods of their beneficiation.

Maintaining the present rate of development of aluminium production and even greatly increasing it by using various aluminium-containing rocks, the world would be supplied with raw material for aluminium production for many centuries.

ID/WG.11/3 SUMMARY — Requirements for alumina for the production of aluminium in an Austrian aluminium reduction plant by E. Nachtigall, Austria

The Austrian aluminium industry is capable of high production based on water power from the Alps. In 1898 a Swiss company established a small aluminium reduction plant in Lend, Salzburg with a hydroelectric generating station. In 1940 significant aluminium reduction works were constructed in Ranshofen, Upper Austria. Both works produced about 78,000 tons of virgin aluminium in 1966.

During the war the works in Ranshofen processed Hungarian bauxite. This bauxite was transported along the Danube and Naab to an alumina factory in Schwandorf, Bavaria for the production of alumina. After this procedure the aluminium was transported along the Naab and Inn rivers to Ranshofen.

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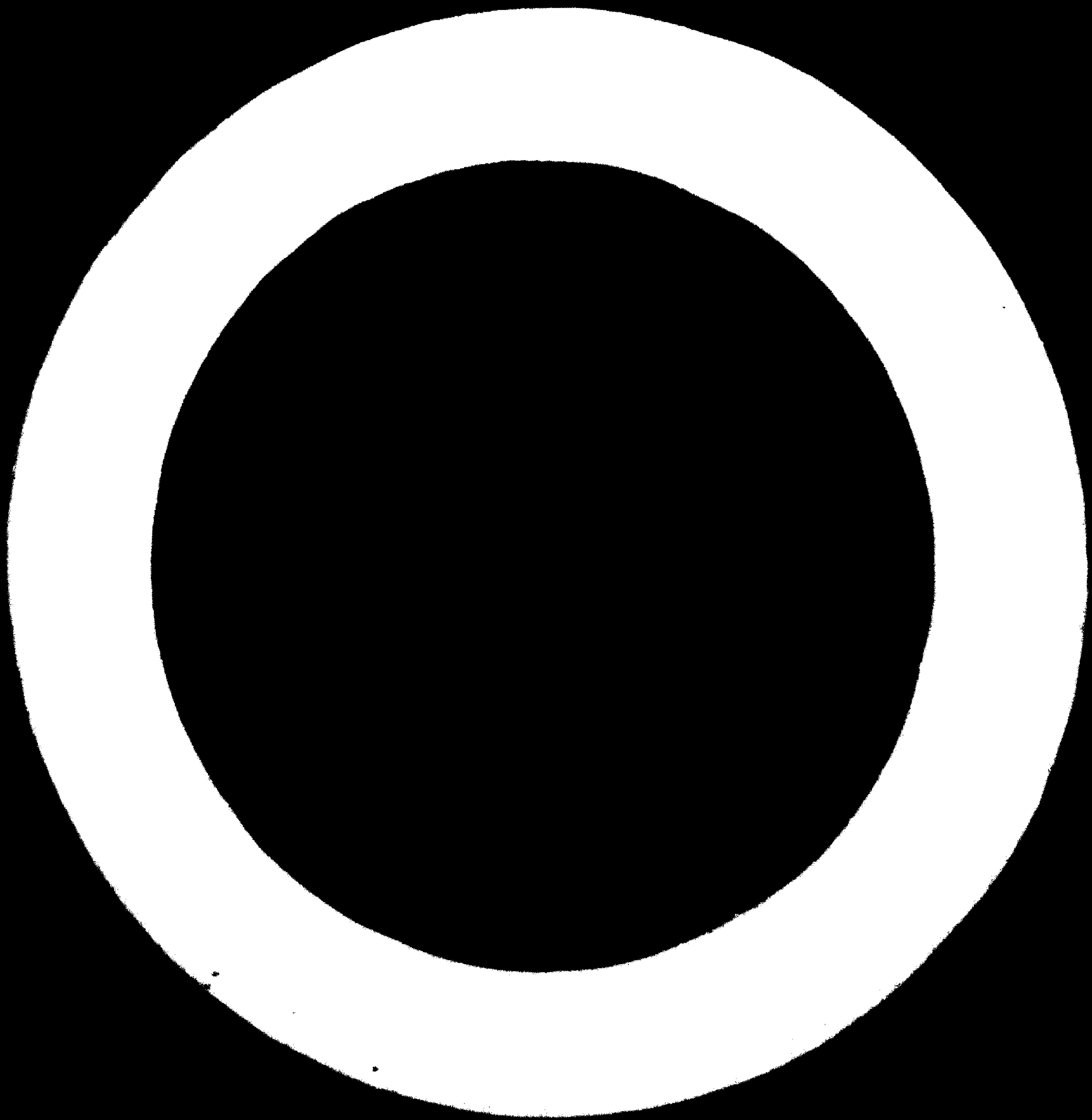
Contents

Tables in text

Annexes



2 OF 2

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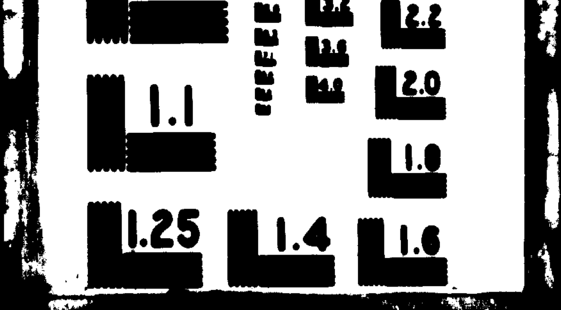


Austria itself does not possess an alueina factory; therefore, alueiniue oxide has to be imported from several countries. Because of the various supplies of alumina it is necessary to sign detailed agreements with suppliers, especially to define quality. Quelity requirements refer to the physical and chemical properties of alumina which are important for the econoey of alueinium production and the purity of the alueinium produced.

Among the physical properties, most attention is paid to the modification and grain size of aluminium oxide. The impurities of aluminium oxide determine the purity of the aluminium produced and also influence the economy of the electrolysis process. The effects of physical properties and particular impurities are treated in the paper and reference is eade to special methods of researching aluminiue oxide.

ID/WG.11/4 SUMMARY — Development and prospects of the Bayer system of alueina production by G. Dobos, Hungary

The Bayer process known for about eighty years, by eeans of which approxieately 95 per cent of alumina produced all over the world is processed, has not changed basically since its introduction. However, in the last twenty-five years, keeping abreast with advances in techniques, the process has undergone substantial development. The Bayer process lends itself to the processing of good quality bauxites froe which, according to their tri-or monohydrate character, two specific variations have been developed, namely the European and the American. Substantially these differ one froa another only in their temperature and concentration conditions; both adapt themselves to an increasing extent to the quality of bauxite that is processed. From the metallurgical point of view alueina production may be considered as an enrichment characterized by the efficiency of the process, its specific consumption of reagents and energy, as well as the extent of specific capital investaent. These factors are determined by the technical level of the realization of the process and by the bauxite composition to be processed. The Beyer process is essentially a solvent circuit, energy consumption froe which is determined by the extent of temperature differences brought about and the efficiency of countercurrent heat recuperation. The letter can be realized with continuously operating equipaent only. A further important condition of its rentability is the selection of high-capacity equipment units as well es the realization of a technological optimue. In plants operating with up-to-dete technology the effect of the bauxite quality is less sensitive to the efficiency of the process. This, however, does not apply to alumina recovery and caustic soda consumption.

Private enterprises own the alumina industries of all but one of the developing countries considered here. But for all alumina enterprises, private or state owned, an essential condition is assured markets for aluminium. World alumina capacity now is divided 80 per cent into private and 20 per cent into state enterprises. By 1971 the share of state enterprises may be greater. Six companies control most of the world's private capacity. Control of the world aluminium smelting industry follows a similar pattern.

Control over alumina capacity is determined largely by control over smelter capacity. The alumina plants of Brazil, the Republic of China and India are small and of high cost and they serve associated aluminium smelters under common ownership protected by high import duties. These plants do not supply export markets. The alumina plants of the other developing counties are larger and operate at lower cost to serve export markets.

In Jamaica and Guinea the alumina industry is based on the use of lower grades of bauxite previously ignored or considered uneconomic. Although there is a general growing interest in the use of low-grade bauxites and other aluminous ores, the trend is not yet established in view of the large resources of higher grade ores being developed in Guinea and Australia.

The growing dependence of the developed countries upon imported bauxite has increased the incentive to locate alumina plants close to the ore in order to save on transportation costs. Political stability and security of investment have also become important locational factors. An uninterrupted flow of alumina is even more important than the amount of the investment risked in an alumina plant. Far greater investment is at stake in the aluminium industry that consumes the alumina, and the other industries that use the aluminium. Sections of industrial economies can be disrupted seriously if the flow of imported alumina is halted or terminated. For these reasons, enterprises have particularly favoured alumina plant locations in certain countries where conditions are favourable both to the security of alumina investment and the sustained flow of output.

Developing countries seeking alumina capacity have to compete both among themselves and with other countries in arranging the terms and conditions acceptable to the alumina enterprises.

The experiences in establishing alumina capacity are reviewed in detail for a number of countries. Considerable variations are evident in background conditions and the kinds of arrangements made. In some details, arrangements negotiated between colonial governments and enterprises appear to have been more favourable to the countries than arrangements later negotiated by independent developing countries, probably because of the greater sophistication of the colonial representatives.

Where the size of the market for an individual enterprise would support less than the most economic arrangement, the consortium device has been used to pool the markets of a number of aluminium enterprises. This method like the joint venture technique is being used not only to combine a number of private enterprises, but also to accommodate mixtures of private and state enterprises. Some developing countries are using alumina developments to support parts of the domestic economy such as the employment and training of native personnel.

ID/WG.11/9 SUMMARY — Experience in the expansion of alumina plants and industry in the developing countries by P. Dayal, India

The importance of an aluminium industry to the development of the economy of a country is indicated in this paper. The pattern of growth of the demand of aluminium and its production in the world has been discussed; world reserves of bauxite have been mentioned briefly.

Developments in the production of bauxite, alumina and aluminium in various countries of the world with particular reference to the developing countries have been described. The production of bauxite in the developing countries has been between 70 to 80 per cent of the world production during the last ten years. Barely one fifth of this bauxite is converted into alumina in these countries; the rest is exported to the developed countries.

The author deals with the status of the alumina and aluminium industry in developing countries and the possibilities of its expansion in the future. The capacity for alumina in the developing countries in 1966 was 3.46 million short tons, that is, 26.6 per cent of the total world capacity (excluding the capacity of centrally planned economy countries) of 13 million tons. It is estimated that by 1971 the capacity for alumina in the developing countries will increase to 5.5 million short tons, that is, 33 per cent of the total capacity as mentioned above of 16.7 million short tons. The export trade of the developing countries in bauxite, alumina and aluminium has also been indicated.

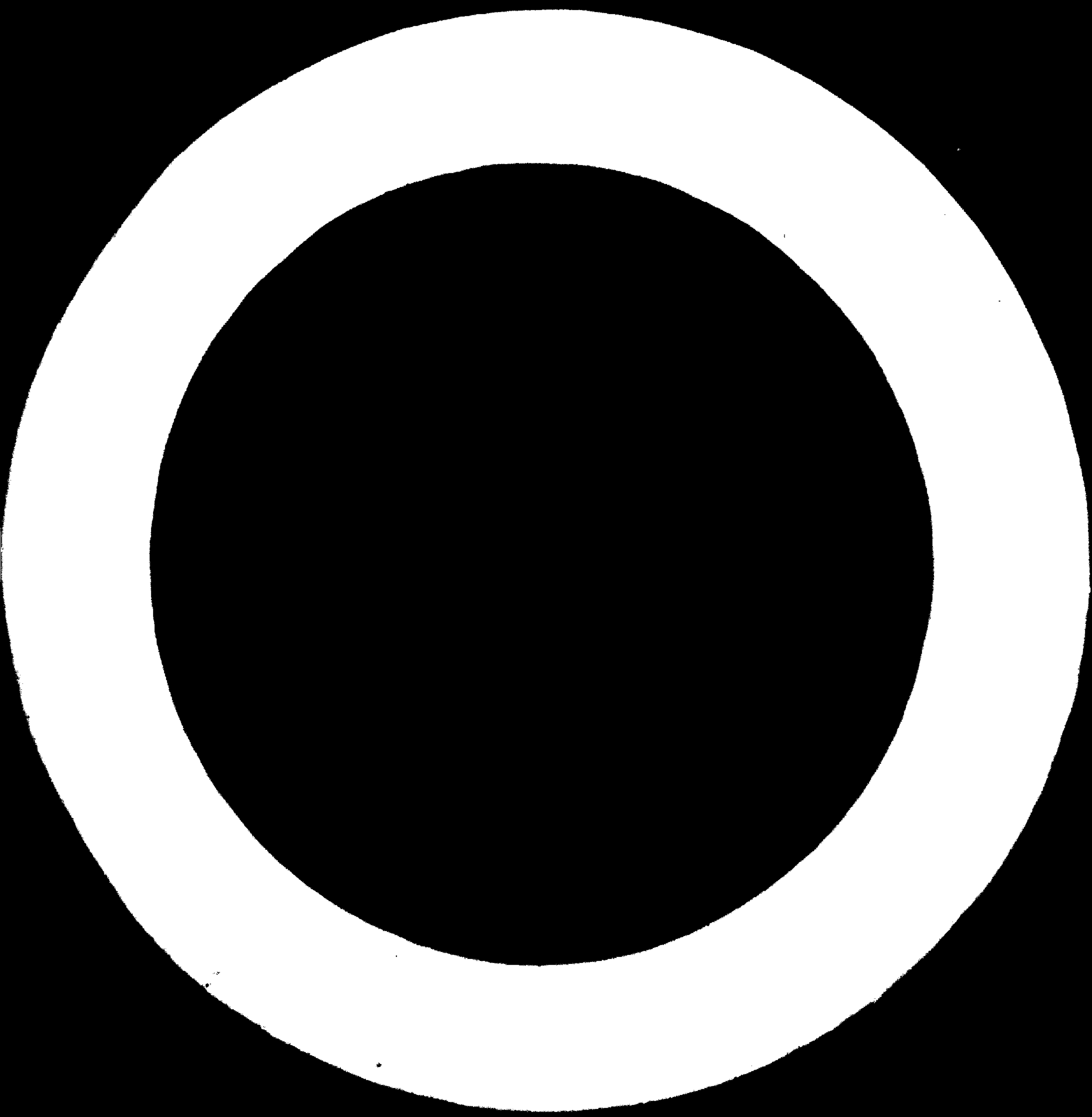
The paper describes the development of the alumina industry in India from its inception 25 years ago, its rapid growth during the last ten years and further expansion envisaged. The installed capacity for alumina in India by the end of this year will be 257,000 tons and is likely to increase to 889,000 tons by 1974. The types of bauxite used and the technology of the processes employed have also been given.

The paper further deals with the experience gained in the expansion of the alumina industry in India with respect to design of the plant; availability of equipment; pilot-plant study of bauxite; space; installation of equipment; and training of technical and operating personnel. These are briefly summaried below.

The alumina industry in India has been developed in technical collaboration with aluminium-producing companies from the advanced countries. India thus got the benefit of the latest know-how from the advanced countries. Indian engineers are now playing a major role in the design and technology of the new plants and expansions. Most of the equipment required for the construction of an alumina plant is now manufactured in the country. It has been experienced that the data collected from laboratory scale tests on bauxite do not give an entire picture to the designer. It is necessary therefore that before taking up the design of a new plant or expansion, composite samples of bauxite should be collected from the mines and their properties studied in a pilot plant.

In an alumina plant which is initially designed for small capacity, adequate space should be provided for future expansion to raise the capacity to an economic size. In order to avoid loss of production from the existing plants, the units for expansion should be built up first and inter-connexions with the older units made by planning a schedule of shut-down of the latter for changeover and simultaneous maintenance. It is also felt that during the erection of the expansion capacity, supervision requires strengthening to ensure that the construction crews do not hamper the operation of the old plant. It is essential that the technical and operating personnel should receive intensive training before the start of a new plant.

It is considered that an annual capacity of 200,000 to 250,000 tons is an economic size for an alumina plant. The cost of investment for such a plant is about $US 125 per annual ton. Finally, it is concluded that there is great scope for the expansion of the alumina and aluminium industry in developing countries.



<u>Annex 2</u>

Table 1

World production of bauxite

(gross weight in thousands of tons)

	Average 1949-54	Average 1955-60	1959	1960	1961	1962	1963	1964	1965
Commonwealth									
Jamaica a/	590	4,496	5,126	5,745	6,663	7,495	6,903	7,760	8,514
Guyana	2,080	2,141	1,674	2,471	2,374	3,036	2,343	2,468	2,638
Australia	5	19	15	69	16	29	354	784	1,162
Malaysia b/	57	423	589	737	663	575	599	622	980
India	64	176	215	381	468	568	556	561	695
Ghana	174 c/	164 c/	148 c/	191 c/	201	239	309	246	304
Sierra Leone	-	-	-	-	-	-	41	148	204
Rhodesia	-	-	-	-	-	1	2	2	2
Pakistan	-	2	2	1	-	-	-	-	-
Total	2,919	7,422	7,768	9,595	10,385	11,942	11,106	12,591	14,499
E.E.C									
France	1,032	1,689	1,729	2,035	2,190	2,124	1,973	2,395	2,610
Italy	207	291	290	308	322	304	264	236	240
Germany (Fed. Rep.)	5	4	4	4	4	5	4	4	5
Total	1,243	1,984	2,023	2,347	2,516	2,433	2,241	2,635	2,855
Other countries									
Surinam	2,751	3,257	3,376	3,400	3,351	3,202	3,453	3,926	4,330 c/
Guinea	154	516	296	1,170	1,739	1,427	1,838	1,652	1,840
United States a/	1,596	1,659	1,700	1,998	1,228	1,369	1,525	1,601	1,655
Yugoslavia	464	842	802	1,009	1,213	1,311	1,265	1,273	1,549
Greece	206	769	904	870	1,102	1,300	1,261	1,046	1,240
Dominican Rep. a/	-	183 d/	419	678	737	665	761	807	927
Indonesia	413	318	381	389	413	484	485	638	600
Haiti a/	-	219	255	268	263	370	327	373	320
Brazil	19	76	95	119	110	188	167	130	190
Other in this group	24	33	35	33	28	29	36	22	23
Total	5,627	7,872	8,263	9,934	10,184	10,345	10,918	11,468	12,674
Total of above groups	9,789	17,273	18,054	21,87f	23,085	24,720	24,265	26,694	30,028
USSR e/	880	2,620	2,950	3,450	4,000	4,200	4,300	4,300	4,700
Hungary	944	1,020	923	1,171	1,334	1,445	1,340	1,464	1,455
China (Mainland) e/		175	300	350	400	400	400	400	400
Romania	12	63	70	87	68	30	10	7	12
Total	1,835 f/	[illegible]	4,245	5,060	5,800	6,075	[illegible]	6,170	[illegible]
World total	11,625 f/	21,160	22,300	26,935	28,885	30,795	30,315	32,865	36,505

a/ Dried bauxite equivalent.

b/ Of which Sarawak 1962: 225; 1963: 155; 1964: 158; 1965: 136.

c/ Exports.

d/ Average 1959-60; production started in 1958.

e/ Estimated by the US Bureau of Mines.

f/ Excluding production in China (Taiwan), if any.

Note: Small discrepancies in the total figures are due to rounding of subtotals.

Table 2

World domestic exports of bauxite
(gross weight in thousands of tons)

	Average 1949-54	Average 1955-60	1959	1960	1961	1962	1963	1964	1965
Commonwealth									
Jamaica a/	522	3,588	4,197	4,148	4,975	5,987	5,162	5,967	6,785
Guyana b/	1,962	1,879	1,515	2,095	1,606	1,832	1,333	1,319	1,758
Malaysia c/	61	411	567	708	541	514	608	629	(820)
Australia	-	30 d/	-	30	30	6	143	406	611
Ghana	124	170	148	225	196	287	207	264	283
Sierra Leone	-	-	-	-	-	-	20	127	(180)
India	2	23	23	74	98	173	133	93	62
Total	2,671	6,076	6,449	7,279	7,447	8,799	7,606	8,805	(10,500)
E.E.C.									
France	287	312	271	312	252	260	199	197	199
Other	-	-	-	-	-	1	2	3	5
Total	287	312	271	312	252	261	200	200	203
Other countries									
Surinam	2,747	3,249	3,338	3,577	3,351	3,202	3,427	3,921	4,330
Yugoslavia	441	662	592	790	915	900	982	1,063	1,144
Greece	204	743	841	891	1,036	887	1,100	1,046	1,132
Dominican Rep. a/	-	522 e/	396	648	703	706	761	748	976 f/
Indonesia	405	299	243	342	414	442	606	(800)	(600)
Haiti a/	-	318 g/	291	341	289	437	328	396 f/	330 f/
Guinea	154	419	276	694	346	13	44	164	(200)
Other in this group	73	19	15	12	54	72	75	62	(70)
Total	4,024	5,773	5,991	7,295	7,108	6,659	7,323	8,000	8,700
Hungary	615	476	459	491	690	708	656	749	555
Romania	(10)	56	81	87	32	15	8	-	
Total	625	531	540	578	722	723	664	749	555
World total	7,605	12,695	13,256	15,465	15,530	16,440	15,795	17,735	20,040

a/ Estimated dried equivalent.

b/ Partly dried and partly calcined.

c/ Of which Sarawak 1962: 190; 1963: 157; 1964: 105; 1965: 150.

d/ 1960 only.

e/ Average 1959-60; exports started 1959.

f/ US imports from country concerned.

g/ Average 1957-60; exports started 1957.

Note: Small discrepancies in total figures are due to rounding of subtotals.

Table 3

World retained imports of bauxite
(gross weight in thousands of tons)

	Average 1949-54	Average 1955-60	1959	1960	1961	1962	1963	1964	1965
Commonwealth									
Canada a/	2,090	2,046	1,690	2,250	1,545	1,365	1,310	1,564	1,828
United Kingdom	299	342	327	375	395	426	331	374	466
Australia	-	56	67	96	52	70	14	1	(35)
Total	2,389	2,443	2,084	2,722	1,992	1,861	1,655	1,939	(2,330)
E.E.C.									
Germany (Fed. Rep.)	638	1,152	898	1,322	1,539	1,369	1,484	1,597	1,610
Italy	106	193	233	276	258	289	344	373	469
France	3	33	44	60	119	100	140	144	115
Other	2	10	24	11	10	7	13	9	28
Total	749	1,388	1,199	1,668	1,925	1,765	1,981	2,122	2,222
Other countries									
United States b/	3,484	7,172	8,258	8,858	9,276	10,605	9,263	10,369	12,702
Japan	195	604	817	1,077	1,138	1,081	1,399	1,595	1,649
China (Taiwan)	26 c/	33	32	24	56	56	52	88	103
Spain	3	17	9	23	40	46	65	52	84
Norway	30	31	35	28	30	38	24	30	29
Sweden	14	13	13	6	25	24	14	31	23
Austria	5	5	-	10	18	13	13	17	23
Other in this group	9	23	25	47	60	51	32	35	40
Total	3,766	7,898	9,189	10,073	10,644	12,004	10,862	12,217	14,653
USSR d/	468	426	447	422	448	303	434	442	595
Czechoslovakia e/	32	204	242	265	351	363	299	414	(330)
Eastern Germany	102 a/	234	251	264	259	281	322	322	246
Poland	6 e/f/	21	24	35	59	42	59	79	(90)
Total	607	885	964	986	1,117	999	1,114	1,257	(1,280)
World total	7,510	12,615	13,435	15,450	15,680	16,620	15,610	17,535	20,465

a/ The share of bauxite in Canadian combined imports of bauxite and alumina has been estimated for the years 1949-63 from the export statistics of supplying countries. From 1964 onwards the figures are official imports.

b/ Partly dried and partly calcined.

c/ Average 1952-54.

d/ Figures comprise exports to the USSR from Hungary 1949-55 inclusive and in 1965, and Soviet imports from Greece from 1955 onwards.

e/ Exports to the country concerned from Hungary and Yugoslavia.

f/ 1949 only.

Note: Small discrepancies in total figures are due to rounding of subtotals.

Table 4

World production of primary aluminium
(in thousands of tons)

	Average 1949-54	Average 1955-60	1959	1960	1961	1962	1963	1964	1965
Commonwealth									
Canada	419.6	562.3	530.0	680.4	592.1	616.3	642.2	752.7	741.9
Australia	-	9.2	11.4	11.7	13.2	16.2	41.3	78.2	86.4
India	3.9	10.8	17.1	18.0	18.1	34.8	52.5	53.7	55.7
United Kingdom	29.7	26.9	24.5	28.9	32.3	34.0	30.6	31.7	35.6
Total	453.1	609.2	583.0	738.9	655.7	701.2	766.2	916.6	919.1
E.E.C.									
France	89.3	166.6	170.3	234.7	275.0	289.8	293.7	311.0	335.1
Germany (Fed. Rep.)	76.7	146.8	148.8	166.3	169.8	175.0	205.5	216.4	233.5
Italy	44.6	68.0	73.8	82.3	82.0	80.0	90.1	113.2	122.0
Total	210.6	381.4	392.9	483.3	526.9	544.8	589.2	640.6	690.7
Other countries									
United States	864.4	1,551.6	1,744.7	1,796.2	1,690.7	1,891.0	2,064.0	2,179.2	2,459.4
Japan	36.8	83.6	98.6	131.1	151.3	168.7	210.4	261.6	289.3
Norway	49.6	113.5	143.6	162.2	168.8	202.6	215.7	243.2	271.6
Austria	30.7	59.9	64.5	66.9	66.6	72.9	75.2	76.5	77.5
Switzerland	24.8	32.3	33.8	39.1	41.5	48.8	60.2	63.2	66.1
Spain	3.4	17.6	22.3	28.3	37.1	41.0	44.8	48.9	50.6
Cameroon	-	30.9 a/	41.6	43.2	46.8	51.4	52.1	50.7	49.7
Yugoslavia	2.6	18.1	18.9	24.7	27.0	27.5	35.3	34.2	39.7
Sweden	7.1	13.3	15.6	15.7	15.6	15.9	17.8	22.0	30.1
Brazil	0.7	10.7	17.8	17.9	19.7	19.8	17.3	26.2	29.1
China (Taiwan)	3.6	7.9	7.4	8.1	8.9	10.8	11.7	19.1	18.6
Mexico	-	-	-	-	-	-	5.2	17.4	18.9
Total	1,023.7	1,929.1	2,208.9	2,335.9	2,283.0	2,550.4	2,820.5	3,153.2	3,400.6
Total of above groups	1,687.4	2,919.7	3,184.8	3,[illegible]8.1	3,465.6	3,796.4	4,176.4	4,710.6	5,010.4
USSR b/	240.0	530.0	615.0	665.0	885.0	890.0	950.0	980.0	1,260.0
China (Mainland) b/	0.5	35.0	69.3 c/	80.0	100.0	100.0	100.0	100.0	100.0
Czechoslovakia	3.0	26.8	25.6	39.4	49.2	29.2	58.0 b/	59.0 b/	61.0 b/
Hungary	22.5	38.1	44.9	48.8	50.3	51.9	54.6	56.0	57.2
Poland	0.9	22.0	22.4	25.6	46.9	47.3	45.9	47.0	46.6
Eastern Germany b/	8.0 c/	33.5	34.0	39.0	39.0	37.0	39.0	40.0	45.0
Total	275	685	810	900	1,170	1,175	1,250	1,280	1,590 d/
World total	1,965	3,605	3,995	4,455	4,635	4,970	5,425	5,990	6,600

a/ Average 1957-60; production started in 1957.

b/ Estimated by the US Bureau of Mines.

c/ Reported production.

d/ Including Romania 22.4.

Note: Small discrepancies in total figures are due to rounding of subtotals.

Table 5

World domestic exports of unwrought aluminium (including alloys)
(in thousands of tons)

	Average 1949-54	Average 1955-60	1959	1960	1961	1962	1963	1964	1965
Commonwealth									
Canada	346.4	452.7	452.9	493.0	434.9	514.5	567.1	560.7	631.7
United Kingdom	5.1	5.0	3.7	3.9	5.4	5.4	7.4	6.7	24.1
Australia	0.2	0.1	0.1	-	-	-	5.3	15.1	21.2
Total a/	351.7	457.4	456.9	496.9	440.3	519.9	579.9	582.5	677.0
E.E.C.									
France	19.6	38.5	50.8	70.6	121.9	103.5	122.7	123.2	179.8
Germany (Fed. Rep.)	16.6	2.9	1.8	2.7	3.8	5.9	14.0	9.7	10.0
Belgium-Luxembourg	1.7	0.8	0.9	0.9	0.6	0.8	0.8	1.1	2.3
Other	5.9	6.4	11.4	1.9	2.5	0.9	0.5	19.6 b/	32.5 b/
Total	43.8	48.6	64.9	76.1	128.7	111.2	138.0	153.6	224.7
Other countries									
Norway	38.4	97.3	130.0	136.0	144.0	169.0	204.2	260.6	238.7
United States	2.6	78.6	108.1	254.4	115.1	135.0	147.6	186.3	184.8
Cameroon	-	28.5 c/	38.6	41.4	45.4	50.1	51.5	48.0	45.2
Austria	14.5	27.0	37.6	21.4	27.9	41.1	34.8	33.3	31.5
Japan	11.4 d/	3.7	0.2	-	-	5.4	13.9	19.2	28.7
Switzerland e/	8.1	8.6	14.7	7.3	6.0	8.4	17.9	18.9	19.1
China (Taiwan)	1.7 f/	2.4	2.0	0.1	2.4	2.6	3.4	7.1	(7.0)
Spain	-	5.6 g/	0.2	11.1	3.9	10.4	10.1	9.0	0.3
Other in this group	0.9	4.3	2.9	1.5	1.5	1.7	3.4	5.2	6.1
Total	77.6	242.8	334.4	473.2	346.2	423.7	486.8	587.6	561.4
USSR h/	-	73.4	76.2	66.9	84.6	113.9	120.2	172.4	225.4
Hungary	5.1	9.3	9.2	11.0	8.6	6.4	10.4	12.0	18.5
Other in this group	-	7.9	2.8	0.2	2.1	2.2	1.3	0.9	7.0
Total	5.1 i/	90.6	88.2	78.1	95.3	122.5	131.9	185.3	251.0
World total	480 j/	840	945	1,125	1,010	1,175	1,335	1,510	1,715

a/ Includes small amounts from India in 1959 and 1964.

b/ Of which Italy 18.9 in 1964 and 31.5 in 1965.

c/ Average 1957-60; exports started in 1957.

d/ Average 1950-54.

e/ Including scrap.

f/ Average 1952-54.

g/ Average 1958-60; exports started in 1959.

h/ Excluding alloys, if any

i/ Imports into known recipient countries of unwrought aluminium from these exporters.

j/ Excluding exports from centrally controlled economy countries other than Hungary.

Note: Small descrepancies in total figures are due to rounding of subtotals.

Taking into account the ever-deeper knowledge of process chemism and the development of investigation methods, it may be expected that on the basis of laboratory investigations more and more accurate consequences will be drawn as to the expected technological properties of bauxites, and this will pave the way for further improvements of the technological process. The effect of mineral modifications of aluminium hydroxide and of silica and titanium oxide on digestion chemistry may already be considered to be cleared. Iron oxide modifications have first of all an influence on red mud settling, appreciation of which should not be neglected. As regards elimination of other impurities, industrial solutions are already available at present; furthermore recuperation of valuable elements (Fe, V, F, Ga etc.) on an industrial scale is also solved. Decomposition kinetics, which in the recent past was still considered a "difficult art", may be set in equations.

In the course of alumina production, large-size equipment serving the exclusive purpose of alumina production has been developed. As a further means of development, introduction of autogenous bauxite milling has also been taken into consideration. Continuous digestion at high temperatures ensuring a good heat recuperation has been realized, and in the near future introduction of digestion over 250°C may be expected, perhaps in the form of tube digestion. For the settling of red mud, one-chamber settling tanks of 30 to 35 m diameter are used and for the filtration of red mud continuously operating drum filters and pressure filters with a large surface (230 m^2) are put into service. The pneumatic automized pressure filters supply adequately transportable storable red mud with a moisture content below 30 per cent.

Development of decomposition technology has resulted in the increase of tanks (2 to 3000 m^3), further in the continuity of operation and the realization of air-lift agitation with low energy consumption. In evaporation the trend of development is likewise an increase in size (up to 1400 m^2 corpus), usage of mixed or countercurrent equipment with a view to decrease scale formation and better heat utilization.

For calcination in general, furnaces of a length of 75 to 110 m are used and efforts are being made to solve preliminary drying of the hydrate and introduction of dust cyclones.

With the development of the Bayer process, the necessity presented itself to elaborate quick automatic analysers of raw materials, intermediate and final products with continuous operation, which, from the point of view of automation and optimization of the process, appear to be of decisive importance. It was thus that alumina plants reached the stage of realizing computer control.

From the technological point of view, processing of poorer quality ores and recuperation of useful components (Fe, Ti etc.) merit certain attention.

Table 6

World retained imports of unwrought aluminium (including alloys)
(in thousands of tons)

	Average 1949-54	Average 1955-60	1959	1960	1961	1962	1963	1964	1965
Commonwealth									
United Kingdom	181.8	242.4	250.1	310.5	235.9	250.6	266.8	325.4	318.8
Hong Kong	0.5 a/	5.4	5.1	6.0	5.2	4.6	6.0	10.3	4.3
New Zealand	0.3	0.6	0.8	0.7	2.1	5.0	5.6	8.0	9.1
India	1.5	6.0	6.8	8.0	9.4	14.7	6.2	4.6	1.3
Australia	8.4	15.7	19.3	26.4	16.1	31.4	12.1	0.6	0.4
Other	1.1	8.3	14.0	6.8	10.2	8.8	3.9	6.1	8.1
Total	193.6	278.4	296.1	358.4	279.0	315.1	300.6	355.0	342.0
E.E.C.									
Germany (Fed. Rep.)	12.1	75.8	88.6	178.1	136.5	116.1	118.8	162.7	166.8
Belgium-Luxembourg	12.2 b/	40.1	48.6	63.4	68.5	67.2	87.6	110.9	115.2
France	2.3	21.9	32.8	53.3	42.0	50.8	55.0	71.3	70.6
Italy	4.6	15.0	15.8	33.5	25.3	43.3	53.3	32.2	33.2
Netherlands	5.8	11.1	14.0	14.4	13.6	14.5	19.5	22.0	20.0
Total	37.0	163.9	199.9	342.8	286.0	292.0	334.2	399.0	405.7
Other countries									
United States	151.9	188.4	213.9	138.1	177.9	277.6	371.4	350.8	470.7
Japan	0.4	8.5	15.3	22.8	32.1	17.5	22.9	33.9	41.6
Argentina c/	7.7	13.4	9.2	11.9	28.8	15.3	14.8	33.1	(37.0)
Sweden	12.9	20.6	21.2	27.7	23.6	30.3	36.1	24.9	26.8
Brazil	8.7	11.4	8.8	14.6	17.9	19.2	25.4	18.5	21.9
South Africa d/	2.0	6.9	7.3	11.1	10.2	13.8	16.5	16.7	(20.0)
Yugoslavia	0.1	4.1	5.8	13.6	10.5	10.5	6.6	15.6	19.5
Spain	2.0	4.9	6.4	1.7	4.2	8.3	10.4	9.8	16.6
Switzerland	5.8	11.6	16.4	16.1	10.3	10.9	4.5	5.9	12.1
Denmark	3.1	5.0	6.4	7.3	6.8	6.6	6.4	7.1	9.2
Greece	0.9 a/	2.1	2.5	4.3	5.4	5.9	5.6	8.4	8.4
Finland	1.2	4.0	7.2	4.0	5.5	6.7	4.0	6.2	8.1
Mexico	3.3	9.5	9.4	11.0	10.2	15.7	8.9	0.1	0.5
Other in this group	5.8 f/	19.9	22.4	25.8	33.4	38.1	39.1	41.0	(50.0)
Total	205.8	310.3	352.2	312.0	376.5	476.4	572.6	571.9	742.4
Eastern Germany g/	-	21.8	28.1	37.4	45.9	41.2	54.0	64.7	86.0
Czechoslovakia g/	1.3	11.3	3.5	9.5	22.8	20.1	15.5	16.2	20.0
Romania g/	-	5.6	6.9	7.8	9.4	10.6	10.9	14.5	5.5
Poland	10.8	7.3	9.9	13.6	5.9	6.3	7.0	7.9	(6.5)
Hungary	1.1	3.0	2.6	0.5	-	0.6	2.4	7.5	(5.0)
Bulgaria g/	-	1.3	2.1	3.0	3.0	3.2	3.2	5.1	4.0
China (Mainland) g/	0.5	14.0	15.6	10.1	4.8	2.9	3.9	-	-
USSR	2.7 a/	2.8 b/	0.1 b/	-	1.8	0.3	0.7	-	-
Total	[illegible] i/	[illegible]	[illegible]	[illegible]	[illegible] h/	[illegible]	[illegible]	[illegible]	127.0
World total	455 i/	829	915	1,105	1,035	1,170	1,305	1,440	1,615

a/ Average 1952-54.
b/ In 1949-51 for Belgium-Luxembourg and 1955-56 and 1959 for the USSR the figures exclude imports of alloys, if any.
c/ Including aluminium bars.
d/ Includes Southwest Africa from 1956.
e/ Average 1951-54.
f/ For some countries averages are for less than 1949-54.
g/ Exports to the countries concerned from known supplying countries.
h/ Including exports to North Korea and North Vietnam.
i/ Excluding Eastern Germany, Romania and Bulgaria.

Note: Small discrepancies in total figures are due to rounding of subtotals.

Table 7

World domestic exports of alumina and aluminium hydrates
(gross weight in thousands of tons)

	Average 1949-54	Average 1955-60	1959	1960	1961	1962	1963	1964	1965
Commonwealth									
Jamaica	35.2	377.5	399.2	665.4	703.5	627.6	725.6	768.3	720.6
Guyana	-	-	-	-	120.2	215.0	222.0	245.2	274.7
Australia	-	5.2 a/	-	5.2	-	-	-	47.7 b/	53.3 b/
United Kingdom	11.1	29.5	33.4	26.3	23.8	15.8	19.5	17.1	20.9
Canada c/	58.4	58.5	74.5	1.9	16.9	3.5	2.6	4.5	6.9
Total	104.7	466.4	507.1	698.8	864.4	861.9	969.7	1,082.7	1,076.4
E.E.C.									
France	70.5	142.7	202.1	152.0	152.0	178.3	180.8	154.1	129.6
Germany (Fed. Rep.)	46.1 d/	97.7	115.5	91.2	99.6	93.2	99.2	109.1	115.0
Italy	24.1	42.2	42.0	42.8	29.1	30.7	22.8	8.3	14.2
Total	140.7	282.6	359.6	286.0	280.7	302.2	302.8	271.5	258.8
Other countries									
Guinea	-	168.7 a/	-	168.7	384.7	450.4	480.0	469.6	510.0
United States e/	10.0	44.0	35.0	30.0	145.0	185.0	260.0	390.0	370.0
Japan	14.6 f/g/	46.3	94.8	79.3	104.5	101.0	104.1	102.6	100.6
Yugoslavia	2.6 h/	15.4	23.5	19.3	14.0	14.0	13.1	13.7	11.4
Total	27.2	133.8	153.3	297.3	648.2	750.4	857.2	975.9	992.0
Hungary	38.8	95.0	112.2	119.2	142.2	124.4	132.1	154.1	191.0
USSR i/	(9.0) f/	10.1	9.8	-	-	-	-	-	(-)
China (Mainland) j/	(-)	5.0	-	-	-	-	-	-	(-)
Total	47.8	110.1	122.0	119.9 k/	143.6 k/	124.4	132.1	154.1	191.0
World total	320	995	1,140	1,400	1,935	2,040	2,260	2,405	2,520

a/ 1960 only.

b/ Japanese imports from Australia.

c/ Before 1961 figures are imports into Norway, Sweden, Mexico and the United States from Canada.

d/ Includes imports into recipient countries from the Federal Republic of Germany in 1949 and 1950.

e/ Imports into recipient countries from the United States which may include some manufactured material (e.g. firebricks and abrasives) in the case of Canada.

f/ 1954 only.

g/ Excluding aluminium hydrates.

h/ Includes imports into recipient countries from Yugoslavia in 1949-51.

i/ Exports of alumina from the USSR to Poland.

j/ Soviet imports of alumina from Mainland China.

k/ Includes 700 tons imported into Poland from Czechoslovakia in 1960 and 1,400 tons in 1961.

Note: Small discrepancies in total figures are due to rounding of subtotals.

Table 8

World retained imports of alumina and aluminium hydrates
(gross weight in thousands of tons)

	Average 1949-54	Average 1955-60	1959	1960	1961	1962	1963	1964	1965
Commonwealth									
Canada a/	15.0	302.0	325.0	415.0	590.0	630.0	660.0	777.7	714.3
Australia b/	(-)	0.6	0.4	0.4	2.6	10.2	54.5	71.4	55.6
United Kingdom	-	2.2 c/	6.1	7.1	4.7	5.0	4.9	5.0	9.6
India	(-)	3.5	10.3	10.5	11.9	17.3	4.6	2.3	1.0
Total d/	15.0	308.3	342.2	433.0	609.2	662.5	724.4	856.6	780.5
E.E.C.									
Germany (Fed. Rep.)	-	0.7	0.1	1.0	26.5	35.0	50.3	54.2	57.6
France	0.1	7.4	0.2	43.8	133.8	191.9	124.7	66.0	19.4
Belgium-Luxembourg	7.4	9.7	9.6	9.6	9.0	9.4	10.2	12.0	10.9
Netherlands	1.3	5.8	7.2	7.2	7.6	7.8	7.7	8.9	10.4
Italy	0.1	0.6	0.9	0.7	1.1	4.9	9.0	4.8	2.7
Total	8.9	24.2	18.0	62.3	180.0	249.0	201.9	146.0	101.0
Other countries									
Norway	81.3	215.7	308.7	323.4	297.4	405.3	437.5	515.7	531.8
United States	0.9	41.8	115.5	79.0	108.9	157.7	171.7	188.1	195.8
Austria	83.6	115.7	134.3	119.1	150.0	140.2	153.8	145.2	188.7
Switzerland e/	51.2	64.4	53.1	85.9	91.1	105.4	122.8	118.8	134.2
Spain	7.8	35.7	38.2	62.1	82.8	86.7	98.5	98.5	113.7
Cameroon	-	82.0 c/	80.0	73.8	102.8	83.3	123.0	92.6	83.6
Sweden	14.8	26.8	30.1	33.2	23.7	39.8	38.5	87.2	60.8
Japan	-	-	-	-	0.3	0.2	40.1	48.3	54.8
Mexico	1.3	4.3	4.1	8.3	3.6	3.8	23.4	36.8	48.7
Other in this group	0.5	10.3	18.9	15.3	14.0	21.0	15.7	24.2	(25.0)
Total	221.4	556.3	778.8	787.8	943.4	1,046.5	1,228.0	1,338.4	1,427.0
Poland	4.8	44.5	41.0	53.0	86.0	106.8	87.5	91.8	86.0
USSR f/	21.9	5.8	-	-	-	-	-	44.0	(80.0)
Eastern Germany f/	4.8 g/	20.8	14.7	25.5	22.8	18.7	18.8	41.5	45.5
Czechoslovakia f/	10.5	33.1	26.0	21.7	21.7	17.7	14.6	15.1	(15.0)
Romania f/		0.8	1.8	1.1	-	-	0.8	0.8	(-)
Total	42.0	104.8	83.5	101.3	130.5	141.3	121.2	193.2	(225.0)
World total	285	995	1,225	1,385	1,865	2,100	2,275	2,530	2,535

a/ The share of alumina in Canadian combined imports of bauxite and alumina in 1949-63 has been estimated from the export statistics of the supplying countries. From 1964 the figures are official imports.

b/ Fiscal years up to and including 1961.

c/ Average 1957-60.

d/ Includes small amounts imported into Pakistan in 1958, 1960, 1963 and 1964.

e/ Before 1960 figures are based on exports to Switzerland from France, the Federal Republic of Germany and Italy.

f/ Exports to the country concerned from Hungary, the Federal Republic of Germany and Yugoslavia.

g/ Average 1951-54.

Note: Small discrepancies in total figures are due to rounding of subtotals.

Table 9

1980 production statistics for bauxite, alumina and primary aluminium

A. Bauxite production

Advanced and intermediary developed countries	Long tons/year		Percentage of total	
United States	1,998,000		7.3	
Canada	-		-	
United Kingdom	-		-	
France	2,006,000		7.4	
Germany (Fed. Rep.)	4,000		-	
Italy	313,000		1.2	
Norway	-		-	
Austria	26,000		0.1	
Switzerland	-		-	
Sweden	-		-	
Spain	3,000		-	
Greece	935,000		3.4	
Australia	71,000		0.3	
Japan	-		-	
Total		5,356,000		19.7
Czechoslovakia	-		-	
Eastern Germany	-		-	
Hungary	1,170,000		4.3	
Poland	-		-	
Romania	87,000		0.3	
USSR	3,450,000		12.7	
Yugoslavia	1,009,000		3.7	
Total		5,716,000		21.0
Developing countries				
Cameroon	-		-	
Ghana	224,000		0.8	
Guinea	1,356,000		5.0	
Jamaica	5,745,000		21.2	
Guyana	2,477,000		9.1	
Dominican Republic	678,000		2.5	
Haiti	280,000		1.0	
Surinam	3,400,000		12.5	
Brazil	118,000		0.4	
India	377,000		1.4	
Malaysia	452,000		1.7	
Sarawak	285,000		1.0	
Indonesia	380,000		1.4	
China (Taiwan)	-		-	
Total		15,770,000		58.0
China (Mainland)		350,000		1.3
Other		-		-
World total		27,200,000		100.0

Source: United Kingdom Overseas Geological Surveys: Bauxite, Alumina and Aluminium, London, 1982.

Note: Small discrepancies in total figures are due to rounding of subtotals.

Table 9 (continued)

B. Alumina production

Advanced and intermediary developed countries	Long tons/year		Percentage of total	
United States	3,458,000		37.8	
Canada	1,000,000		10.9	
United Kingdom	120,000		1.3	
France	586,000		6.4	
Germany (Fed. Rep.)	430,000		4.7	
Italy	218,000		2.4	
Norway	-		-	
Austria	-		-	
Switzerland	-		-	
Sweden	-		-	
Spain	-		-	
Greece	-		-	
Australia	30,000		0.3	
Japan	349,000			
Total		6,191,000		67.6
Czechoslovakia	-		-	
Eastern Germany	58,000		0.6	
Hungary	215,000		2.4	
Poland	-		-	
Romania	-		-	
USSR	1,500,000		16.4	
Yugoslavia	66,000		0.7	
Total		1,839,000		20.1
Developing countries				
Cameroon	-		-	
Ghana	-		-	
Guinea	182,000		2.0	
Jamaica	665,000		7.3	
Guyana	-		-	
Dominican Republic	-		-	
Haiti	-		-	
Surinam	-		-	
Brazil	-		-	
India	26,000		0.3	
Malaysia	-		-	
Sarawak	-		-	
Indonesia	-		-	
China (Taiwan)	20,000		0.2	
Total		893,000		9.8
China (Mainland		160,000		1.7
Other		70,000		0.8
World total		9,150,000		100.0

Source: United Kingdom Overseas Geological Surveys: Bauxite, Alumina and Aluminium, London, 1962.

Note: Small discrepancies in total figures are due to rounding of subtotals.

Table 9 (continued)

C. Aluminium production

Advanced and intermediary developed countries	Long tons/year		Percentage of total	
United States	1,799,000		40.3	
Canada	680,000		15.2	
United Kingdom	29,000		0.6	
France	231,000		5.2	
Germany (Fed. Rep.)	166,000		3.7	
Italy	82,000		1.8	
Norway	162,000		3.6	
Austria	67,000		1.6	
Switzerland	39,000		0.9	
Sweden	16,000		0.4	
Spain	24,000		0.6	
Greece	-		-	
Australia	12,000		0.3	
Japan	131,000		2.9	
Total		3,438,000		77.1
Czechoslovakia	39,000		0.9	
Eastern Germany	39,000		0.9	
Hungary	49,000		1.1	
Poland	26,000		0.6	
Romania	-		-	
USSR	670,000		15.0	
Yugoslavia	25,000		0.6	
Total		848,000		19.1
Developing countries				
Cameroon	43,000		1.0	
Ghana	-		-	
Guinea	-		-	
Jamaica	-		-	
Guyana	-		-	
Dominican Republic	-		-	
Haiti	-		-	
Surinam	-		-	
Brazil	18,000		0.4	
India	18,000		0.4	
Malaysia	-		-	
Sarawak	-		-	
Indonesia	-		-	
China (Taiwan)	8,000		0.2	
Total		87,000		2.0
China (Mainland)		79,000		1.8
Other		-		-
World total		4,460,000		100.0

Source: United Kingdom Overseas Geological Surveys: Bauxite, Alumina and Aluminium, London, 1962.

Note: Small discrepancies in total figures are due to rounding of subtotals.

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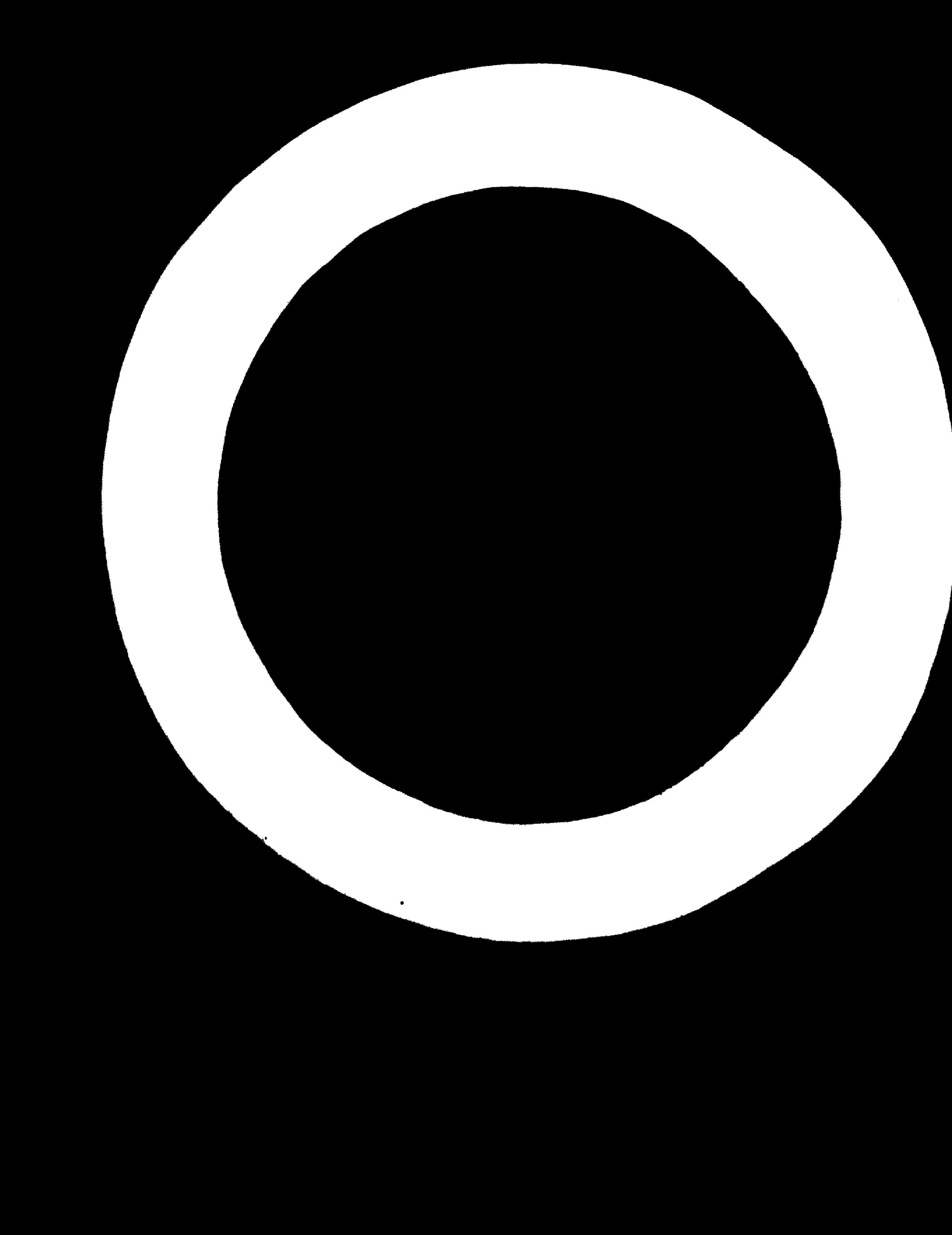

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By means of equipment development, automation as well as computer control, energy, working hours and investment costs have decreased considerably; however, development does not stand still and in the near future appreciable results may be expected.

ID/WG.11/5 SUMMARY — Processing of aluminium ores with heightened content of Si and/or Fe by J. Vosyka, Czechoslovakia

The study contains information on low-grade bauxites with Al_2O_3/SiO_2 ratios lying between the values 8 to 3; industrial scale methods have been given preferred consideration and laboratory methods only a brief mention. Characteristic signs that would be of interest to persons engaged in the planning of industrial development have been emphasized.

In the introduction the problem of increased capital input and stages of technical and economical risk in low-grade bauxite processing are referred to. Good results can be expected only if the designed technology is fully aware of local economic and technical changes.

In complicated situations perspicious planning has been recommended, including flexible technology design and location of the plant, where both the supply of low-grade domestic and high-grade imported bauxites is possible. In the first stage of planning a maximum effort should be made to start production at a profit enabling expansion and development in the future. Also step-by-step planning is mentioned to decrease technological risk.

The influence of heightened silica and iron content in the electrothermical, acid and alkalic extraction methods has been described, also the classification of low-grade bauxites from this point of view. Here a total alumina/total silica weight ratio was taken because for low-grade bauxites more energical extraction means must be used.

The electrothermical methods of molten corunde production and the processing of AlSi 65/35 intermediate alloy by total reduction are also contained in the paper. The Pedersen and Haglund processes have not been described because they do not represent an economic interest for the future.

The acid methods with characteristic main technological problems of acid extraction are described. The Australian BAS process has been briefly mentioned as a perspective method. A perspective of acid processing has been admitted for the production of aluminium sulphate, special alumina modifications for catalysis and alumina salts for the chemistry. For large-scale alumina production, the acid methods have been refused because they represent a high technological risk, fully unjustified for economic advantage.

The alkalic extraction methods, namely the Bayer method of low-grade bauxite processing, the self-reliant sinter process, the parallel Bayer-sinter process, the combination method, the high-pressure digestion, the Ponomarev process and variations of the desilication methods are also described.

For a comparison of three fundamental processing methods, i.e. for Bayer, sinter and the combination method, there was chosen an identical scale of bauxites with decreasing silica modulus from 8 to 3. Illustrative data characterizing alumina and soda recovery, red mud and sinter quantity and total heat consumption as a function of decreasing bauxite quality for each of the above-mentioned methods have been evaluated.

For each alkalic extraction method a brief technological description is given together with characteristic advantages and critical processing problems. Improvements have been cited, for example the Montecatini improvement of the sinter process, the Kaiser method of reduction of sodalite bulk, and the special importance of the high-pressure digestion in low-grade bauxite processing. The desilication methods have not been recommended for industrial application. A detailed comparison of the Bayer, parallel and combination methods and two variations of desilication methods on the basis of the data of one bauxite type with silica modulus above 6 have been cited.

The author's opinion of various alkalic extraction methods is summarized in the conclusions.

Technical conclusions

From the survey and data, it is evident that for economical alumina processing the Bayer line represents a fundamental production unit, the sinter line an auxiliary and complementary unit.

The trend shows that bauxite under the quality limit is gradually being processed by the improved Bayer method by decreasing the silica module of bauxite.

The quality limit of the bauxite up to which the Bayer method can be applied economically must first of all be estimated in each individual case through technological experiments and economic calculations.

The quality limit of which the technological and economic possibilities of wet digestion are terminated and at what point it is necessary to apply a self-reliant pure sinter process cannot yet be determined with satisfying certainty. The reason lies in the fact that for low-grade bauxites all technological and economic applications of the high-pressure technique have not yet been fully recovered and examined. It is now evident that in heat consumption the dispute has been definitely decided for high-pressure digestion, because for the sinter process a heat consumption of 750 kcal/kg represents extreme construction possibilities and cannot further be substantially reduced. The same can be said if we compare the equipment extent of the high-pressure and sinter attack. Under such conditions a decision without risk can be made only in cases where natural and economic conditions allow for installation of the Bayer line as a fundamental processing unit.

The decision to install the classical combination method and the pure self-reliant sinter process is problematic and no satisfying answer can be expected before the next few years.

Installation of the auxiliary sinter unit remains fully entitled for causticization of soda for or from the Bayer process, and this method cannot be replaced, especially for bauxites with heightened carbonate and organic matter content, and where calcined soda is cheap.

Conclusions of planning

The complexity and number of factors influencing good economic results in processing alumina from low-grade bauxite shows that the right decision cannot be made in a few days, but only after a thorough study and analysis of all important questions, for which a minimum of two years is needed before design is started.

A study and analysis of the problems mentioned should therefore be started in actual cases without delay by a few members of domestic qualified engineer groups. This study group should have an opportunity to examine the solutions to problems with a neutral specialized organization and learn the practices of alumina producers by working under similar conditions. They should apprehend, at specialized institutes, model and pilot scale technological experiments, and discuss the results and conclusions with a well-informed group of neutral specialists.

Even if processing alumina from domestic low-grade ores cannot be realized, considerable value for the development of planning can be gained, because the necessary data for evaluating the possibility of processing alumina are valid and of interest for the chemical, the ceramical and the metallurgical industries.

ID/WG.11/6 Technological aspects of alumina production from complex ores
SUMMARY by C. Popov, Argentina

Technological investigation of the methods for alumina production from raw materials other than bauxite is based on the advisability of processing local raw materials, and processing complex ores by extraction of valuable components other than alumina.

Out of many aluminium-containing materials only a few can be considered as perspective ores for alumina production: nepheline (NaK_2), $O.Al_2O_3.2SiO_2$ with 32 to 36 per cent Al_2O_3; alunite (NaK_2) $SO_4.Al_2(SO_4)_3.4Al(OH)_3$ with 37 to 29 per cent Al_2O_3; high-grade clays, kaolinite $Al_2O_3.2SiO_2.2H_2O$ with 39.5 per cent Al_2O_3; pickeringite by $Al_2(SO_4)_4.22\ H_2O$ with 11.9 per cent Al_2O_3 and some others.

There are hundreds of methods known for alumina production; they are divided into three groups: electrothermical, acid and alkalic methods. The electrothermical method can be without deficiency only when electricity is very cheap. The acid method is not used because of the low stability of the equipment. The alkalic method is at present widely used for alumina production in all countries.

However, investigation of the acid method shows that it is, in spite of some disadvantages, more suitable for processing raw materials with high content of SiO_2 than the alkaline method. The acid method, now used in Canada, is being widely investigated in France, the United States and Poland.

The technology of processing nepheline ores by sintering as well as by the new "hydrochemical method" is considered. Special attention is given to consideration of complex processing of kaolinito ores by the acid method, alunite by ammonia-alkaline method and pickeringite ores from argenite deposits. The author's viewpoint is as follows:

(a) The complex processing of aluminium-containing ores is one method of alumina production which at the same time produces other valuable components from local raw materials;

(b) For extraction of iron from the ores, reduction to finely ground ores by using peak coke is recommended. Afterwards it is easy to separate the iron through magnetic separation methods;

(c) Establishment of a research centre in Argentina for the study of complex processing of laterite, pickeringite and alunite ores should be recommended to UNIDO. The results that would be obtained by this centre would be of great importance for Argentina and neighbouring countries where there are rich deposits of peat, natural gas and aluminium containing minerals.

ID/WG.11/7 SUMMARY — Investment cost and economic scale of an aluminium plant in Indonesia by B. Siahaan, Indonesia

Many industries constructed in developing countries cannot compete with those of developed countries. Government subsidy and protection are sometimes required even to guarantee survival of such industries. The inability to operate without subsidy is due not only to the lack of skilled operators, but mainly to extremely high investment costs.

A significant increase in capital investment for the erection of machinery and equipment differs from one country to another. The main factors influencing the amount of capital investment are: infrastructural conditions and facilities existing in the country concerned; the problem of logistics; labour and manpower in general; acceptance of modern technology and local conditions and regulations.

Owing to insufficient facilities during both the development and the operational periods of a plant, each project has to set up infrastructures by its own means. For instance, a project that costs over $US 10 million generally has to:

(a) Construct roads, bridges and a railway leading to the project site;

(b) Provide transportation equipment during the construction and operation, such as trucks and trailers;

(c) Provide construction equipment;

(d) Maintain a repair and maintenance shop during the construction and operation periods;

(e) Construct a power plant with its accessories;

(f) Provide water purification equipment;

(g) Construct a harbour or pier during the construction and operational periods;

(h) Provide equipment for telecommunication; .

(i) Provide a settlement for local and non-local personnel;

(j) Build a hospital, schools, places of worship and recreational halls.

The construction of the above items constitutes a public service.

Experience gained from project construction in Indonesia reveals that all construction equipment used during construction periods depreciated in value 100 per cent. This applies particularly to tools and equipment used to train operators. Such equipment, however, is more easily damaged than normally used equipment. For purposes of construction, equipment and spare parts equivalent to 15 per cent of the total cost of all equipment is usually needed, while expenditure for maintenance costs is approximately 10 to 15 per cent of this price.

Some projects that previously never existed in Indonesia require foreign manpower for construction and during their trial run. In general, all expatriate personnel participating in the project construction receive certain facilities from the recipient country, such as housing, medical treatment, local transportation and insurance. After staying in Indonesia for more than one year, expatriates are permitted to bring their families. The cost of fares to and from Indonesia, including transportation of luggage, is paid by the Indonesian Government. In some instances, the amount of money spent on expatriate personnel amounts to 10 to 15 per cent of the cost of the project.

A great number of difficulties have been encountered with machinery, equipment and technology with the result that investment costs have increased. This has been due mainly to the lack of Indonesian experts, particularly those skilled in ascertaining the type and amount of equipment required for an entire construction and operation. Some imported equipment that proved to be unsuitable had to be substituted by other, more suitable equipment. It has also been noted that unnecessary extravagance occurred as a result of constructing luxurious non-productive factory units, or because of ordering too sophisticated or too automatic equipment which could not be repaired when defects developed.

Problems of local conditions frequently forgotten by project performers, especially the expatriate personnel unfamiliar with local conditions, can increase investment costs. A project in Indonesia, for example, which did not take into account the regional situation, encountered difficulties which resulted in having to import stones at an additional expenditure of $US 831,000.

An even worse problem is that of local and international transportation, or ocean freight. This occurs also in other developing countries as transportation problems always constitute the main obstacle. For transporting building materials during the construction period, a project has to purchase 200 to 300 trucks at the approximate cost of $US 1 million. Sometimes a train must be purchased complete with locomotive and cars, and it is often necessary to build a railway line to the plant site, which can cost about $US 800,000.

Harbour problems in Indonesia make the situation even worse for, apart from the Djakarta harbour, existing equipment is too simple and obsolete. Inadequate unloading equipment means that ships have to wait a long time before they can be unloaded; discharged cargo cannot be transported immediately because of transportation difficulties. Cases and goods of cargo have to be heaped up in an open field, with the result that some of the material gets lost or damaged.

The type of construction contract is very important because it represents a basic factor for determining the price of the factory to be constructed. Western countries, as a rule, prefer the "Turnkey Contract" in which responsibility for all performances and designs are entrusted to the contractor, until the factory achieves its full capacity.

For the recipient country, this contract is advantageous because of the guarantee that the constructed factory will reach its full capacity. On the other hand, it has disadvantages as the price or cost of the project is usually rather high owing to the covered risk.

Another type of contract used in Indonesia is the "Delivery and Supervision Contract". The mere task of the contractor is to design the factory, to manufacture and send the machinery and equipment to the recipient country, while the entire development of the factory and the installation of the machinery, including trial operation, is done by the recipient country. Supervision, however, will be exercised by the contractor.

At a glance, this contract seems all right, but when it is put into practice many difficulties are encountered by both the contractors and especially by the recipient country. Lack of experience results in increased expense. Moreover, tools sent from abroad are found to be inadequate as they have not been guaranteed as being suitable for local use. This is true especially of construction and transportation equipment which is very expensive.

It can be concluded that the investment cost for a factory constructed in a developing country is higher than in developed countries because of the following factors:

(a) The project itself has to bear the cost of the infrastructure that must be constructed;

(b) The perfunctory planning, both by the recipient country as well as by the supplier, and the unfamiliarity of the expatriate personnel with the local conditions contribute to expense;

(c) For the construction of an entirely new plant in a developing country there is a necessary expense involved for training engineers so that they will be able to replace expatriate personnel.

ID/WG.11/8 SUMMARY — Experiences in creating an alumina industry in developing countries by S. Moment, United States

This paper reviews the experiences of some of the developing countries that have obtained an alumina industry either with or without an associated aluminium smelter capacity. The experiences of these countries illustrate substantial economic and political problems in addition to the question of access to an adequate and suitable supply of bauxite. The problems are applicable to developing countries that prefer a state enterprise, or those that prefer a private enterprise, or those that prefer joint state and private participation.

The developing countries, as defined by the United Nations, who possess an alumina industry are Jamaica, Surinam, Guyana, Greece, the Republic of Guinea, Brazil, the Republic of China and India. Also considered in this paper are St. Croix, a possession of the United States, and Australia, a country competing strongly for alumina capacity with developing countries.