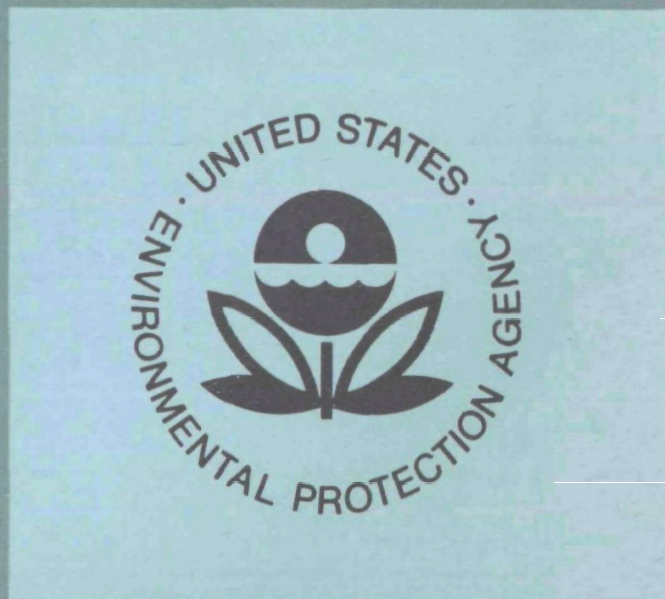


EPA-600/2-76-301
December 1976

Environmental Protection Technology Series

Study does not address radioactive content in bauxite ores and alumina plant red mud ponds - Alcoa red mud pond radiation levels

AN ASSESSMENT OF TECHNOLOGY FOR POSSIBLE UTILIZATION OF BAYER PROCESS MUDS



Industrial Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into five series. These five broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The five series are:

1. Environmental Health Effects Research
- 2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

EPA-600/2-76-301
December 1976

AN ASSESSMENT OF TECHNOLOGY FOR POSSIBLE
UTILIZATION OF BAYER PROCESS MUDS

by

B. K. Parekh and W. M. Goldberger

Battelle
Columbus Laboratories
Columbus, Ohio 43201

Grant No. R-803760-01

Project Officer

Donald L. Wilson
Industrial Pollution Control Division
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report reviews the technology in use in the United States for production of alumina from bauxite. The purpose of the study was to assess the possibility for utilization of the mud wastes generated by the domestic alumina industry. Included in the study is a review of the published literature (1940-1975) on bauxite processing technology, waste mud dewatering, and the utilization of Bayer process muds.

This report will be of interest to alumina producers and to those individuals involved in dewatering studies of slimes and tailings produced in the minerals processing industry.

Further information on the subject could be obtained from the Industrial Environmental Research Laboratory, Office of Research and Development, U. S. Environmental Protection Agency, Cincinnati, Ohio.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

This report concerns a study of the possible utilization of the mud wastes generated in the domestic production of alumina from bauxite ores. The work was done by Battelle's Columbus Laboratories for the United States Environmental Protection Agency under EPA Research Grant No. R 803760-01.

The program comprised review of technical literature published from 1940 to the present on subjects related to technology of processing bauxite, and studies on dewatering and impoundment of the mud residues and their possible utilization. Visits were made to six alumina plants in the United States to observe operations and to discuss mud-handling methods and the possibilities for utilization. Mud samples were received from the alumina plants visited for characterization experiments and dewatering studies at Battelle and at the laboratories of the Dow Chemical Company in Midland, Michigan. The Dow study was conducted under a subcontract from Battelle. A workshop was held at Battelle on March 30-31, 1976, attended by representatives from four domestic aluminum producers. Comments offered by the workshop attendees are, in part, incorporated in this report.

It was concluded from the study that there is no possibility for utilization of the muds that could significantly affect the need for impoundment within the near term. However, it appears possible to develop improved mud dewatering and methods of impoundment, and a program of joint industry-government demonstration and pilot projects is recommended. In addition, a basic research program to study the mineral surface chemistry controlling the mechanism of dewatering is recommended. Investigations of the possible beneficiation of the muds into a raw-material supplement in iron making and the possible use of mud as an absorbent in pollution-abatement processes are also recommended.

CONTENTS

| | |
|---|------|
| Foreword | iii |
| Abstract | iv |
| Figures | vii |
| Tables | viii |
| Acknowledgements | ix |
| | |
| Section I Introduction | 1 |
| Purpose | 1 |
| Authority | 1 |
| Scope | 1 |
| Section II Conclusions | 3 |
| Section III Recommendations | 7 |
| Industry – Government Demonstration and Pilot Projects | 7 |
| Basic Research on Physical-Chemical Mechanisms of Red Mud Dewatering | 8 |
| Red-Mud Utilization | 8 |
| Section IV Technical Background | 10 |
| General | 10 |
| The Domestic Alumina Industry | 11 |
| Bauxite. | 13 |
| Process Technology | 13 |
| The Bayer Process. | 13 |
| The Combination Process | 17 |
| Mud Disposal. | 17 |
| Plant Trips | 22 |
| Section V Literature Review | 24 |
| General | 24 |
| Bauxite Refining. | 27 |
| Bayer Process Technology | 27 |
| Lime-Soda Sinter Process Technology | 28 |
| Alumina From Low-Grade Bauxite | 29 |
| Bauxite Beneficiation | 30 |
| Pedersen Process | 30 |
| Red-Mud Dewatering | 30 |
| Flocculation | 31 |
| Centrifugal Dewater | 32 |
| Filtration | 32 |
| Utilization of Red Mud | 33 |

CONTENTS (Continued)

| | |
|---|-----|
| Metallurgical | 33 |
| Ceramic | 35 |
| Waste Treatment | 41 |
| Section VI Experimental Program | 43 |
| Characterization of Mud Samples | 44 |
| Composition | 44 |
| Particle Size Distribution | 44 |
| Specific Gravity | 47 |
| Dewatering Studies | 47 |
| Sedimentation Experiments | 47 |
| Effect of Synthetic (Polymer) Flocculants | 58 |
| Magnetic Flocculation | 61 |
| Flotation | 61 |
| Centrifuging | 61 |
| Reductive Roasting of Bauxite as an Alternative to Conventional Bayer Processing | 65 |
| Section VII Literature Cited | 71 |
| Section VIII Glossary | 84 |
| Appendix A: Literature References by Category | 89 |
| Bauxite Refining | 89 |
| Red Mud Dewatering | 108 |
| Red Mud Utilization | 115 |
| Nonmetallurgical | 127 |
| Effluent Treatment | 136 |
| Appendix B: Workshop Sessions | 140 |

FIGURES

| <u>Number</u> | | <u>Page</u> |
|---------------|---|-------------|
| 1 | Generalized flow diagram of the Bayer Process. | 16 |
| 2 | Generalized flow diagram of the Combination Process. | 18 |
| 3 | Mud lake dike construction. | 20 |
| 4 | Construction of red-mud lake based on gravity drainage system. | 21 |
| 5 | Distribution of literature in English and non-English languages from the year 1940 to 1975. | 26 |
| 6 | Particle size distribution of various muds | 49 |
| 7 | Particle size distribution of Alcoa - Point Comfort, Texas, red mud using Coulter-counter and Andreason pipette methods | 50 |
| 8 | Generalized settling rate curve | 52 |
| 9 | Settling rate curves for various muds (as received) | 54 |
| 10 | Laboratory evaluation of efficiency of coagulation - the jar test | 59 |
| 11 | Effect of dilution on settling rate behavior of Jamaican Red Mud | 60 |
| 12 | Effect of various synthetic flocculants on filtrability of diluted (10 x) Jamaican Red Mud | 62 |
| 13 | Effect of various synthetic flocculants on filtrability of diluted (10 x) Jamaican Rud Mud | 63 |
| 14 | Settling rate curves for the reductive roasting of bauxite process mud (9.7% solids) and the Jamaican Red Mud (11% solids) slimes (no flocculant added) | 70 |

TABLES

| Number | | Page |
|--------|---|------|
| 1 | List of Domestic Bauxite Refining Plants | 12 |
| 2 | Characteristic Analyses of Various Bauxites | 14 |
| 3 | Publications Pertaining to Bauxite Processing Technology - By Category | 25 |
| 4 | Classification of Literature by Subject on Metallurgical Uses for Red Mud | 33 |
| 5 | Classification of Literature on Red-Mud Utilization By Country (Metallurgical) | 34 |
| 6 | Classification of Literature By Subject on Ceramic Uses for Red Mud | 37 |
| 7 | Classification of Literature on Red-Mud Utilization By Country (Ceramic) | 38 |
| 8 | Raw Materials in Portland Cement | 38 |
| 9 | Classification of Literature on Waste-Treatment Applications of Red Mud | 41 |
| 10 | Classification of Literature on Waste-Treatment Applications of Red Mud by Country | 42 |
| 11 | Initial Characterization of Mud Samples | 44 |
| 12 | Chemical Analysis of Mud Samples | 45 |
| 13 | Optical Emission Spectrographic Analyses of Mud Samples | 46 |
| 14 | Particle-Size-Distribution Data for Various Muds | 48 |
| 15 | Specific Gravity of Mud Samples | 52 |
| 16 | Settling-Rate Data For Various Muds (As Received) | 55 |
| 17 | Effect of pH and Metal Ions on Settling Rate of Jamaican Red Mud | 57 |
| 18 | Synthetic Flocculant Selected for Evaluation | 64 |
| 19 | Settling Rate Data for Undiluted Jamaican Red Mud Using Different Polymer Flocculants | 64 |
| 20 | Centrifuge Test Data of Jamaican Red Mud | 65 |
| 21 | Chemical Analyses of Products Obtained By the Reductive Roasting of Bauxite (Experiment 1) | 68 |
| 22 | Chemical Analyses of Products Obtained by the Reductive Roasting of Bauxite (Experiment 2) | 68 |
| 23 | Metallurgical Weight Balance for Iron and Al ₂ O ₃ Obtained in Reductive Roasting of Bauxite | 69 |
| 24 | Settling Rate Tests Data for the Reductive Roasting Product Mud and the Jamaican Red Mud | 70 |
| B-1 | Program of the Workshop | 141 |
| B-2 | List of the Workshop Attendees | 142 |

ACKNOWLEDGMENT

The technology and processing of bauxite for alumina recovery is well established through more than 75 years of commercial operation in the United States and throughout the world. Within the limitations of a review study, it is not possible to assess fully the interrelationships and constraints relating to the mud disposal problem. The opportunity to visit plant operations and to discuss the study with representatives of Kaiser Aluminum and Chemical, Alcoa, Reynolds, and Martin-Marietta is therefore gratefully acknowledged. Special thanks are extended to Dr. R. M. Hansen, Kaiser, Mr. T. Galloway, Reynolds, Messrs. R. Carwile, R. Frye, and R. Newsome of Alcoa, and Mr. J. Bou, Martin-Marietta, for time spent at the plant and for providing samples for study.

The collaboration of the Dow Chemical Company in the experimental part and the work of Dr. Stacy L. Daniels of Dow are also acknowledged.

The research grant support provided by the Environmental Protection Agency and the interest by individuals of that agency in the Battelle program are also gratefully acknowledged.

SECTION I

INTRODUCTION

The major process waste in production of alumina is the leach residue from the caustic digestion of bauxite. This waste mud is impounded to prevent the contamination of surface waters. In the United States approximately ten-million tons of mud waste is generated annually. This mud is impounded in lakes built adjacent to the refineries; mud impoundments commits land areas in the range of 2000 to 3000 acres (810 to 1215 hectares). Mud impoundment is not an ideal solution to the disposal problem. The dikes of mud lakes must be maintained, and there is always risk of a break and spill of the mud into a nearby stream or waterway. There has been little economic opportunity to date to utilize the mud.

PURPOSE

This study was made to determine whether technology is available that could make possible the economic utilization of alumina-process red- and brown-mud wastes to an extent that would eliminate the need for impoundment.

AUTHORITY

This program was initiated on June 1, 1975, by Battelle's Columbus Laboratories under U.S. Environmental Protection Agency Grant No. R-803760-01.

SCOPE

The study comprised a review of technical literature published worldwide on subjects related to technology of processing bauxite, and studies on the dewatering and utilization of red and brown muds produced during the processing. The literature review covered the period 1940 to present. Visits were made by Battelle staff to six alumina production sites to observe operations and the methods used in current disposal of the mud wastes.

Selected experiments were done to characterize red- and brown-mud samples received by Battelle from five of the six alumina plants visited. Emphasis in this experimental work was on study of the red mud derived from Jamaican bauxite because this type of mud is more difficult to dewater and presents a greater disposal problem. Laboratory studies on the use and effect of synthetic polymer flocculants to promote the settling and dewatering of the mud were made by the Dow Chemical Company under a subcontract to Battelle.

The results of the program were reviewed by Battelle with representatives of EPA and the alumina-producing industry during a workshop conference sponsored by the EPA and held at Battelle on March 30-31, 1976.

This report discusses the general background of the red-mud problem and reviews the reported research on the subject. Experimental results obtained in this program are included with Battelle's conclusions and recommendations for research to alleviate and ultimately to possibly eliminate the need for mud impoundment.

SECTION II

CONCLUSIONS

On the basis of this review, Battelle has reached the following general conclusions:

- (1) Despite extensive studies made worldwide to develop means to utilize Bayer Process muds, no technology has been developed that would enable economic processing of the muds into products having sufficient existing markets to reduce the present need for impoundment of the muds generated in current domestic alumina-production operations.
- (2) Virtually all potential commercial uses of the muds require that the muds be dewatered to the extent that the solids can be transported and/or stored in consolidated dry form without tendency to leach or repulp. Low-cost dewatering of the muds is therefore considered the key to their possible future utilization.

The present cost of mud impoundment ranges from \$0.50 to perhaps as high as \$4.00 per ton of dry solids, depending on factors such as land cost, distance of the impoundment area from plant, availability of sand and other aggregate for dike construction, rainfall, evaporation conditions, and the characteristics of the mud. Costs for future impoundment by present methods are projected to increase. It was therefore concluded that methods enabling muds to be dewatered to the conditions cited at a cost less than about \$5.00 per ton of dried solids would be of interest to the industry. However, no process technology is reported to be available to do this.

- (3) The chemical and physical characteristics of the Bayer Process muds, i. e., composition, particle size, and mineralogy, differ with the origin of the bauxite ore. Variations in settling and dewatering characteristics of red muds relate to these differences in the bauxite ores. Chemical factors such as pH and presence of metal ions appear to have little effect on the settling rate and ultimate settled density. Use

of flocculants can increase settling rate but offer little promise to increase ultimate settled density beyond that now achieved in mud lakes. It was therefore concluded that from the standpoint of mud disposal, little change in dewatering properties and the requirement for impoundment can be effected by changes in the conditions of operation of the Bayer Process.

- (4) Chemical treatment in combination with mechanical dewatering was not found to result in a higher degree of dewatering of red mud. No improvement in ultimate solids content was achieved in tests made using magnetic flocculation, or using flocculants or coagulants in combination with centrifugation. Additional research of this type is not warranted.
- (5) The physical characteristics of Bayer Process red muds may be substantially altered by energy-intensive processing such as kiln treatment, as in the case of the Combination Process used to process Arkansas bauxites. So called "brown muds" generated by the Combination Process are sintered materials of coarser particle size which settle and dewater more readily than the red muds of the more conventional Bayer Process.
- (6) The addition of energy-intensive process steps to the present Bayer Process, for example, an initial reductive roasting of the bauxite, may alter its physical character and that of the mud residues in a manner analogous to the changes brought about by the Combination Process, and possibly lead to improved dewatering and a possible basis for increased recovery of metal values. However, in-plant modification of this type would probably require very substantial addition of new process equipment and major changes in present Bayer Process operations. It was concluded that relative to red-mud disposal, process-development effort that would entail substantial change in the Bayer Process flowsheet is not warranted.
- (7) Installation of bottom drainage in newly constructed mud lakes appears to offer improved rates of dewatering and the opportunity to achieve high-density, stable mud solids, particularly in geographic regions with a net accumulation of rainfall. Mud lakes constructed with a bottom drainage system may develop greater permeability and a higher degree of leaching of solubles from inactive or dried mud lakes. The incorporation of bottom drainage may therefore improve the ability to grow vegetative cover on old mud-impoundment areas. Bottom drainage may also lead to improved ability to harvest dry mud which could be more economically utilized. Additional study of bottom drainage

systems and their construction, drainage and effluents, cost factors, and maintenance characteristics is warranted.

Conclusions reached by Battelle related to specific areas for possible utilization of the muds are these:

- (8) Metallurgical Uses - Past interest in red mud for metallurgical purposes has been mainly as a possible source of iron for iron and steel manufacture. The production of iron from muds represents one possible use that could consume the total tonnage of mud generated by the domestic alumina industry. The muds as generated represent unacceptable material for ironmaking by conventional blast furnace or direct reduction methods. To be useful as a source of iron, the muds require processing to concentrate the iron to 55-60 percent and to substantially eliminate alumina, titania, phosphorus, and vanadium components which are considered detrimental in iron and steel making. Technology to effectively and economically do this is not presently available. Additional study to develop a nonmelting method for concentration of iron and elimination of undesired elements for iron and steel making is considered to be warranted. Emphasis should be on production of an iron-rich material suitable for blending with other sources of iron units in iron- and steel-making operations.

To be economically viable, the cost of drying, beneficiation, and pelletizing to meet iron-making specifications, including transportation to the steel mill, must be competitive with cost of iron units as ore pellets. At present, this cost would be of the order of \$50 per ton of contained iron, or equivalent to about \$30 per ton of dried mud solids.

Metals other than iron and aluminum can be recovered from the muds. For example, in some cases titanium can be recovered as ilmenite or rutile concentrates by conventional gravity concentration. Removal of titanium minerals may be economical, depending on the amount and mineralogical form, but such processing has little influence on the need for impoundment of the bulk of the mud. Work on titanium-mineral separation technology is therefore not warranted. Vanadium, gallium, and scandium have also been recovered from muds in laboratory studies. Because these elements are present in very low concentration and have very limited markets, there is little merit to further development of extraction methods for these metals from the standpoint of any impact such work would have on the impoundment of alumina-process muds.

- (9) Ceramic Uses - The possible use of Bayer Process muds in ceramic applications has been very extensively studied and reported. Although muds may have been tested as an additive agent in high-tonnage products such as cements, construction block mix, and lightweight aggregate, the muds have not been proven to offer any unique and beneficial properties as a raw material for these applications. It was therefore concluded that no additional general studies of use of muds in ceramic mixes is warranted.
- (10) Use as a Waste Treatment Agent - Bayer Process muds have been tested and found effective as agents in treatment of both gaseous and liquid effluents. The potential merit of the use of mud for waste-treatment processing depends on location, the need to predry the mud, and the subsequent disposal procedures that will be needed. Additional study of this possible use is warranted.

SECTION III

RECOMMENDATIONS

In view of the foregoing conclusions, the following recommendations are offered.

Industry - Government Demonstration and Pilot Projects

Emphasis in the near term should be directed toward study of methods that not only will assure environmentally acceptable containment, but also offer potential for improving reclamation of impoundment areas and the possibility of harvesting the dried mud, either for commercial use or for alternative off-site disposal. Recognizing that each operating plant has different conditions and constraints in disposal related to bauxite sources, geography and hydrology of the site, land availability, and other factors, it is recommended that a series of demonstration or pilot projects be initiated in collaboration with EPA and interested individual operating companies on the site of the company. Such demonstration projects could be of sufficient general interest to the industry and to the public benefit to warrant EPA program funding on a cost-sharing basis. Specific topics considered pertinent by Battelle as subjects for such EPA-industry cooperative demonstration projects at specific operating sites are:

- (1) Impoundment area drainage systems, construction, and cost factors
- (2) Development of methods to achieve vegetative cover over inactive disposal areas to include study of flora that could tolerate high levels of sodium ion
- (3) Study of methods to prevent airborne dust from dried mud areas
- (4) Factors in the removal of dried mud solids for alternative storage or use
- (5) Ability to reclaim mud lake areas for alternative uses.

Such demonstration projects should be conducted by the operating company and the activity reported to and monitored by the EPA. Award of funding support for such programs should be based on proposals submitted by the operating company to the EPA. An estimated budget believed to be warranted for demonstration projects is of the order of \$500,000 during a 3-year period with cost sharing at a 50 percent Government-industry basis.

Research and development efforts considered by Battelle to have merit for possible longer range improvement and which warrant Government support are:

Basic Research on Physical-Chemical Mechanisms of Red Mud Dewatering

The inherent difficulty in developing chemical agents or apparatus to dewater the muds is related to the extreme hydrophilic tendency of the clay-like minerals comprising the structure of many of the bauxites and muds. Despite extensive research and development by the alumina industry worldwide on various chemical and mechanical methods of dewatering muds, a relatively simple or rapid and economic means to achieve a relatively high degree of dewatering of Bayer Process muds has not been found. Because of the importance of improving technology to possibly eliminate the need for impoundment, it is recommended that a research effort be established to study the mineral surface chemistry of various red muds and to better understand the mechanisms which limit and/or control the removal of interstitial and bound water by physical-chemical methods. This research should include detailed study of the mineralogic structure of various muds, using a combination of optical and physical-chemical analyses to examine the microstructure and nature of the surfaces and their affinity for water. The physical chemistry of the response of mud surfaces to various flocculants, floc strength, use of chelating agents, and possible chemical adsorbents for water should be part of a broad basic program on dewatering fundamentals and mechanisms.

An estimated budget of \$150,000 covering a period of 2 years is recommended.

Red-Mud Utilization

Pertaining to possible future utilization of mud residues, Battelle recommends the following studies:

Metal Recovery-

Red muds contain a significant amount of iron and could be developed as a source of iron units in the production of iron and steel. Emphasis should be

on technology for beneficiating the mud into a usable iron-ore supplement to blast furnace charge ore. For this purpose, the beneficiated mud would not be required to meet the rigid specifications placed on blast-furnace feed ore. A metallurgical process that could offer merit as a beneficiation procedure is the segregation roast method that has been applied commercially for extraction of copper and nickel from oxide ores. Segregation roasting employs a reductive chloride roast conducted with solid carbon present in the charge. In situ volatilization and reduction occur under proper roasting conditions to yield a roaster calcine containing coalesced iron adhering to the surface of the carbon particles in the charge. Iron can be removed relatively free of contaminants by usual magnetic-separation methods.

It is recommended that initial laboratory study be made of the technical feasibility of the application of the segregation roasting method for beneficiation of selected red muds.

This program can be completed within 12 months at an estimated cost of \$50,000.

Adsorbent Material for Pollution Abatement--

Red and brown muds could be used as adsorbents in removing sulfur oxides from flue gases and for other gaseous- or liquid-effluent treatments. The ability to leach and recover other metal values from sulfated muds, and the factors involved in the disposal of the sulfated and/or leached mud adsorbent are of sufficient interest to warrant investigation.

To properly evaluate this potential use, it is recommended that system studies be made, including development of data on the structural strength of various dried muds to determine whether muds can be used as adsorbent without need for prilling or pelletizing. The extent of sulfur oxide adsorption of various muds and effect of different conditions of temperature should be evaluated.

A systematic study of the possible use of mud residues as adsorbents is estimated to require 18 months to complete at a cost of approximately \$75,000.

SECTION IV

TECHNICAL BACKGROUND

GENERAL

Aluminum metal and aluminum oxide products are made almost entirely from bauxite ore. Bauxite is a naturally occurring mineral composed principally of a mixture of one or more of the hydrated aluminum oxide minerals gibbsite ($\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$), boehmite ($\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$), and diaspore ($\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$) and impurities of silica, iron oxide, titania, and other elements in trace amounts. It is generally believed that bauxite deposits result from intense chemical weathering of aluminum-bearing rocks or formations under tropical or subtropical conditions with alternating wet and dry seasons. Depending on the source location, the texture of the ore may be fairly granular or it may contain or be essentially all extremely fine-grained claylike material.

Alumina is extracted from bauxite using the Bayer Process. The initial step is to partially digest the ore in a caustic solution. The caustic reacts with the major part of the aluminum oxide content of the bauxite and causes it to dissolve. This reaction is specific to the aluminum oxide and some reactive silica; however, unreactive silica (i. e., quartz), iron, and titania minerals are not dissolved to any significant degree and remain as a solid residue. The residue is a solid waste which is washed to recover the active solution and then discarded. This mud material is generally extremely fine and difficult to filter. It has been least costly to dispose of this waste by pumping it as a relatively dilute suspension to holding ponds and lakes constructed for that purpose. Sufficient pond area is provided to allow the mud to settle and for clear water to be recycled to the process. Because of the iron oxide content of the waste, the waste has a red color and has been termed "red mud"; the impoundment areas are called "red-mud lakes".

From the standpoint of effluent control, impoundment of the red mud is a practical method which has been used for many years by the industry. With proper pond construction and adequate pond holding area, the red-mud waste can be retained and contamination of surface waters can be virtually eliminated.

Impoundment is not an ideal solution to the red-mud disposal problem, however, for many reasons. Red-mud lakes require a significant amount of land. The settling rate of solids is generally slow. Certain muds are almost thixotropic in character and even the old, apparently dried lakes cannot support heavy equipment or construction. These ponds, in fact, must be maintained even after they are no longer in use, and always there is some risk that a break or spill will occur and allow mud into a nearby stream or waterway.

The problems, of course, vary with the location. Availability of land is a most important factor. Moreover, commitment of the land for mud disposal may impact on land-use plans in the region. Rainfall and seasonal weather conditions play a significant role. Long periods with little rainfall cause the mud lakes to dry on the surface and become a source of windblown dust. Long periods of heavy rainfall increase the risk of a break in the dikes or can cause runoff from the pond into surface waters.

The question of whether technical developments can be made to provide practical improvements in or alternatives to present impoundment is not simple to answer. Alumina refineries are major complexes with many inter-related operations and, therefore, considerable constraint in operating conditions. Major changes in processing would be difficult and costly to implement. Ideally, such changes would provide economic benefit to the processor through recovery of additional values or reduced overall cost in disposal of the muds. It is, therefore, important to consider the structure of the domestic industry, the Bayer Process, present impoundment methods, and the probable future costs for impoundment.

THE DOMESTIC ALUMINA INDUSTRY

Bauxite ore is refined into alumina in nine refineries in the United States.* These process plants are owned by five primary aluminum producers. The location of the refineries, countries of origin of bauxite used, annual production, and waste (mud) produced are shown in Table 1. Most of the bauxite used in the United States is imported. Jamaica and Surinam are the principal suppliers. The only commercial bauxite deposits in the United States are located in Arkansas.

The amount of mud produced in processing differs for the types and ranges of bauxite and ranges from 0.3 ton (Surinam bauxite) to 2.0 ton (Arkansas bauxite) per ton of alumina produced. The domestic alumina plants generate about 10 million tons of mud waste annually.

*The term domestic industry is intended to include the refinery in St. Croix, Virgin Islands.

TABLE 1. LIST OF DOMESTIC BAUXITE REFINING PLANTS

| Company | Plant location | Type of bauxite used | Approximate plant capacity ^(a) , metric tons alumina/year | Approximate waste (mud) produced ^(a) , metric tons/year |
|-------------------------------------|---------------------------|---|--|--|
| Aluminum Company of America (Alcoa) | Mobile, Alabama | Surinam-African | 1,500,000 | 450,000 |
| | Point Comfort, Texas | Caribbean-Surinam-African-Australian | 1,100,000 | 1,100,000 |
| Aluminum Company of America (Alcoa) | Bauxite, Arkansas | Domestic (Arkansas) | 225,000 | 450,000 |
| Kaiser Aluminum and Chemical Corp. | Baton Rouge, Louisiana | Jamaican | 1,000,000 | 1,000,000 |
| | Gramercy, Louisiana | Jamaican | 800,000 | 800,000 |
| Reynolds Metals Co. | Corpus Christi, Texas | Jamaican-Haiti | 1,300,000 | 1,300,000 |
| | Hurricane Creek, Arkansas | Domestic (Arkansas) | 755,000 | 1,510,000 |
| Ormet Corporation | Burnside, Louisiana | Surinam | 560,000 | 168,000 |
| Martin-Marietta Aluminum Co. | St. Croix, Virgin Islands | Weippa-Guyana-Surinam-Kassa-Boke (Guinea) | 325,000 | -- |

(a) Information provided by individual operating company.

Bauxite

Alumina is produced domestically only by extraction from a bauxite ore mineral. The term bauxite refers to an ore or mixture of minerals formed by the weathering of aluminum-bearing rocks. Bauxite deposits are found throughout the world. Bauxites are composed principally of a mixture of one or more of the hydrated aluminum oxide minerals. Gibbsite (also called hydrargillite) is a trihydrate form of alumina ($\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$). Boehmite and diasporite are two forms of alumina monohydrate ($\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$). The relative amount of each form present in the bauxite is very important because the trihydrate is more readily extracted and milder digestion conditions can be used.

Other aluminum oxide minerals generally contained in bauxites include the hydrated aluminum silicate minerals halloysite and kaolinite. The associated iron minerals are goethite and hematite. Titanium is often present in the minerals rutile, anatase, and ilmenite. Silica is present in quartz and clays. The form and extent of silica contained are very important in the economics of alumina extraction. Silica in the form of quartz is only moderately attacked during the extraction of bauxite; however, silica in kaolinite ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$) dissolves in the caustic (soda) causing a loss of soda and loss of alumina through formation of insoluble sodium aluminum silicate ($3\text{Na}_2\text{O} \cdot 3\text{Al}_2\text{O}_3 \cdot 5\text{SiO}_2 \cdot n\text{H}_2\text{O}$). Soda represents a significant investment and its recovery makes the process economical. Other elements are generally present as indicated in Table 2. It might be noted that bauxites used by the domestic industry are relatively low in the monohydrate minerals. Monohydrate ores are processed more commonly in Europe.

PROCESS TECHNOLOGY

The domestic alumina industry uses two basic processes for alumina production. Imported bauxites are treated by the Bayer process. The Arkansas bauxites are processed by a "Combination Process" which incorporates a sinter step with the Bayer method.

The Bayer Process

The Bayer Process for extracting alumina from bauxite was invented by Karl Josef Bayer in Austria in 1888. This process has been used in the U. S. since 1894.

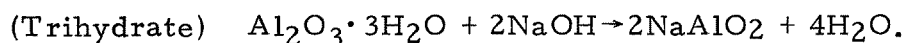
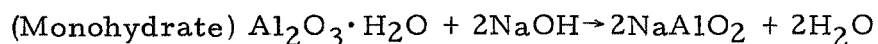
The basic principle involved in the Bayer Process is to dissolve the aluminum component of bauxite ore in caustic soda solution. The solution is first treated to remove impurities such as silica and iron, and is then conditioned to precipitate alumina trihydrate. This material produces aluminum oxide (alumina).

TABLE 2. CHARACTERISTIC ANALYSES OF VARIOUS BAUXITES^(a)

| Constituents | Weight percent | | | |
|--|----------------|---------|----------|--------|
| | Jamaican | Surinam | Arkansas | Guyana |
| Al ₂ O ₃ , total | 49.2 | 55.0 | 48.7 | 58.6 |
| SiO ₂ | 0.7 | 3.8 | 15.3 | 4.9 |
| Fe ₂ O ₃ | 19.3 | 7.0 | 6.5 | 4.1 |
| TiO ₂ | 2.5 | 2.4 | 2.1 | 2.5 |
| F | -- | -- | 0.2 | 0.02 |
| P ₂ O ₅ | 0.4 | 0.06 | -- | -- |
| V ₂ O ₅ | 0.03 | 0.04 | -- | -- |
| H ₂ O, combined | 26.5 | 31.2 | 25.8 | 29.6 |
| Al ₂ O ₃ , trihydrate | 44.4 | 50.0 | 34.1 | 52.7 |
| Al ₂ O ₃ , monohydrate | 2.8 | 0.2 | 14.6 | 5.9 |

(a) Analyses provided as typical by the operating company.

A generalized flowsheet of the Bayer Process is shown in Figure 1. The first step in the process is to grind or break up the nodules of bauxite. The bauxite is then slurried with a portion of the recycle caustic soda solution (spent liquor) and pumped to large pressure vessels (digestors) where it is mixed with the main stream of spent liquor and heated with live steam. The temperature and pressure required for alumina digestion depend on the relative amount of monohydrate and trihydrate in the ore. For a predominantly monohydrate bauxite, a temperature of 200 to 250 C (392 to 482 F) and a pressure of about 35 atmospheres (500 psi) would be used; for trihydrate, a temperature of 120 to 170 C (248 to 338 F) and a pressure of 3 to 5 atmospheres (50 to 70 psi) are used. The operating conditions are also adjusted depending on the ratio of monohydrate and trihydrate alumina forms. The digestion reactions form soluble aluminate by the following reactions:



The solution bearing the dissolved aluminum component of the bauxite (green liquor) is sent to a "flash" heat recovery operation, where both the elevated temperature and pressure are reduced to near atmospheric conditions. The heat recovered from the green liquor as flashed steam is used in heat exchangers to preheat the solution going into the digester. From the flash tanks, the slurry is sent to thickeners where the suspended undissolved solids are flocculated (usually with a starch) and removed in the thickener underflow. The separated mud is washed by countercurrent decantation to recover dissolved alumina and caustic. The mud in the thickener underflow is pumped at 15 to 22 percent solids to the mud-lake-impoundment areas.

The separation and washing of mud from the pregnant liquor can also be done by filtration. The use of filters depends on the characteristics and the amount of mud produced.

The thickener and washer overflow (green liquor) is sent to the pressure filter (Kelly filters) for removal of fine solids. The green liquor is then supersaturated with respect to the dissolved alumina content by a further cooling operation (vacuum flash). The liquor is then sent to precipitators, where fine alumina (known as seed) is added to enhance trihydrate alumina $[\text{Al}(\text{OH})_3]$ precipitation. The settled coarse particles of alumina trihydrate are washed, filtered, and calcined in a kiln to yield the calcined alumina (Al_2O_3) product. The spent liquor from the primary classification is sent to secondary and tertiary classification to recover fine alumina that is used as the seed material in the classifiers. The spent liquor from the final classification is sent to vacuum evaporators for concentration and is then recycled to the digestion process. A certain amount of caustic is lost in processing and this is made up either through direct addition of caustic,

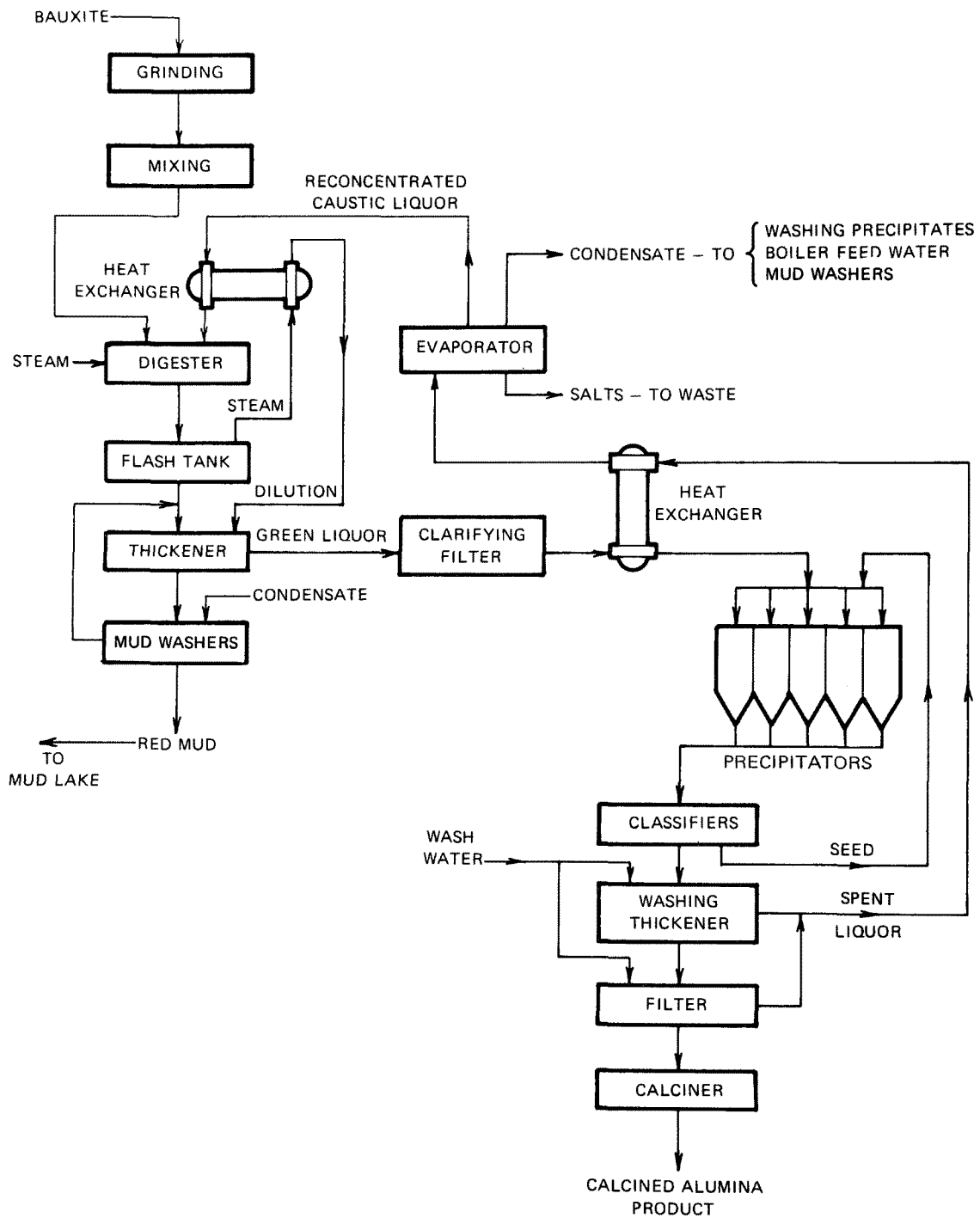


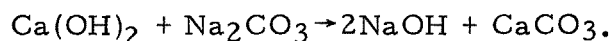
Figure 1. Generalized flow diagram of the Bayer Process.

through use of soda ash, or by use of hot caustic solution for descaling of various items of equipment such as the digestors, flash chambers, and classifiers.

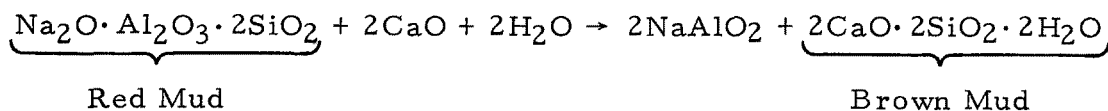
The Combination Process

The Combination Process is a modification of the Bayer Process developed for bauxite containing high amounts of silica, such as those from Arkansas. The digestion of this type of bauxite by the conventional Bayer method would result in excessive loss of alumina through formation of insoluble sodium aluminum silicate. The Combination Process, also known as the sinter/leach process, recovers the alumina values that become trapped in the Bayer red mud as silicates. This additional extraction step is accomplished by mixing the red mud from the Bayer circuit with limestone and sodium carbonate and then sintering the mixture in a kiln at 1100 to 1200 C (2030 to 2192 F). The kiln product is ground and leached to produce additional sodium aluminate solution which is filtered and is either added to the main stream for precipitation or is precipitated separately. Precipitation of aluminum trihydrate is done as described previously for the Bayer Process. The washed residual solids (brown mud) consisting mainly of dicalcium silicate are pumped to a mud lake. A generalized flow diagram of the Combination Process is shown in Figure 2.

One feature of the Combination Process is that lime and soda ash substitute totally for caustic soda as the starting agent, utilizing the familiar causticizing reaction:



During sintering of red mud with lime and soda ash, the important reaction is the conversion of silica to calcium silicate and residual alumina to sodium aluminate:



Mud Disposal

Solid wastes are generated in virtually all mining and processing of hard rock minerals. Mineral process wastes are generally impounded in tailings ponds. Alumina production is no exception. The mud-lake impoundment is the lowest cost method for containment of these muds from alumina production. Because of the enormous tonnage of solids generated and their near-colloidal character, these lakes present special problems in construction and maintenance. It is pertinent to consider present mud disposal and the cost

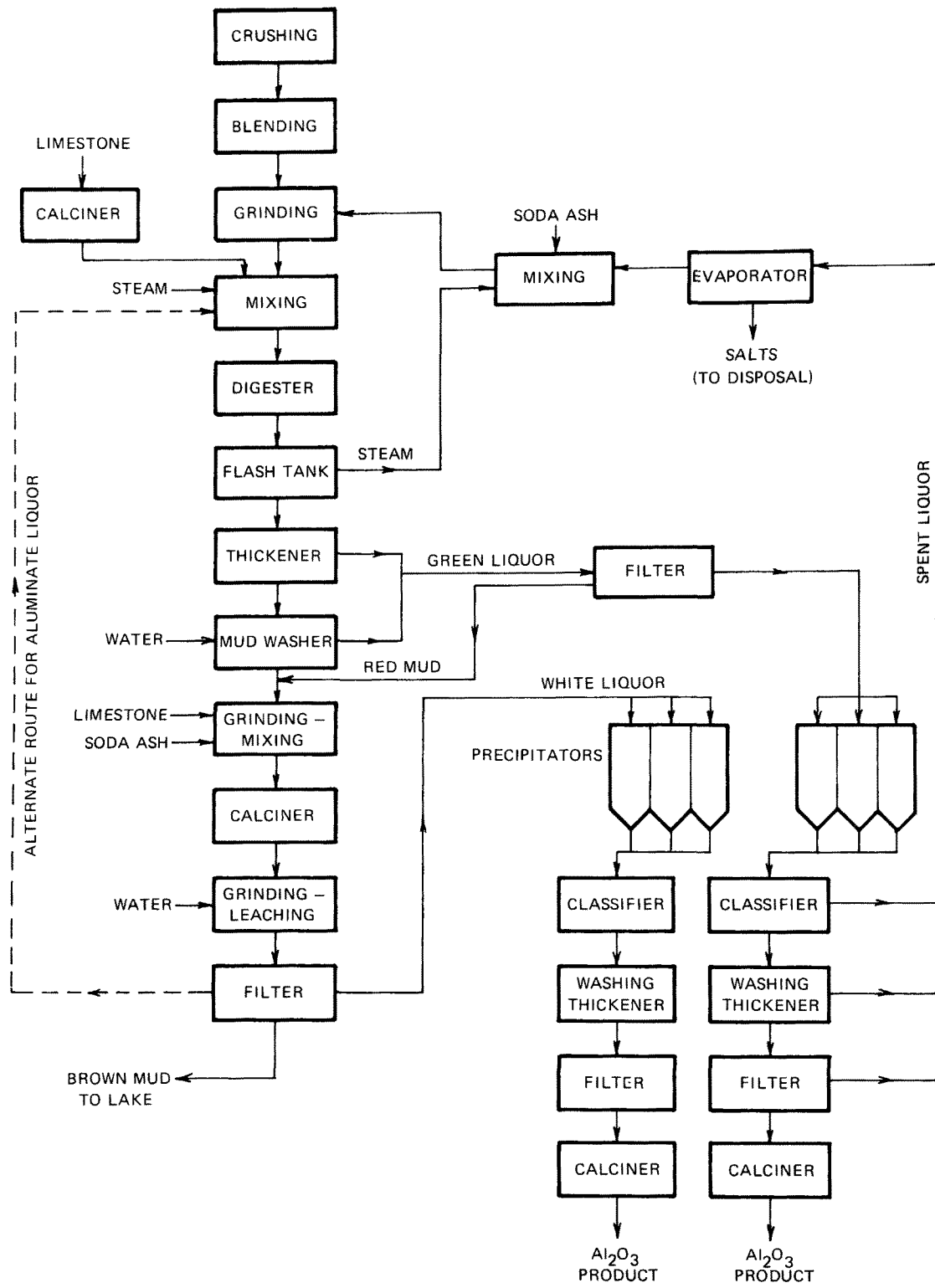


Figure 2. Generalized flow diagram of the Combination Process.

factors involved in evaluating possible alternative uses for the mud and costs likely to be required to convert the mud into usable forms.

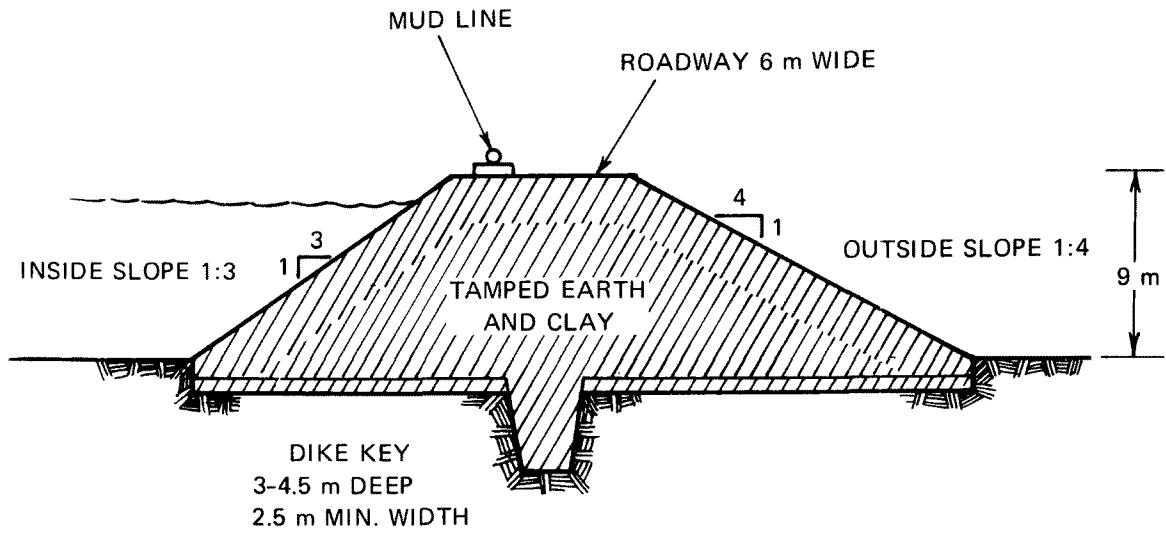
Construction of mud lakes depends principally on the type of mud to be impounded. The mud-lake dikes for the more claylike muds will differ from those for the sandlike muds. The general approaches to the construction of the mud lakes have been previously described.^(1,2) Typical construction plans are illustrated in Figure 3. These differ in that one is for initial full-height dike construction, while the other calls for first building a low dike which is later raised as the lake fills. A final construction plan for a mud lake will depend on the type of mud and the extent of land available.

The cost of mud-lake construction and mud disposal can vary significantly depending on the location and the nature of the mud. Land cost is a major factor. The distance of the lake from the plant is important as is the net rainfall/evaporation rate. Available costs data were in the general range of \$1.00 to \$5.00 per metric ton (dry) of mud disposed.

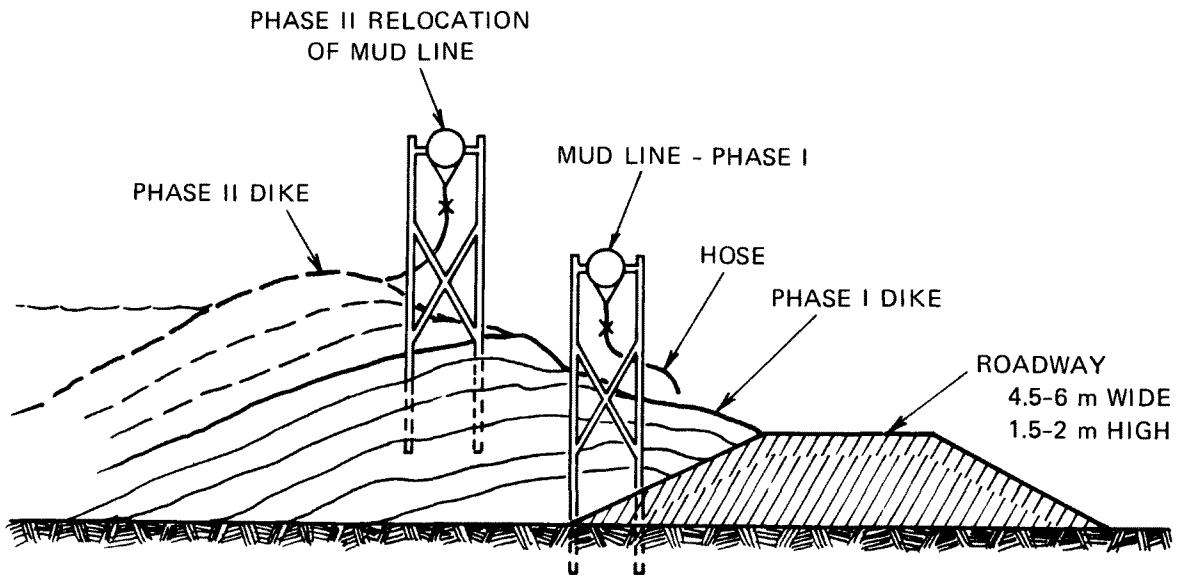
The Kaiser Aluminum and Chemical Corporation has reported studies^(3,4) made to develop improved methods for impoundment of red muds generated by processing Jamaican bauxite at Kaiser's plants in Baton Rouge and Gramercy, Louisiana. On the basis of results from laboratory and pilot impoundment projects, Kaiser has constructed a 200-acre red-mud lake to serve the Gramercy plant. This lake incorporates sand-bed filtration of the "French Drain" type with drainage pipes and covering layers of different size sand and gravel to give permeability through the base of the lake. The placement of a drainage pipe during construction of the lake is shown in Figure 4.

Kaiser has termed the disposal system the Deep DREW System (Decantation, Drainage, and Evaporation of Water). A mud lake employing the DREW System is being constructed by Kaiser to serve its Baton Rouge refinery.

The mud-disposal program and pilot development work by Kaiser has provided a basis to anticipate a reduction in slurry volume contained in a lake with bottom drainage to about one-fourth the volume in the conventional "as-is" impoundment. Kaiser anticipates that the mud will consolidate in these lakes to an overall average of 50 percent solids through the combination of drainage and evaporation. It is believed, based on demonstration plots, that the lakes will dry to sufficient stability to support men and equipment. Thus, the dried lakes might be periodically surface mined to remove a substantially dry mud that would be a more economical source for iron values or for other purposes than the wet muds.



A. INITIAL FULL DIKE CONSTRUCTION



B. BUILDUP CONSTRUCTION OF MUD LAKE DIKE

Figure 3. Mud lake dike construction.



A system to permit use of red mud tailings as land fill instead of discharging them into the Mississippi River is under construction at a Louisiana alumina plant. Here drainage pipe is placed in a trench at bottom of storage pond; later it will be covered with coarse permeable gravel bed.

Kaiser Aluminum & Chemical Corporation photo

Figure 4. Construction of red-mud lake based on gravity drainage system. (Reprinted by special permission from Miller Freeman Publications, Inc.)

PLANT TRIPS

Visits were made by Battelle staff to review the refinery practices and methods used in mud disposal and to arrange for acquisition of mud samples for laboratory study. The plants visited by Battelle were:

- (1) Alcoa - Point Comfort, Texas
- (2) Alcoa - Mobile, Alabama
- (3) Alcoa - Bauxite, Arkansas
- (4) Reynolds Metals - Hurricane Creek, Arkansas
- (5) Kaiser Aluminum - Gramercy, Louisiana
- (6) Martin-Marietta - St. Croix, Virgin Islands.

These plants were selected because each used a different ore source and the mud-disposal requirements for each were different. Except for the Arkansas operations, the Bayer Process was in use. Because of the high silica content of the Arkansas bauxite, the Combination Process is used for this ore.

During the visits to the plants, discussions were held with company personnel concerning factors related to alumina production and the mud problem. The salient points were as follows.

(1) The key factor is the nature of the bauxite used. Both the quantity of mud produced and the ability to wash and dewater the mud depend almost entirely on the bauxite. The quantity of mud obtained from processing a sandy-type bauxite is generally substantially less per ton of alumina made. Sandy bauxites usually contain hematite as the predominant iron mineral and can be filtered and more easily washed.

(2) Within practical limits of variation of the process conditions, the chemistry of the process has little influence on the nature of the mud or its dewatering characteristics.

(3) Transportation of the mud from the plant to the impoundment lake is done most conveniently and economically by pumping as a slurry. The practical limit of the solids content of such a slurry is 25 to 40 percent solids; 20 percent solids content is usual. To transport the mud by mechanical means such as a conveyor belt would require dewatering the mud to at least 55 to 60 percent solids. It does not appear possible by conventional dewatering methods to achieve a mud with this high a solids content except by partial drying. In-plant drying would generally involve substantially higher disposal costs than present mud-lake disposal.* It must be anticipated, therefore, that general practice in the near-term will continue to be impoundment of the mud slurry.

*One operating company stated that mud-disposal methods now being implemented at that operation will allow the mud to be transported from the plant as material dried to its maximum shrinkage.

(4) The development of a more rapid settling character of a mud has benefits of interest to the operators. Methods used to control the flocculation in the thickener circuit are considered a highly proprietary subject. Use of synthetic flocculants is of continuing interest because synthetics offer opportunities to achieve better quality control of the flocculant and, therefore, better process control. Synthetics have been tested in plant runs with mixed success. Only one processor stated that synthetic flocculants were being used at that site as standard plant practice.

(5) All operators are aware of prior commercial use of red and brown muds of certain size fractions, for example, the making of aggregates for dike construction and as a soil conditioner for acidic soil. However, these have been specialty uses that have involved only a minor amount of the total mud discharged. No major use was reported by the operators.

SECTION V

LITERATURE REVIEW

GENERAL

A detailed review was made of the published technical literature pertaining to the processing of bauxite and the red-mud problem. The period covered by the review was 1940-1975. The following journals were used to make the search:

- Chemical Abstracts
- Engineering Index
- National Technical Information Service (NTIS)
- U. S. Bureau of Mines Reports of Investigations
- Mining Engineering.

Chemical Abstracts was noted to cover Metallurgical Abstracts, Ceramic Abstracts, and World Aluminum Abstracts.

The journals were searched under the following key terms:

- Bauxite refining/treatment
- Red-mud (or brown-mud) dewatering/bauxite refinery waste treatment
- Red-mud (or brown-mud) utilization.

The articles found in the search that were determined by review of the abstracts to be of interest were reviewed in the original and classed in the following categories:

- (1) Bauxite Refining
- (2) Red-Mud Dewatering
- (3) Red-Mud Utilization.

The literature review disclosed more than 600 pertinent articles. Much of the publically available information was found in non-English-language publications. Table 3 shows the number of publications reviewed under each

category. Figure 5 shows the overall distribution of articles published in English and non-English languages from the year 1940-1975. After 1950, a majority of articles were found to be in foreign languages. The number of foreign publications on bauxite processing increased sharply in the early 1970's. Approximately 45 percent of the abstracts reviewed were patents. Of these, only 30 percent were in English.

TABLE 3. PUBLICATIONS PERTAINING TO BAUXITE PROCESSING TECHNOLOGY - BY CATEGORY

| Title | Number of publications | Language distribution | |
|---------------------|------------------------|-----------------------|-------------|
| | | English | Non-English |
| Bauxite refining | 250 | 78 | 172 |
| Red-mud dewatering | 80 | 20 | 60 |
| Red-mud utilization | <u>286</u> | <u>56</u> | <u>230</u> |
| Total | 616 | 154 | 462 |

The literature review established that new methods are being developed to utilize alumina sources other than bauxite. However, the majority of the publications concern modifications of the basic Bayer Process to increase alumina recovery and to reduce alkali (soda) loss.

Developments were reported concerning red-mud dewatering technology. Most of the publications were related to the use of synthetic polymers to flocculate the red-mud suspensions. The use of combination flocculants for example, starches and polymers, metal ions and polymers, and flours and polymers, was described.

The literature search also showed that a substantial amount of research has been conducted on the subject of utilization of red muds. Numerous publications were noted which dealt with recovery of different metals from the muds. Of these, the recovery of iron, aluminum, and titanium shows some potential. Publications were reviewed which concerned use of the red mud in ceramic products. Other publications relate to the application of the red mud in paints, as a fertilizer, and as an adsorbent for gases.

A complete listing of the literature references found in the search is given in Appendix A. Pertinent articles in the various categories were reviewed in detail and the information obtained in each category is described in brief in the following sections.

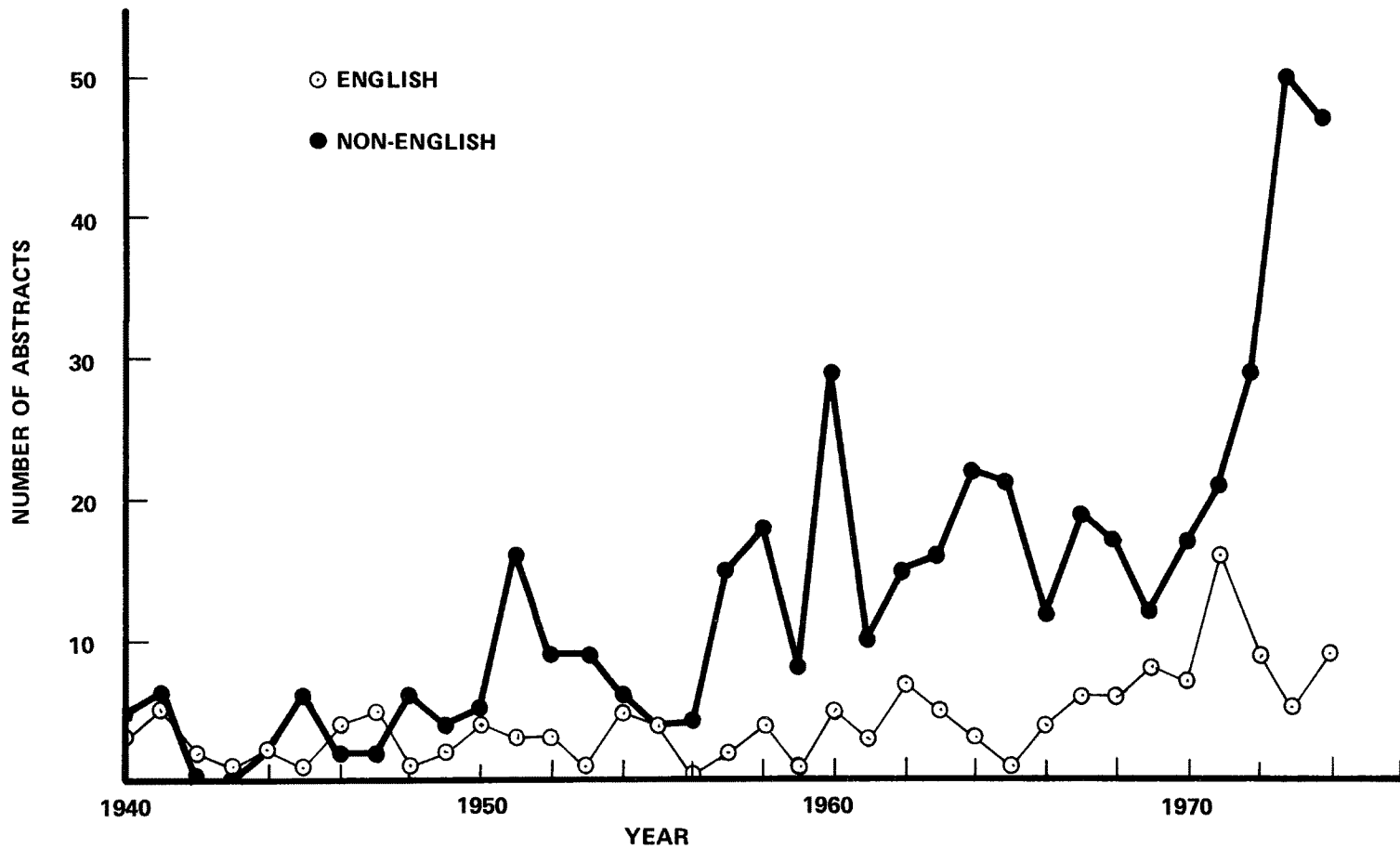


Figure 5. Distribution of literature in English and non-English languages from the year 1940 to 1975.

BAUXITE REFINING

Bayer Process Technology

The Bayer Process is the conventional method used worldwide for extraction of alumina from bauxite. Of the total 250 literature references to refining of bauxite reviewed in this study, approximately 60 percent referred to the basic Bayer Process while the remainder referred to methods to process alternative sources of alumina and various bauxites not suitable for Bayer methods.

In general, hot alkali leaching of the bauxite as is used in the Bayer Process allows recovery of 90 percent or more of the contained Al_2O_3 .⁽⁵⁾ Various techniques to improve recovery, for example, using additives to the alkali such as Al_2O_3 ⁽⁶⁾, changing the temperature and pressure⁽⁷⁾, or grinding the bauxite during digestion in the autoclave⁽⁸⁾, are reported, but these offer only a marginal advantage. Dunn⁽⁹⁾ recommended use of vertical digesters rather than the more common horizontal units where "sand" or insoluble coarse portions of bauxite are present which tend to be held in suspension in the lower part of the vessel. This was found to avoid scaling of interior of digesters and to decrease retention time needed in the digester. Adjustment of the alumina-to-soda ratio was shown to provide means to improve decantation and also to reduce the amount of soda solution to be concentrated and recycled.⁽¹⁰⁾

For continuous rather than batch or semibatch digestion of bauxite, a tubular reactor in a turbulent flow condition was proposed by Plass.⁽¹¹⁾ He recommended heating an ore suspension of 3 to 6 volume percent solids at 95 to 150 C (200 to 300 F) and at 200 atmospheres (3000 psi). Soudan, et al,⁽¹²⁾ proposed using a gradually increasing temperature of digestion from 88 to 234 C (190 to 450 F) in two heating tanks and eight autoclaves operated in series. Ninety-five percent solubility of alumina was reported. Similarly, Juhasz, et al,⁽¹³⁾ recommended preheating a bauxite-soda mixture in several stages in a shell-tube heat exchanger at 100 to 140 C (212 to 280 F) before digestion in autoclaves.

The use of increased temperature during bauxite digestion was also recommended as a means to increase Al_2O_3 yield and also to allow reduction in the strength of the recirculating solution. This procedure was reported to reduce the heat requirement by 35 to 40 percent.^(14, 15, 16) Use of high Na_2O concentration, however, was recommended to avoid Al_2O_3 precipitation in thickeners and to digest excess of bauxite without increasing the digester capacity.⁽¹⁷⁻¹⁹⁾

The Al_2O_3 recovery was found to be increased by Scholder⁽²⁰⁾, who proposed decomposing calcined bauxite by heating for several hours at

180 C (360 F) in a liquor containing an alkali metal oxide and a halide such as NaCl, NaBr, or KCl in a ratio of 3:1. Antipin, et al, ⁽²¹⁾ suggested adding a small quantity of organic matter to leached pulp, while others ⁽²²⁾ recommended using a mixture of K-Na alkali mixture to increase Al₂O₃ yield and to decrease alkali loss during the process.

Belyaev, et al, ⁽²³⁾ observed improved leaching of bauxite when MgO was used with lime as an activator. Wolf ⁽²⁴⁾ reported that on addition of meta-, tetra-, or perborate to the bauxite at a digestion temperature of 145 to 165 C (290 to 330 F), the Al₂O₃ extraction requires about half the usual time and calcining of the ore may often be omitted. Similarly, addition of lime or soda ash ⁽²⁵⁾ or FeO ⁽²⁶⁾ was noted to reduce the alkali and alumina losses and to improve sedimentation rate of the red mud.

Numerous pretreatment steps and other modifications have been recommended to increase Al₂O₃ recovery in the Bayer Process. Preliminary calcination of bauxite at 260 to 310 C (500 to 600 F) was proposed ⁽²⁷⁾; addition of lime to bauxite and then calcining and grinding of the mixture before digestion was recommended ⁽²⁸⁾; addition of some red mud in digester was reported to be beneficial ⁽²⁹⁾, as was the addition of 0.6 to 0.7 g (1.3 to 1.5 lb) lignin/ton of bauxite ⁽³⁰⁾. One of the proposed methods ⁽³¹⁾ involved heating of bauxite with NaOH at 220 C (430 F) in a rotating stainless steel autoclave for 10 to 20 minutes and then quenching the apparatus in water to lower the temperature to 100 C (212 F). The resulting suspension when washed with dilute NaOH; the alumina extraction was found to be essentially complete with 0.05 ton NaOH/ton Al₂O₃ consumed.

Gebefuegi ⁽³²⁾ reported an improvement in Al₂O₃ recovery by first mixing ground bauxite with 10 percent Na₂CO₃ at 95 to 105 C (203 to 225 F). Then CaO and NaOH was added to the mixture and maintained at 105 to 125 C (225 to 260 F) for 10 minutes before subjecting it to Bayer Process. Other publications on improved methods to increase Al₂O₃ recovery included grinding of bauxite with recycled sodium aluminate solution ⁽³³⁾; leaching bauxite with alkaline aluminate solution ⁽³⁴⁾; addition of 5 to 20 g NaCl and/or Na₂SO₄/liter to the digestion system ⁽³⁵⁾; pulverizing and sintering a mixture of bauxite, Na₂CO₃, lime, and coke to make pellets and then grinding it and leaching at 90 C (194 F) with water ⁽³⁶⁻³⁸⁾; utilizing a tube reactor for bauxite leaching ⁽³⁹⁾; and treating bauxite with CaO and NaCl, which converted goethite to hematite which, in turn, also improved red-mud filterability ⁽⁴⁰⁾.

Lime-Soda Sinter Process Technology

This process was initially developed by Alcoa during World War II to recover Al₂O₃ from domestic kaolinite. The technique is a modification of the Bayer Process whereby the red mud obtained after the usual Bayer digestion is mixed with soda ash and lime and sintered in a kiln. The sinter

product is ground and leached with hot water to extract sodium aluminate liquor which is recycled back in Bayer's circuit.⁽⁴¹⁾ This method is particularly suitable for processing siliceous ores in which the alumina is chemically bound to silica.⁽⁴²⁾ Flint, et al,⁽⁴³⁾ described a cyclic process in which high-silica bauxite is boiled with NaOH-NaCl solution, filtered, and Al₂O₃ precipitated with carbon dioxide gas. The leach residue in this process was also sintered with CaCO₃, ground, and the Al₂O₃ extracted at 70 to 80 C (160 to 180 F) with water.

Grigoréva, et al,⁽⁴⁴⁾ reported that when bauxite was roasted with soda and lime in the presence of solid carbon, less soda was consumed and high Al₂O₃ was extracted. Fusion of bauxite with Na₂CO₃ and CaCO₃ gave a porous material which could be leached at low temperature.⁽⁴⁵⁾

Dobos⁽⁴⁶⁾ proposed an improved technique involving leaching bauxite by the Bayer Process, then reduction of the red mud by puddling and removal of iron by magnetic separation. The slag was sintered with Na₂CO₃ and CaO and then leached to recover additional Al₂O₃. An alternative to the sinter method proposed by Calhoun, et al,⁽⁴⁷⁾ involved calcining bauxite at 980 C (1796 F) and then leaching by percolation with 15 percent NaOH solution at 94 to 96 C (201 to 205 F). This procedure was reported to remove up to 77 percent SiO₂.

Alumina From Low-Grade Bauxite

Numerous methods have been proposed to recover Al₂O₃ from low-grade ores. One method involves reduction to yield a product containing an Al-Fe-Si metallic phase. This can be leached with NaOH to recover sodium aluminate.⁽⁴⁸⁾ Digestion of the ore in an autoclave with both NaOH and Ca(OH)₂ solution was proposed⁽⁴⁹⁾; and use of a tube autoclave with NaOH at 300 to 350 C (570 to 660 F) was recommended⁽⁵⁰⁾.

For bauxite which digests slowly in NaOH, the rate and yield can be increased by grinding in a vibratory ball mill which disturbs the internal structure of bauxite and increases the solubility by a factor of six.^(51, 52)

Different methods and reagents have been recommended to remove impurities from the leach liquor; for example, HCl and Ba(OH)₂ were used to remove organics.⁽⁵³⁾ Boiling the liquor with 1 percent activated carbon⁽⁵⁴⁾ or roasting the bauxite at higher temperature⁽⁵⁵⁻⁵⁷⁾ are suggested steps. Sulfur, if present, can be removed by agglomerating it with lime and coke and then heating it.⁽⁵⁸⁾ Other methods involved treating bauxite with Na₂SO₄ in oxidizing and reducing medium.⁽⁵⁹⁾ Phosphorus present in bauxite could be controlled by adding CaCO₃.⁽⁶⁰⁾

Desilication of aluminate liquor has been recommended by adding hydrated alkali aluminosilicate⁽⁶¹⁾ or by adding 4 percent white mud (mineral noselite with sulfate)⁽⁶²⁾ to the heated liquor. General methods recommended to remove most of the impurities referred to removing CO₃ and SO₄ by evaporation and crystallization at 40 C (104 F). On cooling the liquor, a residue rich in P₂O₅ and V₂O₅ was found.⁽⁶³⁾ Addition of Ca(OH)₂ to the liquor was noted to precipitate all salts.⁽⁶⁴⁾ Zinc, if present, could be removed by precipitation as ZnS.⁽⁶⁵⁾

Bauxite Beneficiation

Studies on the physical beneficiation of bauxite in general concern the removal of reactive silica. Pickens⁽⁶⁶⁾ recommended dispersing the bauxite in an agitated slurry and then removing silica by desliming. Prasad, et al⁽⁶⁷⁾ reported that a majority of silica from bauxite could be removed by grinding and screening at minus 20 mesh. Other publications referred to flotation of silica with a cationic collector (e. g., an amine)⁽⁶⁸⁾ or, flotation of bauxite with an anionic collector (e. g., oleic acid)⁽⁶⁹⁾, gravitation-magnetic separation⁽⁷⁰⁾, photoseparator⁽⁷¹⁾, and selective dispersion⁽⁷²⁾.

Pedersen Process

The process was developed to process ferruginous bauxite containing high SiO₂ and TiO₂ which could not be effectively treated by standard Bayer methods. It involves smelting the bauxite with lime and coke in an electric furnace at 1750 C (3180 F). The iron oxide can be reduced to molten iron with the formation of a calcium aluminate slag; alumina is recovered from the slag by grinding and leaching with Na₂CO₃ solution. The Al₂O₃ is precipitated by neutralizing the liquor with CO₂.⁽⁷³⁻⁷⁵⁾ Some improvement in the leaching step was reported by using a temperature of 80 C (176 F). This allows an increase in the Al₂O₃ content of the solution which then permits precipitation of the Al₂O₃ by seeding.⁽⁷⁶⁾

RED-MUD DEWATERING

The partial dewatering of red mud is an integral part of the Bayer Process operations in the washing circuit for recovery of caustic. Practical considerations require that the mud be thickened to about 20 percent solids. If the degree of thickening is not achieved, plant capacity is adversely affected. For this reason and to reduce the capital cost of thickening and washing, considerable laboratory and in-plant studies have been made of the factors that affect the settling and thickening of the red mud.

Seventy-one literature abstracts pertaining to red-mud dewatering were reviewed. About 85 percent of this literature referred to the flocculation of red mud with a wide variety of reagents. The remainder referred to

filtration and centrifugation methods of dewatering. The pertinent literature on dewatering is reviewed in the following paragraphs.

Flocculation

Flocculation is the addition of a chemical agent which causes the fine particles in suspension to agglomerate and, therefore, settle more rapidly by gravitational force. The common flocculating agent used in the alumina extraction industry is cooked starch. It was reported that the method of preparation of the colloidal starch solution was important; for example, heating the starch solution makes it a more effective flocculation agent.⁽⁷⁷⁾ Some investigators^(78, 79) reported starch phosphate as being more effective than natural starch. The use of rye bran, rye flour, and corn flour as a red-mud flocculant has also been tried.^(80, 81) The most effective of these were found to be rye bran and corn flour in the range of concentration from 0.1 to 0.125 g/l of slime pulp.

Numerous publications describe the use of synthetic polymers (polyacrylamide) as a red-mud flocculant. Wolf, et al,⁽⁸²⁾ reported different sedimentation rates and end volume percent for red mud, depending on the molecular weight of the polymer used. In general, the high-molecular-weight polymers are more effective than the lower molecular weight ones. Generally, also, a lesser amount of polymer [50 to 100 g/ton (0.11 to 0.22 lb/ton) of red mud] is required compared to the amount of natural starch needed [1 kg/ton (2.2 lb/ton) of red mud].^(83, 84) Sullivan⁽⁸⁵⁾ reported an increase in settling rate of red-mud slime by adding 0.0125 to 0.2 weight percent solution of an ultrahigh-molecular-weight polyvinyl aromatic sulfonate and also by the addition of lignosulfate product (about 25 weight percent active lignosulfonic acid). Polysodium acrylate prepared by irradiation was also reported to be an effective coagulant for red mud.⁽⁸⁶⁾ Ismatov, et al,⁽⁸⁷⁾ reported an optimum settling of solids at a polymer concentration of ≤ 125 g/ton and liquid:solid ratio of 20:1. Werner⁽⁸⁸⁾ reported that the polysodium methacrylate gave the highest settling rate of all the polymers investigated. A higher sedimentation rate was also reported when an emulsion of polyacrylic acid ester and polymethylacrylate was used.⁽⁸⁹⁾

Skobeev⁽⁹⁰⁾ reported a threefold increase in settling rate of red-mud slurry using a flocculating mixture of 6.25 g/m³ polyacrylamide and 25 g/m³ flour. Sibert^(91, 92) observed that the separation rate of dispersed red mud was increased when treated with cooked starch and a polymer of molecular weight greater than 50,000.

Addition of certain minerals was shown to accelerate or retard settling of red mud, e.g., rutile, magnetic, melanterite, and siderite accelerated the settling; limonite, kaolinite, quartz (opal), and pyrite retarded the settling rate of the red-mud suspension.⁽⁹³⁻⁹⁵⁾ Chu, et al,⁽⁹⁶⁾ reported that the

addition of CaO to the Bayer Process increased the extraction of Al_2O_3 and increased the sedimentation rate of the red mud. He also reported that addition of lime and BaO increased, while MgO retarded, the sedimentation rate of red-mud suspension.

Makary, et al, (97) reported using homogenizing wheat flour with caustic for red-mud sedimentation, while Goldman, et al, (98) obtained positive results with a composite flocculant consisting of 1.1 ratio of polyacrylamide and rye flour.

A mixture of 0.1 to 2.0 weight percent starch (based on red mud) and 0.3 to 12 times the weight of starch of calcium compounds, e. g., $\text{Ca}(\text{OH})_2$, CaCO_3 , and CaO, gave a high sedimentation rate compared to that obtained by starch alone. (99) Similarly, a mixture of calcium compounds and a polymer, lime Na polyacrylate, accelerates sedimentation and filtration of red mud. (100)

Derevyankin, et al, (101) reported that an optimum concentration of Na_2O (15 to 20 g/dm^3) is necessary for attaining maximum settling rate. Other publications on red-mud sedimentation dealt with addition of sea weeds (102), clarified aluminate solution (103), gelatinizing (104), freezing and thawing of red mud (105), and use of higher temperature (106).

Centrifugal Dewatering

Centrifugal methods studied for partial dewatering of red muds included the use of the hydroclones and centrifuges. However, the number of studies done were limited. German-Galikana, et al, (107) found that hydroclones installed ahead of thickeners are able to eliminate 75 percent of solids provided that the liquid-to-solid ratio in the cyclone feed is maintained at 0.8 to 1.0.

Good, et al, (108) showed an increase in solids content of sludge from 20 to 25 percent to 40 percent with a centrifuge. They also reported an increase in centrifuge capacity by about 35 percent by addition of a flocculant.

Filtration

Polyakov, et al, (109) concluded that for efficient filtration of the red mud, the liquid-to-solid ratio should be 1.8:1, and that the rate of filtration increases proportionally to the increase in pulp temperature and inversely to total thickness of cake layer. These workers also reported that filtration rate depends little on the Na_2O or sodium aluminate contents in the pulp within 5 to 40 g/l (0.011 to 0.088 lb/ton) concentration.

Kaempfer⁽¹¹⁰⁾ and Plaetschke⁽¹¹¹⁾ have reported that rotary drum filters are more economical than the conventional Kelly press for red-mud filtration due to reduced labor and wash water requirements. The Na₂O losses were also noted to be reduced considerably. Konig⁽¹¹²⁾ reported achieving a filtration rate of 125 to 155 kg/m² (25 to 32 lb/ft²) with a rotary drum filter. Recently, Vogt⁽⁴⁾ reported a filtration rate of 190 kg/m² (39 lb/ft²) of Jamaican red mud using a rotary drum filter operating at 75 C (167 F). The filter cake obtained had 40 percent solids and was thixotropic in behavior.

Martine⁽¹¹³⁾ reported that red mud obtained from previous filtration is more effective as a filter aid than the conventional materials such as diatomite.

UTILIZATION OF RED MUD

The search of the literature pertaining to possible commercial use of red mud was organized in three categories: (1) metallurgical, (2) ceramic, and (3) waste treatment. The references totaled 267 articles, and more than half concerned metal recovery from the mud. Ceramic-use references totaled 96 articles, or approximately 30 percent of the citations. The pattern that the recent research has been done largely outside the United States is clearly established. More than 90 percent of all literature in the field of red-mud utilization was based on the work of foreign investigators.

Metallurgical

Literature references on metal recovery totaled 140 articles classed as shown in Table 4. It can be noted that approximately half the references pertain to recovery of iron. Recovery of titania and additional alumina is also proposed. The higher value metals such as niobium, gallium, and vanadium have received attention but are present in such low concentration that their commercial recovery has not been tried.

TABLE 4. CLASSIFICATION OF LITERATURE BY SUBJECT ON METALLURGICAL USES FOR RED MUD

| Material recovered | Number of articles |
|----------------------|--------------------|
| Alumina | 12 |
| Titania | 11 |
| Iron | 62 |
| Iron, alumina | 20 |
| Iron, titania | 2 |
| Miscellaneous metals | 33 |
| Total | 140 |

A listing of these references by country of origin is given in Table 5.

TABLE 5. CLASSIFICATION OF LITERATURE ON RED-MUD UTILIZATION BY COUNTRY (METALLURGICAL)

| Country | Number of abstracts |
|----------------|---------------------|
| U. S. S. R. | 37 |
| Japan | 18 |
| Hungary | 24 |
| U. S. A. | 9 |
| Germany | 10 |
| France | 10 |
| Czechoslovakia | 6 |
| India | 4 |
| Yugoslavia | 3 |
| England | 1 |
| Italy | 1 |
| Canada | 1 |
| Spain | 1 |
| Belgium | 1 |
| Korea | 1 |
| Unidentified | 13 |
| Total | 140 |

Iron—Several processes have been developed to recover iron from the red-mud residues. One method is the carbon-lime-soda sinter process which can be applied either to ore or to the red mud.^(114, 115) In this process, the iron is reduced and recovered by magnetic separation from the waste residues after alumina leaching. A U. S. patent has been issued describing the application of a fluidized bed to produce sponge iron by these techniques.⁽¹¹⁶⁾ Another patent was granted for a process to treat high-iron-content bauxite ores involving reductive roasting with magnetic separation of iron from the leach residues.⁽¹¹⁷⁾

Direct electric arc smelting of the red mud has been proposed for recovery of iron from high-iron-content bauxites. In this case, pig iron can be produced with up to 98 percent recovery of iron value in the bauxite. The slag from the smelting operation can also be further treated to recover up to 84 percent of the alumina lost by the Bayer Process. This particular process was recently advocated by the McDowell Wellman Engineering Company as being both technically and economically feasible and they have developed the process through a pilot-scale stage.⁽¹¹⁸⁾ The economics

assume that the pig iron or steel would be produced near the bauxite refining plant to take advantage of low-cost iron units in the red mud. The U. S. iron and steel industry has not taken steps to commercialize the process. Economics require a low-cost means to completely dewater the mud. Trace elements, for example, phosphorus, can have a very significant and adverse effect on steel quality.

Alumina and titania recovery - Alumina and titania recovery from the red mud are only of secondary interest. However, if the mud is smelted for iron recovery, the slag from the smelting operation can be leached with sodium carbonate solution to recover most of the alumina values. Titania can be recovered by leaching the residue of the carbonate leach with sulfuric acid.⁽¹¹⁴⁾ The recovery of titanium from the red mud is technically feasible but the complicated processing is too costly to compete with the recovery from natural titanium ores such as ilmenite or rutile.

Other metals - Various other rare metals such as gallium, vanadium, and scandium can be recovered from the red-mud residues or at various stages in the Bayer Process. It has been reported that gallium recovery is economical by direct electrolysis of the caustic aluminate liquors.⁽¹¹⁹⁾ Several studies have also been conducted on vanadium recovery. In one method a vanadium slag is separated from the pig iron mud.⁽¹²⁰⁾ In another method, liquid-liquid extraction by amines is used on the leach liquors from the Bayer Process to recover vanadium.⁽¹²¹⁾

Again, it appears that these recovery methods are only of secondary interest after first extracting the iron values from the red-mud residues.

Ceramic

For most of the possible uses of the mud in ceramics, it would be necessary to dry or at least partially dry the mud, for example, before firing in a brick kiln. Certainly the red mud would require drying to allow transportation for distances greater than 50 miles. Drying would likely entail costs of the order of the present cost of most raw materials for the large-tonnage ceramic products. Although certain specialty uses might be made of the mud, they are of little significance, since uses relate to the overall problem of utilization of the muds to eliminate the disposal problem. Therefore, review of the literature was done using the general criteria that uses offering the greatest potential would be those that are large-volume applications, require minimum pretreatment of the red mud, and require minimum transportation, e. g. , less than a distance of 50 miles.

Cement, building blocks, or brick and to a lesser extent lightweight aggregate and rubber are potential large-volume applications where red mud might be used. It is expected that a minimum pretreatment (dewatering)

would be required for use of red mud in brick and lightweight aggregate. For use in cement and as a rubber filler, acid washing would be required and complete drying and powdering would be necessary for the filler application. Cement and brick manufacturing plants are fairly widely distributed throughout the United States, with lightweight aggregate plants being less numerous. There is potential for such plants being located near the source of the red mud which is considered necessary to minimize transportation costs.

Other applications for red mud, such as those listed in Table 6, as well as applications in exothermic mixes, as a scouring or polishing medium, or as a drilling mud, are considered of low potential for either technical, economic, or low-volume reasons.

Ninety-six papers were found on uses of red mud in ceramic applications. The various uses are shown in Table 6. Table 7 indicates the degree of activity, by country, relative to developing uses for red mud.

From these tables, it can be noted that about 65 percent of the abstracts dealt with applications of red mud as cement, construction block material, lightweight aggregate material, plastic and resin filler, and pigment. The other 35 percent of the abstracts concerned 13 other applications.

Five countries, Japan, Germany, France, the U.S.S.R., and Hungary, were the origin of slightly more than 75 percent of the publications. Three abstracts were of U.S. origin.

Cement - Three potential applications for red mud as a cement material, with varying degrees of promise, were indicated in the literature.

Cement raw material - Portland cement generally consists principally of silicates and aluminates as shown in Table 8.

Thus, the oxides of calcium, aluminum, silicon, and to a minor extent iron make up the major portion of the cement. A typical red mud contains CaO, SiO₂, and Fe₂O₃ in the range around 5 to 10 percent, 2 to 10 percent, and 40 to 50 percent, respectively. Thus, its potential use as a raw material for cement manufacture has been of interest. (112, 123) However, the amount of red mud that might be incorporated directly as a raw material would be low because it contains a relatively high iron oxide. (124)

Additions of ~5 percent of treated red muds to portland cement were reported to increase strength and affect setting time. (125-128) Greater additions decreased strength. Pretreatments of the red-mud slurry included carbonic or sulfurous acid treatments, drying or calcining, and grinding. Untreated red-mud additions in small amounts had some affect on setting time.

TABLE 6. CLASSIFICATION OF LITERATURE BY SUBJECT
ON CERAMIC USES FOR RED MUDS

| Field of application | Number of abstracts |
|---|---------------------|
| Cement material | 22 |
| Construction block material | 16 |
| Lightweight aggregate material | 10 |
| Plastic and resin filler | 9 |
| Pigment | 6 |
| Miscellaneous materials recovery | 6 |
| Caustic recovery | 5 |
| Catalyst material | 4 |
| Fertilizer material | 4 |
| Coating material | 3 |
| Insecticide material | 2 |
| Refractory cement material | 2 |
| Road, pavement, soil stabilization material | 2 |
| Metal surface treatment material | 1 |
| Sewage treatment material | 1 |
| Glass material | 1 |
| Insulation material | 1 |
| Coke additive | 1 |
| Total | 96 |

TABLE 7. CLASSIFICATION OF LITERATURE ON
RED-MUD UTILIZATION BY COUNTRY
(CERAMIC)

| Country | Number of abstracts |
|----------------|---------------------|
| Japan | 32 |
| Germany | 21 |
| France | 8 |
| USSR | 9 |
| Hungary | 6 |
| U.S. | 3 |
| India | 2 |
| England | 2 |
| Taiwan | 2 |
| Czechoslovakia | 2 |
| Australia | 1 |
| Switzerland | 1 |
| Ukraine | 1 |
| Poland | 1 |
| Unidentified | 5 |
| Total | 96 |

TABLE 8. RAW MATERIALS IN PORTLAND CEMENT

| Component | Amount, percent |
|-------------------------------|-----------------|
| Tricalcium silicate | 45 |
| Dicalcium silicate | 27 |
| Tricalcium aluminate | 11 |
| Tetracalcium aluminum ferrite | 8 |
| MgO | 3 |
| Other miscellaneous | 6 |

Cement for iron ore briquetting - Cements produced by sintering red mud or red mud and limestone have been considered as possible binders in iron ore briquetting. (129, 130) For this application, the relatively high Fe_2O_3 content of the red mud is an advantage.

Construction block and brick material - The use of red mud for making structural shapes was considered in 16 publications. However, it was found that the resulting products were mechanically weak. The compressive strength of the standard U. S. common bricks exceeds 8000 psi. In most cases the red-mud products had strengths less than this. This was true even in the case of brick made of mixtures of red mud and clay fired at temperatures comparable to those used in firing all-clay brick. (131, 132) A 5 to 10 percent addition of red mud to clay was used to make roofing tile. (133)

However, brickmaking could be an important possible use of the muds. Construction, and thus the structural brick industry, is currently below its peak of several years ago. However, in 1973, around 350 plants in the U. S. were producing 18 million tons of brick annually. Sixty-four of these plants were in Alabama, Arkansas, Louisiana, and Texas. At a 300 ton/day typical capacity of a plant, these 64 plants would account for 19,200 tons of brick/day.

It is judged from the literature that it is not likely that the red-mud content of brick can exceed 50 percent and that 25 percent is a more likely prospect. Brick with more than 50 percent red mud were mechanically weak by U. S. standards.

If the 64 plants cited above made brick comprising 25 percent red mud, the daily red-mud consumption (on a dry red-mud basis) would be 4,800 tons. It is questionable that all of the 64 plants could use red mud because of the distance of some of them from the source of the red mud, resulting in prohibitive shipping costs. If one-fourth of these 64 plants could use the red mud, 1,200 tons/day could be consumed. This is considered a likely maximum use of red mud for brickmaking but is still a significant use.

Possible contributions of a red-mud addition to clay in brickmaking include

- Pleasing color and color shades dependent on content
- Improved dry strength for handling before firing
- Lower firing temperature and thus fuel or energy savings.

In the evaluation of this use of red mud, it is recommended that various red muds be blended with a light (color) burning clay in various ratios. Specimens formed from this mixture would be evaluated for dry strength,

strength after firing at various temperatures, water absorption, and color. The water absorption, as well as fired strength, would indicate whether the typical 1900 F firing temperature was appropriate or whether a lower temperature might be tolerated or even preferred.

Lightweight aggregate material - Lightweight aggregate is used with cement to make a lightweight strong concrete. Some clays or shales bloat and expand when heated to give the lightweight aggregate. Others do not. The literature⁽¹³⁴⁻¹³⁸⁾ indicated that combinations of red mud and non-bloating clays or shales would bloat on heating to yield lightweight aggregate. One mechanism accounting⁽¹³⁶⁾ for the bloating is the evolution of CO₂ gas resulting when Fe₂O₃ in the red mud converts to Fe₃O₄ on heating. The oxygen that is evolved during heating of the mud combines with carbon from organic matter to give the CO₂. Red mud:clay ratios for making lightweight aggregate in the range of 50:50 to 90:10 were given which could potentially represent a significant use of red mud in this product.

It is estimated that the lightweight aggregate industry is about one-eighth the size of the brick industry. However, it also appears from the literature that a lightweight aggregate comprising 75 red mud (dry basis) - 25 clay or shale is feasible. This would be three times the maximum consumption in brick using 25 red mud - 75 clay. Thus, at a maximum daily consumption of 1200 tons of red mud/day for brickmaking, the maximum consumption for lightweight aggregate production would be of the order of

$$\frac{1200 \text{ tons} \times 3}{8} = 450 \text{ tons/day.}$$

A possible attraction to the use of red mud in lightweight aggregate lies in location of the plant site. Since red mud can be the predominant raw material, possibly up to 90 percent in content, location of the plant should be at or near the source of the red mud. The clay or shale, which apparently need not possess bloating characteristics itself and which comprises the minor raw material, can then be shipped to the red-mud source.

There could be merit in study of the mixing of red muds with nonbloating clay or shale in the ratios of the order of 75 red mud - 25 clay and the mixes granulated and fired to determine bloating characteristics. Evaluation of the fired granulated material would be by visual inspection and bulk density measurement, the latter to determine how "lightweight" the aggregate is.

Plastic and resin filler - Though numerous materials can be used as fillers, it was considered significant that red mud as a filler in rubber gave a rupture strength higher than all other fillers excepting carbon black. (139-141) It should thus be a suitable substitute for carbon black in some applications. Thus use as a filler requires that the red-mud slurry be acid washed, dried, and powdered.

Pigment - Red mud was indicated to have possible application as a pigment for coloring concrete⁽¹⁴²⁾, glass⁽¹⁴³⁾, and paint⁽¹⁴⁴⁾. Consistency of color is a requirement for any pigment application. This factor could make it difficult to use the mud for this purpose.

Miscellaneous applications - There was no evidence that red mud has unique yet useful characteristics not to be found in other materials. Basically, it is a "filler" type of material which can be used in some applications. For instance, it can be used as an insecticide carrier^(145, 146), a soil liming equivalent⁽¹⁴⁷⁾, a coating filler^(148, 149), a soil stabilization material⁽¹⁵⁰⁾, or a fertilizer^(151, 152) if potassium or nitrogen chemicals are added to it. Other materials can serve these same purposes.

Some of the publications^(153, 154) dealt with the recovery of caustic associated with the red mud while others mentioned its application as a catalyst material^(155, 156), a refractory cement material⁽¹⁵⁷⁾, a metal surface treatment ingredient⁽¹⁵⁸⁾, a sewage treatment material⁽¹⁵⁹⁾, an insulation material⁽¹⁶⁰⁾, and a coke additive⁽¹⁶¹⁾.

Waste Treatment

Red mud has been tested as a possible agent in a number of waste-treatment-abatement applications involving both gaseous and liquid effluents. For example, it has been found effective as an adsorbent for various chemical pollutants such as sulfur oxides^(162, 163) and H₂S⁽¹⁶⁴⁾ from gaseous effluents. It has also been reported as a good adsorbent of arsenic⁽¹⁶⁵⁾ from industrial wastewaters. In addition to these aspects, it has been investigated as a coagulant or flocculating agent^(159, 166) for municipal wastewater treatment.

The total number of articles published on different waste-treatment applications and by country of origin are listed in Tables 9 and 10.

TABLE 9. CLASSIFICATION OF LITERATURE ON WASTE-TREATMENT APPLICATIONS OF RED MUD

| Application | Number of articles |
|--------------------------------|--------------------|
| Adsorption of sulfur oxides | 14 |
| As a coagulant | 8 |
| Adsorption of H ₂ S | 7 |
| Others | 2 |
| Total | 31 |

TABLE 10. CLASSIFICATION OF LITERATURE ON WASTE TREATMENT APPLICATIONS OF RED MUD BY COUNTRY

| Country | Number of articles |
|--------------|--------------------|
| U.S.S.R. | 4 |
| Japan | 11 |
| U.S.A. | 7 |
| Germany | 4 |
| France | 1 |
| England | 1 |
| Unidentified | 3 |
| Total | <u>31</u> |

Adsorbent for sulfur oxides - Dried or calcined red mud has been found effective for adsorption of sulfur dioxide from industrial waste gases. (164) In this investigation, the gases were passed through an adsorption bed of red-mud granules at modest temperatures. The adsorbent bed was found to be over 90 percent effective in removing SO₂ and could be regenerated with a reducing gas such as hydrogen. Similarly, good results were obtained when red mud was mixed with coal for SO₂ control in industrial boilers. (162)

Use as a coagulant - An interesting possible use of red mud is as a coagulant for the treatment and sedimentation of municipal wastewaters and for sludge flocculation. This has been done on a commercial scale in England before the war. (159) The process involves treatment of the red mud with concentrated acids, then drying at modest temperatures, and crushing to give a granular product. Either sulfuric or hydrochloric acids can be used to convert the iron and aluminum oxides in the red mud to sulfates or chlorides. Thus, ferric chloride or alum can be produced which are well known for their coagulating properties. In addition to these effects, it has also been reported that the red-mud materials are effective for removing phosphorus from the municipal wastewaters with 70 to 80 percent effectiveness.

SECTION VI

EXPERIMENTAL PROGRAM

There are substantial differences in various bauxites and the red muds or residues from current alumina recovery operations. A part of this study concerned acquisition of samples and a comparison of the chemical and physical characteristics of these materials.

In addition to analytical characterization, it was considered important to examine the relative ability to dewater the muds. Particular attention was given to factors affecting the flocculation and settling of mud suspensions using various synthetic polymer flocculants. The influence of dissolved metals on the coagulation of the muds was studied. Limited experiments were made on mechanical dewatering, magnetic flocculation, and flotation as possible methods to achieve partial dewatering. These experiments were intended to provide a basis to judge the practical limit in partial dewatering by methods conventionally applied in general processing of minerals.

In addition to the analyses and characterization of the bauxites and mud samples, several experiments were done to verify results previously reported in the literature concerning a kiln pretreatment of bauxite before leaching that might allow magnetic separation of iron from the residue after leaching for recovery of alumina. The results of these experiments are provided in this section of the report.

SAMPLE ACQUISITION

Mud samples were provided to Battelle from five alumina refineries. These samples were obtained as slurry samples, generally from the pipeline going to the mud lake. The slurry samples were sent to Battelle in 55-gallon drums.

The samples were prepared for study by first mixing thoroughly, using a motor-driven agitator to mix the entire sample. When it was determined that all settled material was in active suspension, 5-gallon aliquot samples were taken from the drum for the various tests and analyses.*

*The brown-mud sample provided by Reynolds was not effectively redispersed after receipt by Battelle. This mud appeared to have partially set with cementlike character.

A listing of the samples received along with the initial characterization is provided in Table 11. The solids pulp density provided in the table was measured by weighing 200 ml of the well-mixed pulp, and then filtering and drying the solids at 105 C for subsequent weighing.

TABLE 11. INITIAL CHARACTERIZATION OF MUD SAMPLES

| Company | Location | Type bauxite | Physical properties of mud slurry | | | |
|-----------------|------------------------------|--|-----------------------------------|------|-------------------|-----------------|
| | | | Color | pH | Percent solids | Pulp density |
| Kaiser Aluminum | Gramercy, Louisiana | Jamaican | Red | 11.7 | 22.1 | 1.16 |
| Alcoa | Mobile, Alabama | Surinam- African | Reddish- orange | 11.9 | 7.8 | 1.08 |
| Alcoa | Point Comfort, Texas | Surinam- Caribbean- Australian- African | Red | 11.8 | 31.0 | 1.30 |
| Reynolds Metal | Hurricane Creek, Arkansas | Arkansas | Brown | 11.7 | 34.5 | 1.33 |
| Martin-Marietta | St. Croix, Virgin Islands | Boké (Africa) | Red | 12.5 | 35.6 | 1.27 |

CHARACTERIZATION OF MUD SAMPLES

The mud samples as received at Battelle were analyzed for chemical composition, particle size distribution, specific gravity, and settling rate. It should be noted that these samples may be typical but not necessarily representative of the average mud compositions. Details of these analyses studies are presented below.

Composition

The wet chemical analysis of the dried muds and the supernatant liquid associated with the as-received samples is given in Table 12.

The results of semiquantitative analyses by optical emission spectroscopy (OES) are given in Table 13.

Particle Size Distribution

The particle size distribution of the mud samples was determined by wet screen analysis in the size above 44 microns and by Coulter counter

TABLE 12. CHEMICAL ANALYSES OF MUD SAMPLES
(PERCENT BY WEIGHT)

| Component | Kaiser Aluminum, Gramercy, Louisiana, Jamaican bauxite | | Alcoa, Mobile, Alabama, Surinam-African bauxite | | Alcoa, Point Comfort, Texas, mixture of four bauxites | | Reynolds Metal, Hurricane Creek, Arkansas, Arkansas bauxite | | Martin-Marietta, St. Croix, Virgin Island, mixture of bauxites | |
|--------------------------------|--|--------------------------------------|---|--------------------------------------|---|--------------------------------------|---|--------------------------------------|--|--------------------------------------|
| | Dry mud | Supernatant liquid ^(a) | Dry mud | Supernatant liquid ^(a) | Dry mud | Supernatant liquid ^(a) | Dry mud | Supernatant liquid ^(a) | Dry mud | Supernatant liquid ^(a) |
| Al ₂ O ₃ | 15.00 | 0.58 | 29.10 | 8.79 | 17.80 | 3.34 | 6.31 | 1.89 | 33.80 | N. A. |
| Fe ₂ O ₃ | 51.50 | | 28.20 | | 40.00 | | 10.70 | | 22.90 | |
| SiO ₂ | 1.70 | | 10.80 | | 9.59 | | 19.90 | | 8.49 | |
| TiO ₂ | 6.70 | | 12.70 | | 8.48 | | 3.32 | | 12.90 | |
| CaO | 7.0 | | 5.72 | | 7.57 | | 42.50 | | 3.52 | |
| Na ₂ O | 0.97 | 1.11 | 1.34 | 15.96 | 2.69 | 14.24 | 1.34 | 7.62 | 6.0 | N. A. |
| LOI ^(b) | 9.30 | | 12.90 | | 10.30 | | 5.04 | | 12.4 | |

(a) The amounts are reported in grams/liter.

(b) Loss on ignition at 1000 C.

TABLE 13. OPTICAL EMISSION SPECTROGRAPHIC
ANALYSES OF MUD SAMPLES

(Percent by Weight)

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

technique for particles less than 44 microns in size. For Coulter counter studies, the particles were suspended in the supernatant liquid and were thoroughly dispersed with an ultrasonic bath. These data are given in Table 14 and are shown as composite curves in Figure 6. Particle-size analyses were also performed on the Gramercy and Point Comfort mud by the Andreason pipette technique for particle sizes finer than 44 microns. The results for the Alcoa - Point Comfort, Texas, mud are presented in Figure 7 for both the techniques. The results are in general agreement, with each method giving about 50 percent of the mud less than 4 microns.

Specific Gravity

Specific gravities of the dried mud samples were determined with a pycnometer. The specific gravities were calculated as follows:

$$\text{Specific Gravity} = (C-A)/[(B-A) - (D-C)] ,$$

where: A = weight of pycnometer (plus stopper), B = weight of pycnometer filled with water, C = weight of pycnometer and some solids, and D = weight of pycnomer plus solid plus water. The results obtained are given in Table 15.

DEWATERING STUDIES

Dewatering of suspended solids as it applies to this discussion refers to partial dewatering by removal of bulk and interstitial water from the suspension. Such physical dewatering methods as sedimentation, filtration, and centrifugation are of interest. Coagulation and flocculation induced by addition of chemical agents to the suspension can agglomerate the solids into larger and more compact aggregates which in turn are more readily dewatered. Therefore, the influence of such agents is pertinent to this study.

The mud samples used for the dewatering studies were obtained from the pipeline going to the mud lake. Hence, the muds were in a partially flocculated state. Dewatering studies presented in this report do not simulate the plant flocculation of mud, but pertain to dewatering of mud being discharged to the lake.

Sedimentation Experiments

The partial dewatering of suspended solids by sedimentation is induced by gravity and follows the generalized pattern illustrated in Figure 8. A plot of the height or volume of the settled solids versus settling time provides initial and final settling rates calculated from the slopes of

TABLE 14. PARTICLE-SIZE-DISTRIBUTION DATA^(a) FOR VARIOUS MUDS

| Size | Kaiser Aluminum Company, Gramercy, Louisiana, Jamaican Bauxite | | Alcoa, Mobile, Alabama Surinam-African Bauxite | | Reynolds Metals, Hurricane Creek, Arkansas, Arkansas Bauxite | | Point Comfort, Texas Jamaican-Australian- African Bauxite | |
|---------------------------------|--|------------------------------|--|------------------------------|--|------------------------------|---|------------------------------|
| | Weight percent | Cumulative weight percent | Weight percent | Cumulative weight percent | Weight percent | Cumulative weight percent | Weight percent | Cumulative weight percent |
| +28 mesh | -- | -- | 0.2 | 0.2 | -- | -- | 0.1 | 0.1 |
| 28 x 48 | 0.1 | 0.1 | 1.7 | 1.9 | 0.4 | 0.4 | 0.4 | 0.5 |
| 48 x 100 | 0.4 | 0.5 | 6.8 | 8.7 | 8.5 | 8.9 | 1.0 | 1.5 |
| 100 x 200 | 1.2 | 1.7 | 11.8 | 20.5 | 19.7 | 28.6 | 2.9 | 4.4 |
| 200 x 270 | 0.6 | 2.3 | 3.1 | 23.6 | 6.7 | 35.3 | 1.3 | 5.7 |
| 270 x 325 | 0.4 | 2.7 | 1.5 | 25.1 | 4.7 | 40.0 | 0.7 | 6.4 |
| 325 x 35 microns | 0.8 | 3.5 | 0.9 | 26.0 | 1.0 | 41.0 | -- | -- |
| 87 Average Diameter, microns | | | | | | | | |
| 29 | 0.2 | 3.7 | 0.9 | 26.9 | 1.1 | 42.1 | 0.7 | 7.1 |
| 13 | 0.8 | 4.5 | 1.6 | 28.5 | 3.7 | 45.8 | 0.7 | 7.8 |
| 18 | 1.3 | 5.8 | 1.6 | 30.1 | 4.3 | 50.1 | 0.8 | 8.6 |
| 15 | 1.8 | 7.6 | 1.5 | 31.6 | 4.3 | 54.4 | 1.3 | 9.9 |
| 12 | 1.8 | 9.4 | 1.8 | 33.4 | 3.7 | 58.1 | 1.5 | 11.4 |
| 9 | 2.2 | 11.6 | 1.5 | 34.9 | 3.4 | 61.5 | 3.6 | 15.0 |
| 7 | 3.9 | 15.5 | 3.4 | 38.3 | 3.8 | 65.3 | 5.9 | 20.9 |
| 6 | 7.0 | 22.5 | 10.4 | 48.7 | 4.7 | 70.0 | 8.6 | 29.5 |
| 5 | 19.0 | 41.5 | 15.6 | 64.3 | 7.1 | 77.1 | 13.9 | 43.4 |
| 4 | 14.8 | 56.3 | 7.6 | 71.9 | 5.8 | 82.9 | 16.3 | 59.7 |
| 3 | 5.7 | 62.0 | 4.8 | 76.7 | 9.5 | 92.4 | 9.0 | 68.7 |
| 2 | 13.1 | 75.1 | 8.4 | 85.1 | 4.2 | 96.6 | 8.2 | 76.9 |
| 1.5 | 19.1 | 94.2 | 9.9 | 95.0 | 2.0 | 98.6 | 9.7 | 86.6 |
| 1.2 | 4.8 | 99.0 | 4.4 | 99.4 | 1.0 | 99.6 | 8.6 | 95.2 |
| 0.9 | 1.0 | 100.0 | 0.6 | 100.0 | 0.4 | 100.0 | 4.8 | 100.0 |

(a) Obtained with Coulter-counter method.

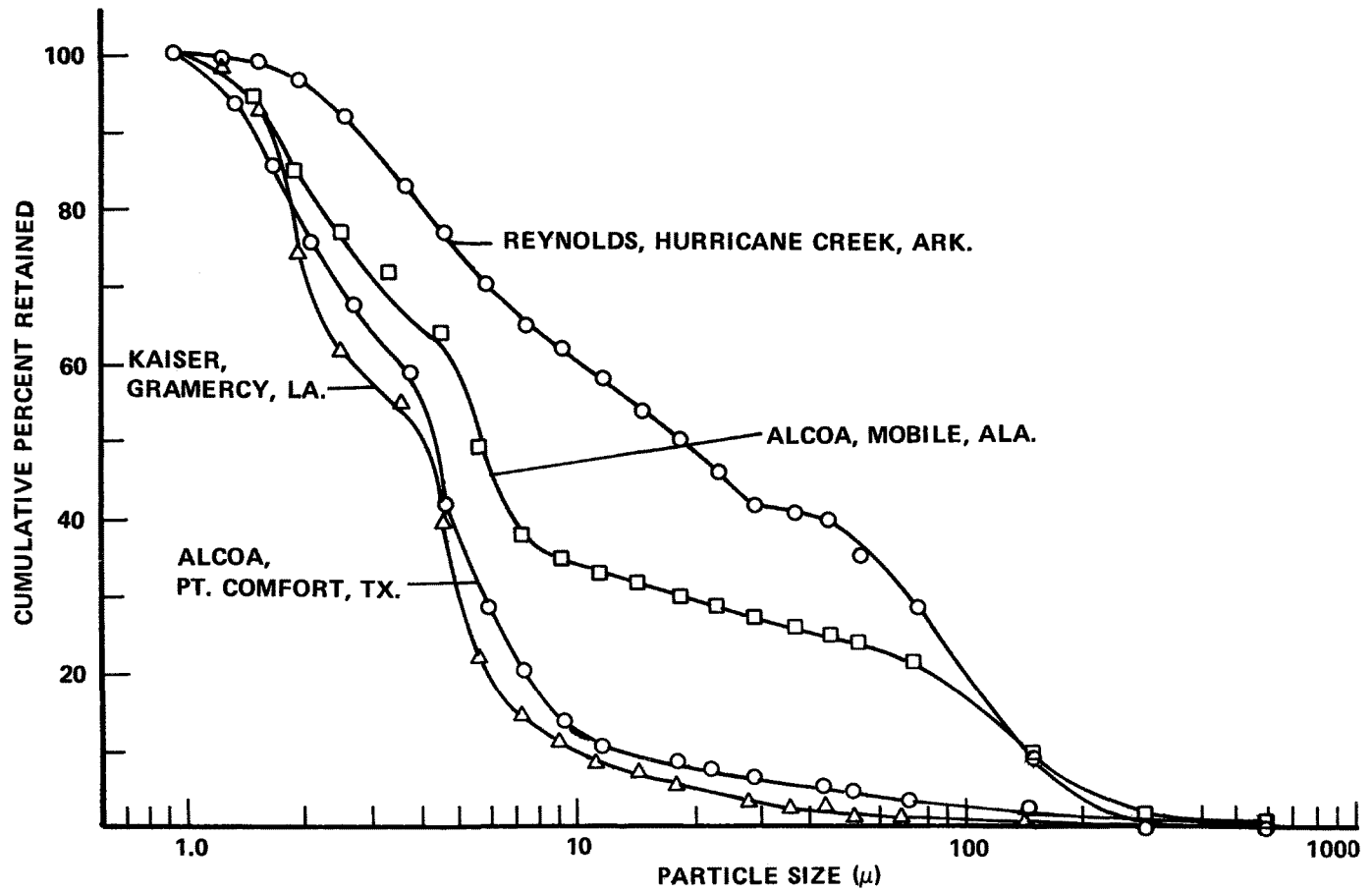


Figure 6. Particle-size distribution of various muds

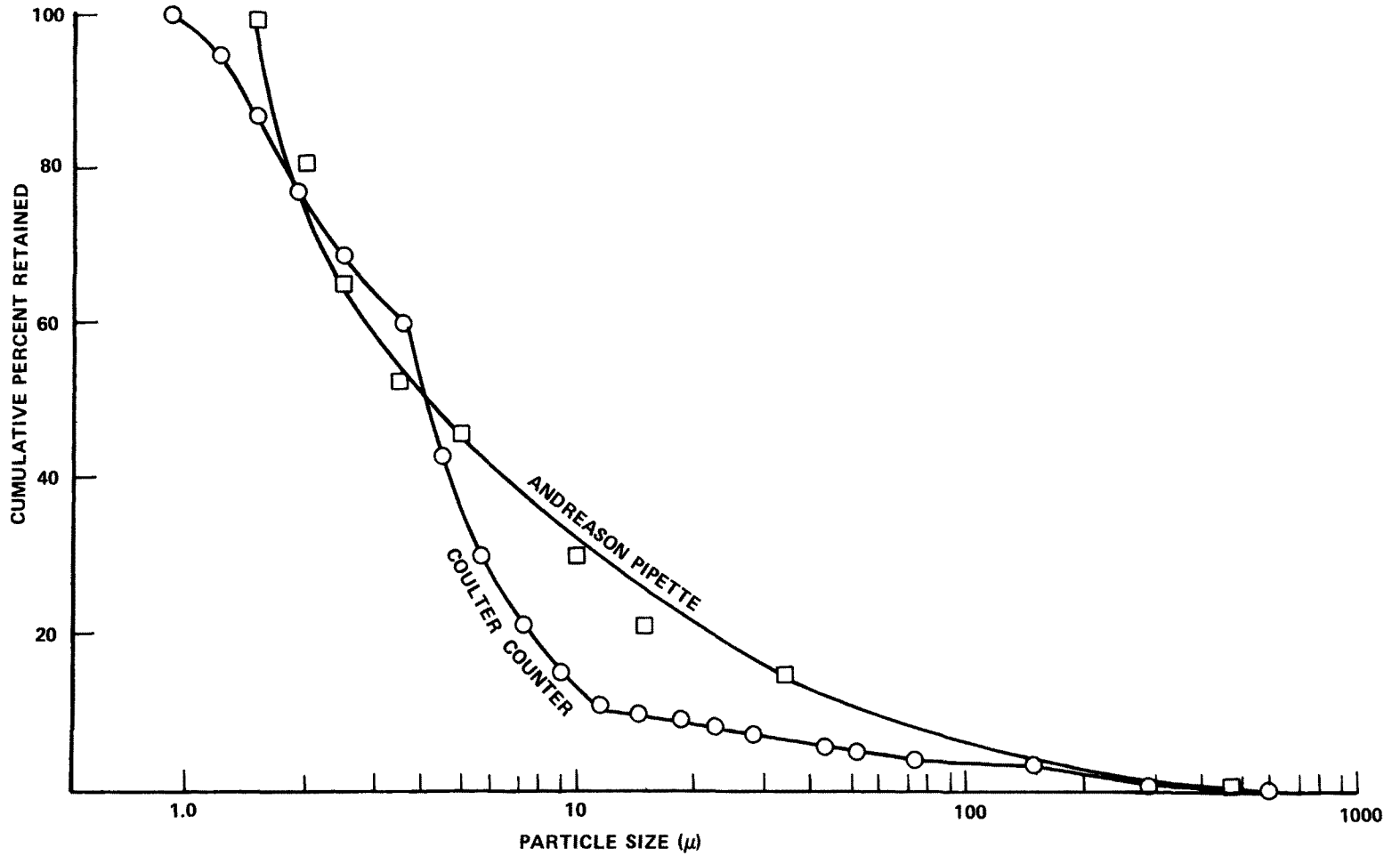


Figure 7. Particle size distribution of Alcoa-Point Comfort, Texas, red mud using Coulter-Counter and Andreason pipette methods

TABLE 15. SPECIFIC GRAVITY OF MUD SAMPLES

| Company | Mud Type | Specific Gravity |
|-----------------|--|------------------|
| Kaiser | Jamaican Red Mud | 3.10 |
| Alcoa | Surinam - African Red Mud | 2.67 |
| Alcoa | Australian - African - Jamaican - Surinam Red Mud | 2.69 |
| Reynolds | Arkansas - Brown Mud | 2.65 |
| Martin-Marietta | Boké (South Africa) - Red Mud | 2.89 |

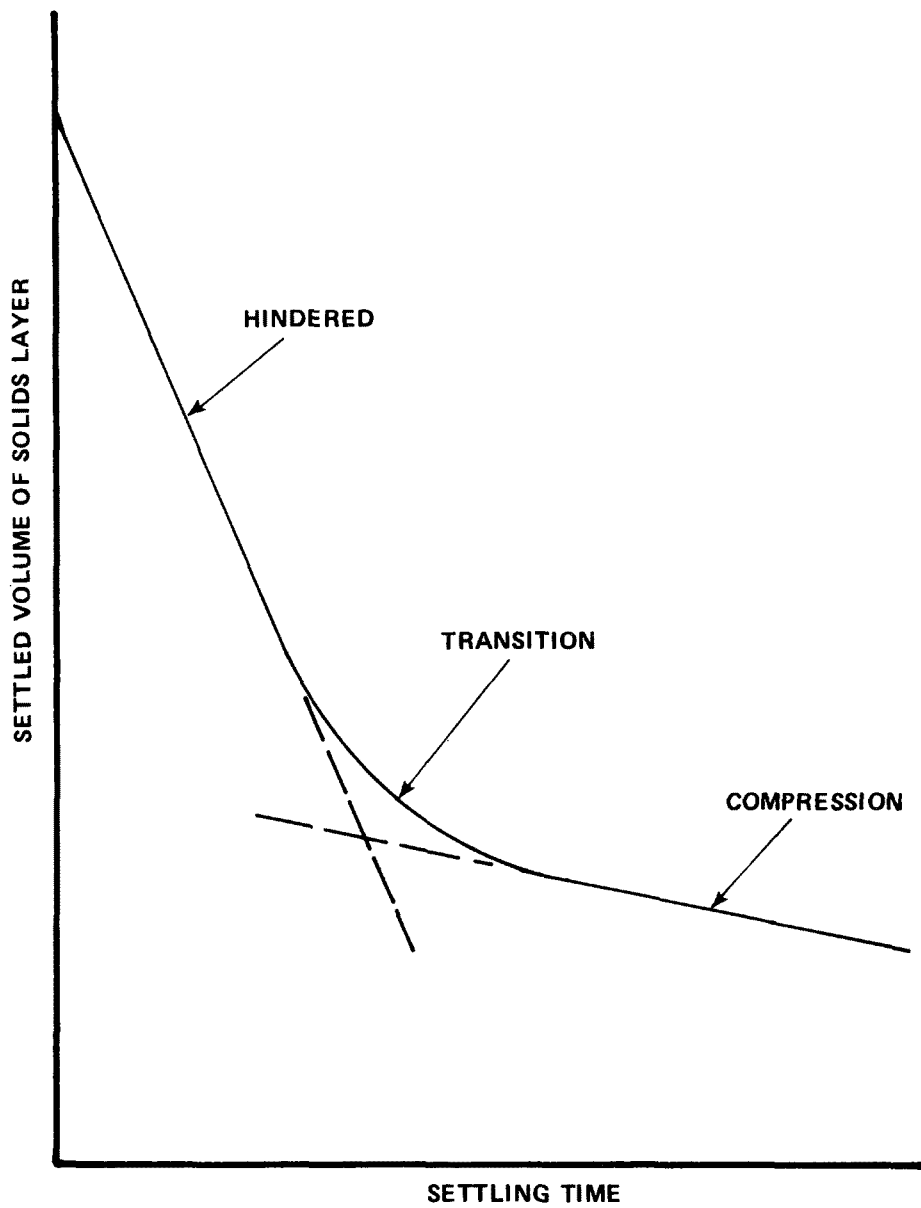


Figure 8. Generalized settling rate curve

the straight line representing the hindered and compression regimes, respectively, as shown in the illustration.

The settling-rate studies of the red-mud-samples suspensions were performed in graduated cylinders. The mud slurry, after gentle but thorough mixing, was poured into the cylinder and the settling tests were begun. The volume corresponding to the heights of the developing interfaces between settled solids and bulk overhead liquid were measured at intervals during a total period of up to 24 hours. The final volume of the solids layer was noted and the percent solids in the settled sludge was determined by weighing the sludge before and after filtering and drying. The sedimentation rates reported are based on measured rates in the hindered settling regime. The initial part of the experimental study involved sedimentation experiments without any addition of chemical reagents to establish the differences in the individual samples received. Subsequent work was done to examine the influence of various flocculants and solution chemistry on the sedimentation.

The settling-rate data for the as-received mud samples are plotted in Figure 9. It was noted that the Kaiser-Gramercy (Jamaican) mud, the Alcoa-Point Comfort mud, and Martin-Marietta-St. Croix mud* had a very similar slow settling behavior. The Alcoa-Mobile (Surinam-African) mud and the Reynolds-Hurricane Creek (Arkansas) brown-mud sample showed substantially higher initial settling rates. With the exception of the Arkansas brown mud, the final settled density of the red muds was 25 to 33 percent solids (Table 16).

As the initial settling tests illustrate, the more severe problem in dewatering is with the red mud from digestion of Jamaican bauxite. The settling characteristics of the samples of red mud received from Kaiser's Gramercy refinery and Alcoa's Point Comfort plant appeared to be quite similar. The sample from Alcoa, Point Comfort, was not fully representative as it contained an unexpectedly high percentage of solids (~30.0 percent) and no coarse sand. According to information provided at the plant, the solids content of the mud is generally between 15 and 20 percent and the material contains a sand fraction. Because the experimental activities in this program were of limited scope, detailed dewatering studies were conducted only on the red mud derived from Jamaican bauxite. The term Jamaican Red Mud, as used in the report, refers to the red mud supplied by Kaiser Aluminum Company, Gramercy, Louisiana. The following conditions and operations were studied:

- (1) Effect of pH on settline rate
- (2) Effect of metal ions on settling rate

*A very small sample of the mud was provided for the study; therefore, no detailed tests were made.

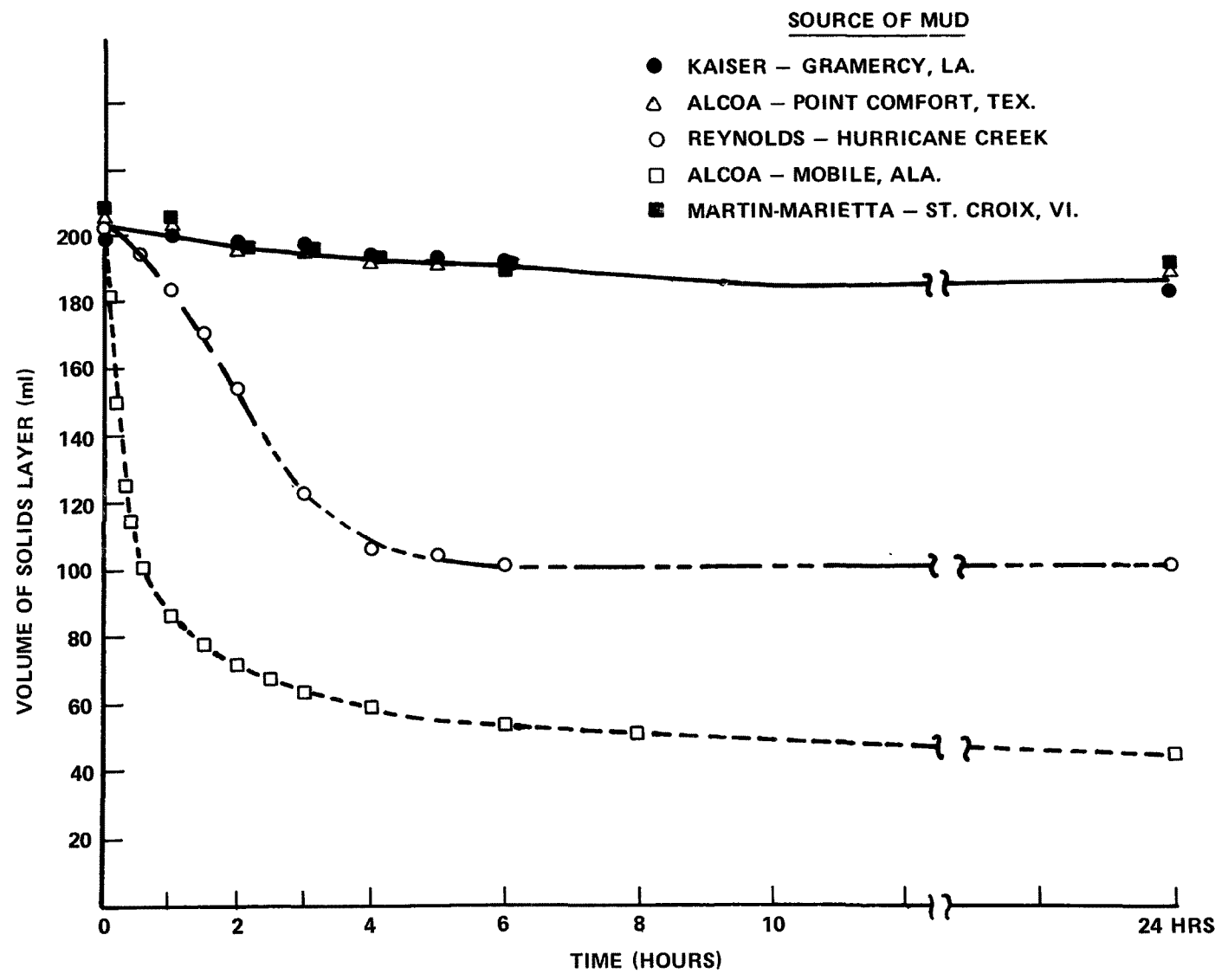


Figure 9. Settling rate curves for various muds (as received)

TABLE 16. SETTLING-RATE DATA FOR VARIOUS MUDS (AS RECEIVED)

| Mud source | Type of mud | pH | Settling rate, cm/hr | Initial percent solids in the mud slurry | Percent solids in the sludge after 24-hr settling |
|--|-----------------|------|----------------------|--|---|
| Kaiser, Gramercy, Louisiana | Jamaican | 11.8 | 0.10 | 22.2 | 25.6 |
| Alcoa, Mobile, Alabama | Surinam-African | 11.7 | 2.96 | 7.8 | 28.2 |
| Alcoa, Point Comfort, Texas | Mixed | 11.9 | 0.05 | 31.0 | 33.0 |
| Reynolds, Hurricane Creek, Arkansas | Arkansas | 11.8 | 2.15 | 35.06 | 55.5 |
| Martin-Marietta, St. Croix, Virgin Islands | Boke | 12.3 | 0.12 | 35.85 | 38.04 |

- (3) Effect of polymers on settling
- (4) Effect of solids concentration on settling
- (5) Effect of magnetic field, i. e., magnetic flocculation, on settling
- (6) Flotation as a means to dewater
- (7) Centrifuging with and without reagents as a means to dewater.

Effect of pH—The red mud contains different solids with different surface electrical charges. The chemistry of a suspension, particularly the condition of pH can be used to induce a mutual coagulation of mud particles and thereby alter the settling and dewatering character. For this reason, sedimentation experiments were made at different pH.

The settling rate data for the Kaiser-Gramercy (Jamaican) mud at pH 5.2, 7.0, 8.5, and 11.7 are given in Table 17. The pH was not found to have a significant effect on the settling rate. It was noted that adjustment of the pH to below 5.0 caused considerable effervescence and swelling of the mud. No significant change was found in the final solid density of the sludge with pH variation within the 24-hour time period of the experiments.

Effect of metal ions—The fact that metal salts and metal precipitates induce coagulation and settling is well established. Precipitated metal hydroxides enmesh fine particles and accelerate the settling of a suspension.

Several experiments were performed by adding the red-mud slurry to solutions of aluminum (Al^{+3}), ferric (Fe^{+3}), and magnesium (Mg^{+2}) salts. The quantity added was adjusted to give pH values of 8.0, 7.0, and 10.5, respectively, in the final slurry. These pH levels are known to be effective for these metals in industrial wastewater-treatment systems.

An experiment was also made by first lowering the pH of the mud to ~2.0, assuming some of the iron present in the mud might dissolve at this low pH, and then raising the pH to 8.0 to precipitate any dissolved iron as hydroxide. The results are summarized in Table 17. Despite some apparent improvement in the initial rate of settling, particularly in the case of iron, the ultimate settled density of the sludge was not increased above that of the "as-received" sample, or, in the order of 20 to 25 percent solids.

TABLE 17. EFFECT OF pH AND METAL IONS ON SETTLING RATE OF JAMAICAN RED MUD

| Volume of red mud, ml | Reagent | Volume of reagent, ml | pH of the mixture | Settling rate, cm/hr | Percent solids in original slurry | Percent solids in sludge after 24 hr |
|-----------------------|--|-----------------------|-------------------|----------------------|-----------------------------------|--------------------------------------|
| 100 | H ₂ SO ₄ | 1.0 | 5.2 | 0.188 | 22.72 | 23.97 |
| 100 | H ₂ SO ₄ | 0.5 | 7.0 | 0.072 | 22.18 | 23.68 |
| 100 | H ₂ SO ₄ | 0.3 | 8.5 | 0.085 | 24.85 | 25.91 |
| 100 | -- | -- | 11.8 | 0.100 | 24.70 | 25.46 |
| * * * * * | | | | | | |
| 75 | 0.1 M Al ₂ (SO ₄) ₃ | 25.0 | 8.0 | 0.080 | 15.03 | 25.28 |
| 50 | 0.01 M Al ₂ (SO ₄) ₃ | 50.0 | 8.0 | 0.148 | 7.25 | 8.14 |
| 75 | 0.1 M FeCl ₂ | 25.0 | 7.5 | 0.789 | 16.94 | 21.79 |
| 75 | 0.1 M MgSO ₄ | 25.0 | 10.5 | 0.12 | 19.56 | 22.60 |
| 100 | H ₂ SO ₄ NaOH (1N) | 4.0 10.0 | 8.0 | 0.075 | 22.61 | 24.07 |

Effect of Synthetic (Polymer) Flocculants

This part of the experimental program was conducted by the Environmental Products Research and Development Group of the Dow Chemical Company under subcontract from Battelle.*

Flocculation due to polymers (or polyelectrolytes) involves adsorption of the polymer with formation of larger aggregated flocs due to a chainlike bridging action. Polymer flocculants are linear or branched high-molecular-weight organic polymers which are water soluble. They are classed according to their ionic character as anionic, cationic, or nonionic, depending on whether their electrical charge is negative, positive, or neutral, respectively.

The flocculation tests made in this program comprised visual observations and optical measurements made when varied quantities of selected flocculants were added to the red-mud sample. Measured volumes of a sample of the suspension were placed in glass containers ("jars") equipped with paddle agitators. Flocculants were then added in measured amounts at prescribed times and agitation conditions. The experimental apparatus comprised six jars arranged as illustrated in Figure 10.

Filtration tests were also made on the flocculated samples. For these tests, the flocculated samples were transferred to a Buchner funnel supported over a graduated cylinder. A record was made of the volume of filtrate collected with time.

In the initial experiments with polymer flocculants, it was noted that the red mud as received formed a gel. The relative effect of different polymers, however, could be determined only by diluting the mud samples.

The initial tests were conducted to establish the proper dilution. These were performed with samples diluted to the following percentage of the as-received samples: 100 (undiluted), 50, 20, 10, 5, and 2 percent. The diluted red-mud suspensions were prepared by dilution with caustic of strength comparable to the original red-mud supernatant. The settling-rate curves for this series of samples are given in Figure 11. It was observed that the 10 percent sample (2.2 percent solids) exhibited a moderate settling rate with a well-defined interface and hence this dilution was selected for all subsequent comparative tests of dewatering agents. The concentration of suspended solids was measured by scattered light and reported in Formazin Turbidity Units (FTU).

*Dow's report on "Dewatering of Red Mud" is available upon request from the United States Environmental Protection Agency, Cincinnati, Ohio.

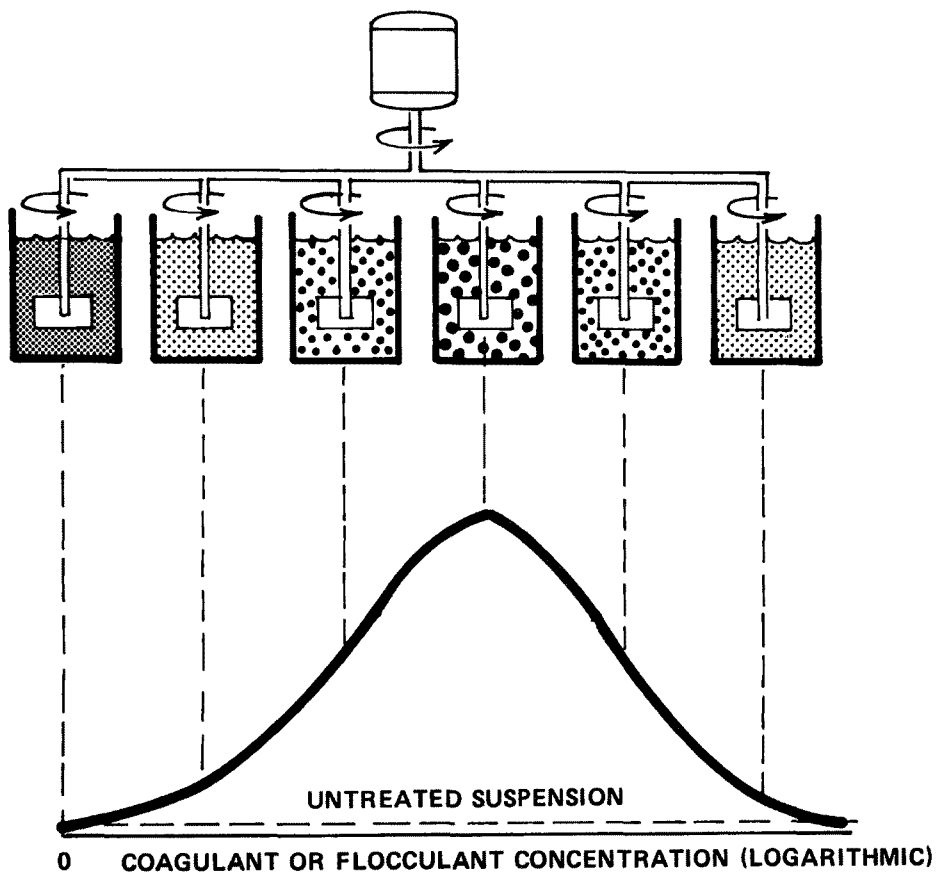


Figure 10. Laboratory evaluation of efficiency of coagulation - the jar test

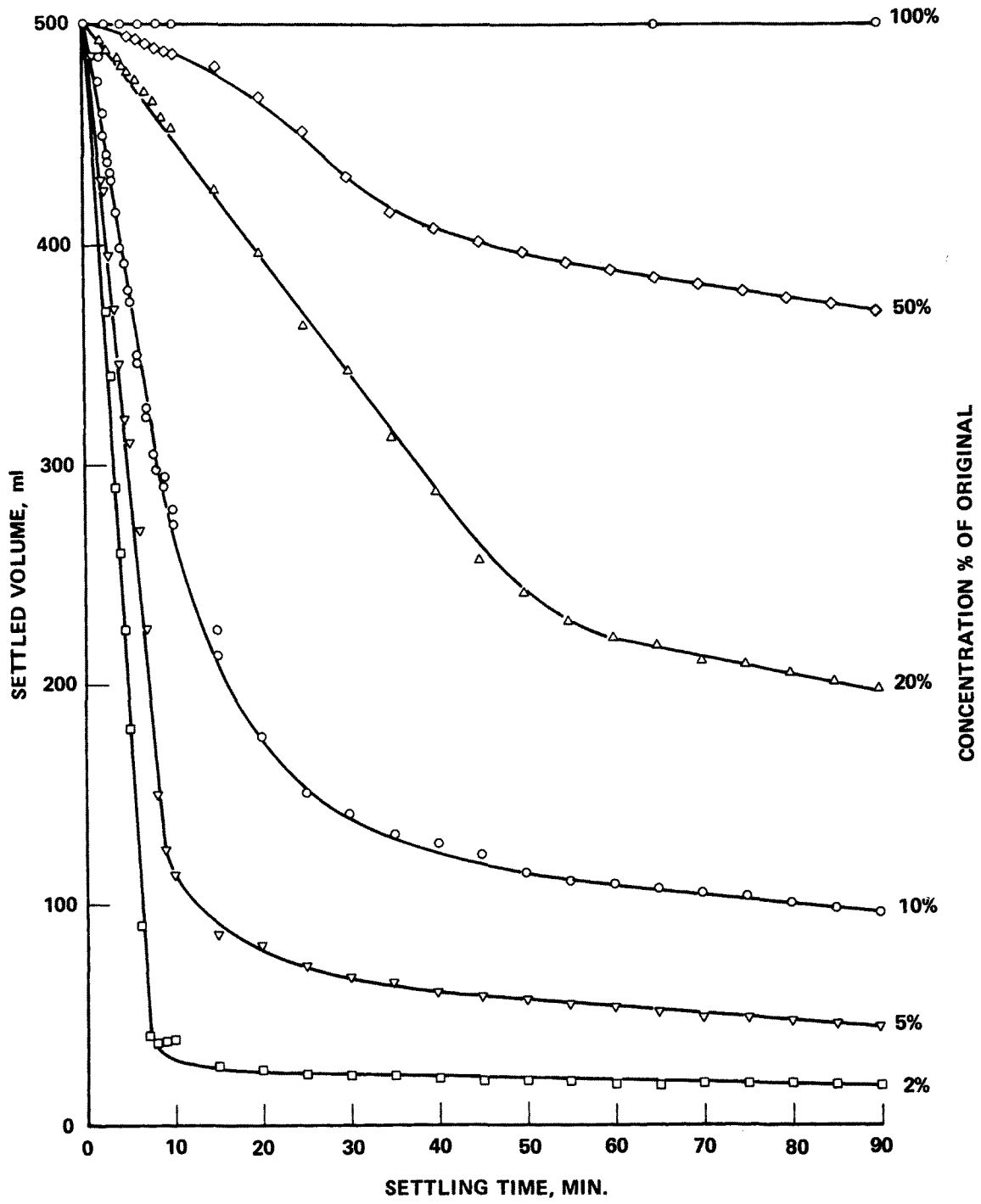


Figure 11. Effect of dilution on settling rate behavior of Jamaican Red Mud

Various synthetic flocculants, listed in Table 18, were tried with the diluted 10 percent red-mud sample. The settling rate and the filtration rate with each flocculant are shown in Figure 12 and Figure 13, respectively. All loadings of flocculants are equal to 0.54 lb/ton of dry solids. Figure 12 shows that anionic and nonionic flocculants are more active than cationic flocculants in effecting settling. The hydrolyzed polyacrylamide (Series III) was most active of all dewatering agents tested for both settling and filtration at this low loading of flocculant.

A few experiments were also conducted at Battelle with undiluted red-mud slurry containing ~22.0 percent solids. The settling-rate experiments using different types of anionic polyelectrolytes indicated that the addition of a synthetic flocculant to the undiluted mud does not significantly improve the settling rate or percent solids of the settled sludge (Table 19).

Magnetic Flocculation

Red mud contains a small amount of free iron and a part of the iron oxide is present as magnetite. A few experiments were conducted to determine whether a magnetic field would affect flocculation. One of the experiments was also conducted with addition of fine magnetite powder (minus 200-mesh size) to the red mud. The results did not show any improvement in the settling behavior or percent solids in the sludge.

Flotation

Flotation of the red mud was performed with two different collectors (an amine and the oleic acid) and frothers (MIBC and cresylic acid). In either case, no segregation of solids was observed in either the froth or the tailings.

Centrifuging

The Kaiser-Gramercy (Jamaican) mud was centrifuged in a laboratory machine at 1000 rpm. The objective was to determine the maximum solids content of a mechanically dewatered mud. Experiments were made with and without addition of a synthetic flocculant (Superfloc C-100).

The centrifuge tubes were 200-ml capacity. These were charged with 100 ml of the mud suspension. Any reagents were added prior to charging. Initial experiments established that compaction was essentially complete after 10 minutes.

The data obtained without reagents and with addition of tallow amine and various amounts of Superfloc C-100 are given in Table 20. The results

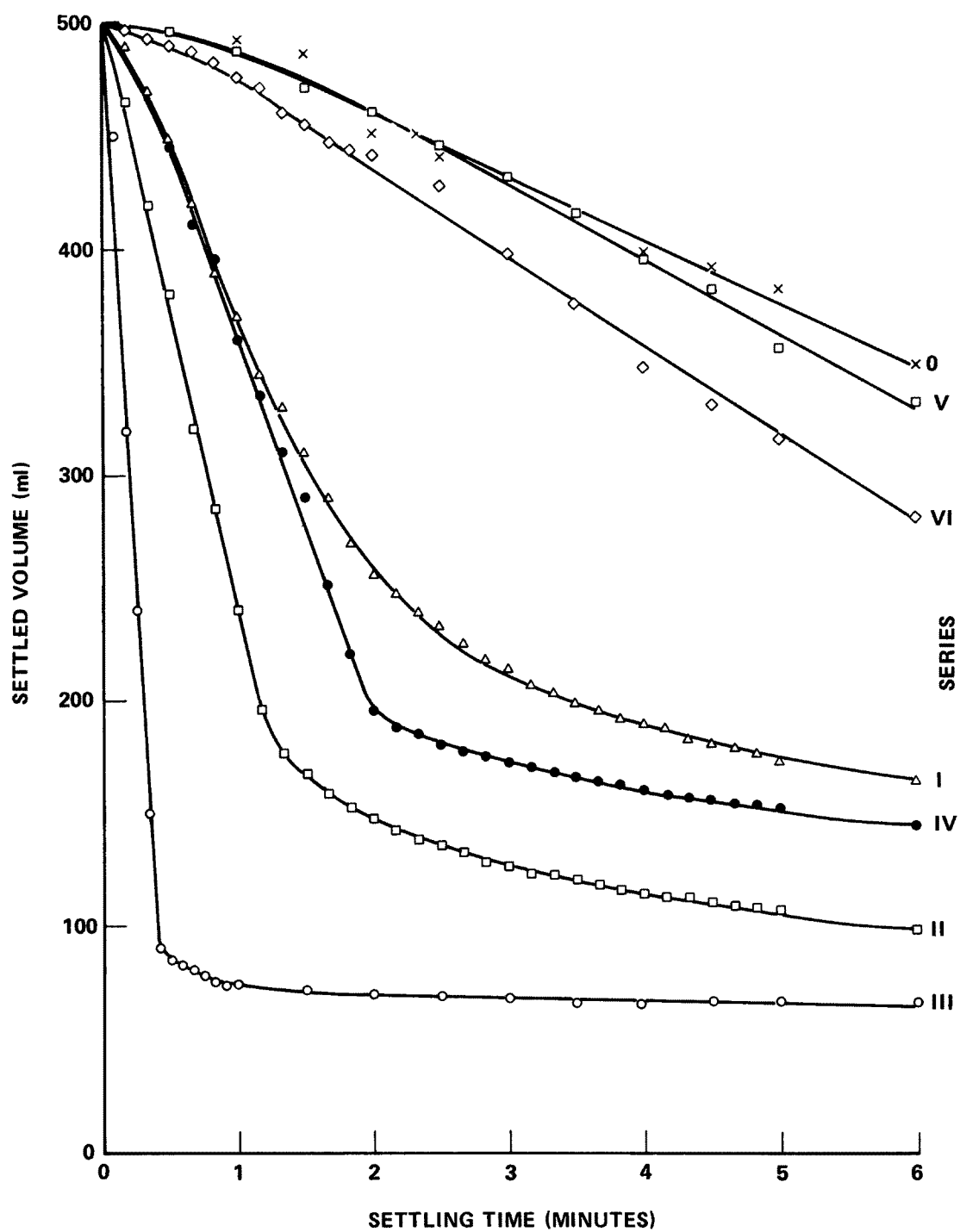


Figure 12. Effect of various synthetic flocculants on the settling rate of diluted (10X) Jamaican Red Mud (Loading of flocculant 0.54 lb/T of solids.)

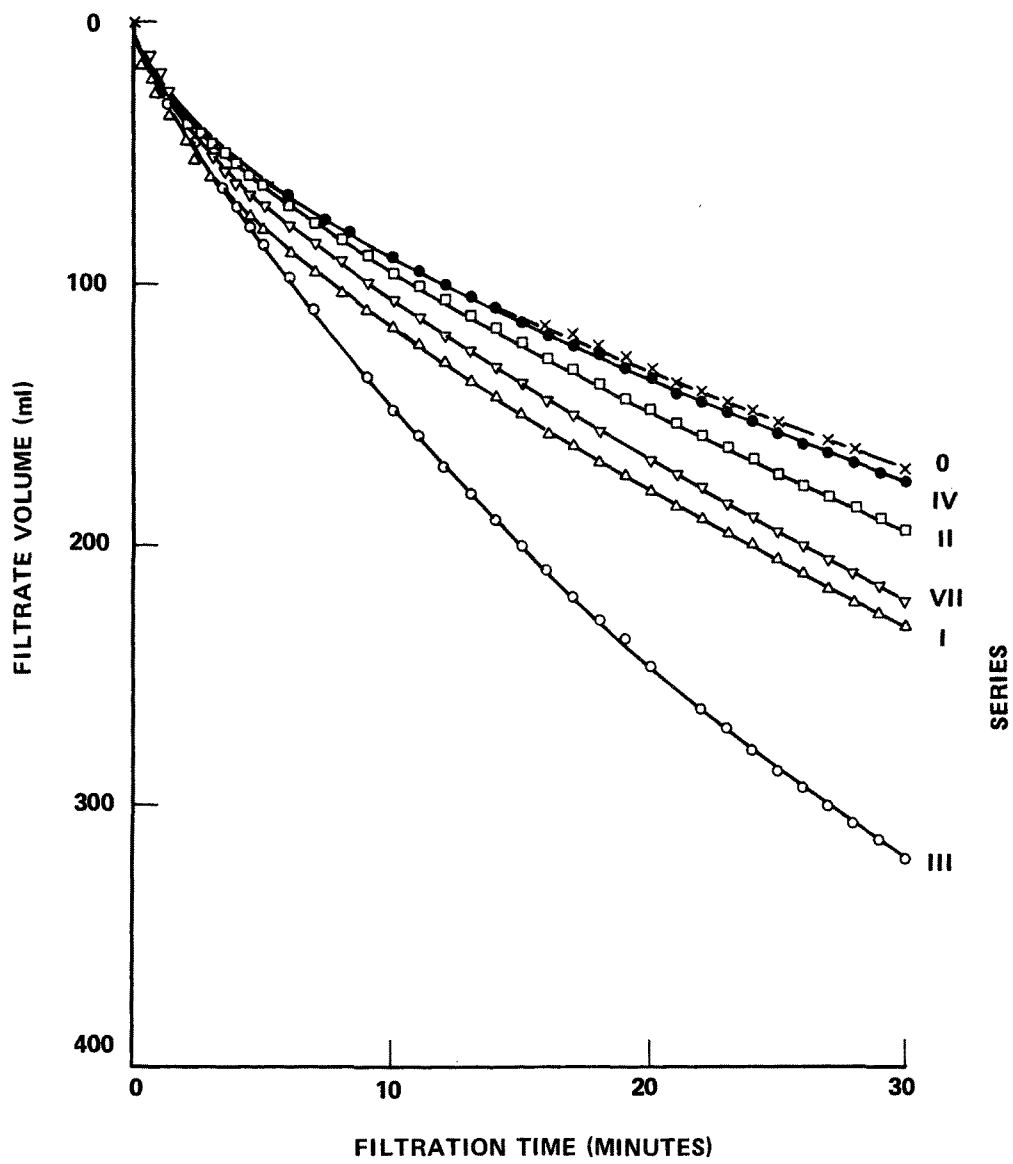


Figure 13. Effect of various synthetic flocculants on filterability of diluted (10X) Jamaican Red Mud (Loading of flocculant 0.54 lb/T of solids.)

TABLE 18. SYNTHETIC FLOCCULANT SELECTED FOR EVALUATION

| Series | Chemical description | Specific product ^(a) | Ionic character |
|--------|------------------------------------|---------------------------------|-----------------|
| I | Sodium Polyacrylate | XFS-4111L | Anionic |
| II | Sodium Polystyrene Sulfonate | Purifloc A21 | Anionic |
| III | Hydrolyzed Polyacrylamide | Purifloc A23 | Anionic |
| IV | Unhydrolyzed Polyacrylamide | Purifloc N20 | Nonionic |
| V | Dimethylaminomethyl Polyacrylamide | Purifloc C41 | Cationic |
| VI | Polyalkylene Polyamine | Purifloc C31 | Cationic |
| VII | Starch Derivative | Flocgel | -- |

(a) All products of Dow Chemical U. S. A. except Flocgel which is produced by W. A. Scholtens Chemische, The Netherlands.

TABLE 19. SETTLING RATE DATA FOR UNDILUTED JAMAICAN RED MUD USING DIFFERENT POLYMER FLOCCULANTS

| Polymer | Amount of polymer | | Settling rate, cm/hr | Percent solids in original slurry | Percent solids in sludge after 24 hr |
|-------------------------------|-------------------|----------------------|----------------------|-----------------------------------|--------------------------------------|
| | Ppm | Lb/ton of dry solids | | | |
| Control (No Polymer Addition) | -- | -- | 0.03 | 22.0 | 25.0 |
| DOW PEI 1090 | 1 | 0.09 | 0.54 | 17.6 | 25.8 |
| DOW PEI 1090 | 5 | 0.50 | 0.60 | 15.1 | 21.2 |
| DOW PEI 1090 | 10 | 0.95 | 1.20 | 12.6 | 17.8 |
| Cyanamid Superfloc C-100 | 5 | 0.50 | 0.16 | 13.2 | 28.4 |
| Cyanamid Superfloc C-100 | 10 | 0.95 | 0.10 | 20.4 | 23.2 |
| Starch (potato) | 100 | 9.5 | 0.22 | 23.0 | 24.2 |

show that a dewatered mud of about 40 percent solids is possible by centrifuging. Addition of flocculants did not appear to provide a means to achieve a higher ultimate solids content, thus indicating that only the free water and not the interstitial (bound) water associated with red mud is removed.

TABLE 20. CENTRIFUGE TEST DATA OF JAMAICAN RED MUD^(a)

| Reagent | Volume of reagent, ppm | Initial percent solids in the slurry | Final percent solids in the sludge |
|-----------------|------------------------|--------------------------------------|------------------------------------|
| -- | -- | 22.80 | 39.00 |
| Tallow amine | 50 | 21.78 | 32.00 |
| Superfloc C-100 | 5 | 18.75 | 37.58 |
| Ditto | 10 | 17.98 | 38.43 |
| " | 20 | 16.72 | 38.20 |
| " | 40 | 15.24 | 37.00 |

(a) Conditions: Centrifuge speed --1000 rpm; time of experiment --10 minutes; volume of mud sample -- 100 ml.

All of the above studies indicate that additional basic research is needed to better understand the mechanisms which limit or control the removal of interstitial water by physical-chemical methods. This will involve study of surface chemistry of various components of red mud, their affinity for water, and the possibility that the hydrophilic surface properties can be altered.

Reductive Roasting of Bauxite as an Alternative to Conventional Bayer Processing

In the Combination Process, calcination of Bayer Process red mud with soda ash and limestone produces the brown mud (a cement-type material), which is much more readily dewaterable and compacts to a high percent solids. On the basis of this, it was speculated that calcination or sintering of Jamaican bauxite before caustic leaching might alter the clay structure of the ore and yield a different type of red mud.

Technology described by Kamlet⁽¹¹⁷⁾ in his patent U. S. 2,964,383 assigned to Reynolds Metals Company is of interest not only because it describes a kiln pretreatment before digestion, but it discloses that if the pretreatment is done under a reducing atmosphere condition, it is possible to reduce the iron in the bauxite to a magnetic form, recoverable by usual magnetic separation methods from the leach residue. Several preliminary experiments were made by Battelle using the Kaiser-Gramercy bauxite (Jamaican) ore as the feed to the process. The laboratory procedure comprised the following sequence of steps:

- (1) Blending the bauxite ore with sufficient sodium carbonate, calcium carbonate, and carbon. The quantities were based on providing sufficient soda to combine with the alumina to form soluble sodium aluminate, sufficient calcium to combine with silica and titania, and adequate carbon to reduce iron oxides to metallic iron.
- (2) Pelletizing the mixture in a balling drum using 10 percent by weight water addition (Experiment 2).
- (3) Firing the mixed material (pellets) in a reducing atmosphere at a temperature of 1000 C (1832 F).
- (4) Comminuting the calcined product and separating the metallic iron by magnetic separation.
- (5) Leaching the residue with an aqueous solution of sodium carbonate to recover the alumina.

The composition used in the experiments was prepared in accordance with the following ratios:

- (1) 1.1 moles of Na_2CO_3 added for each 1.0 mole of Al_2O_3
- (2) 1.0 mole of CaCO_3 added for each 1.0 mole of TiO_2
- (3) 2.0 moles of CaCO_3 added for each 1.0 mole of SiO_2
- (4) Carbon added to amount to 20 percent of the furnace charge.

This part of the experimental program comprised two experiments, which are described below.

Experiment 1 - This experiment was made with a 25-g sample obtained from a ground mixture of bauxite (270 g), sodium carbonate (168 g), calcium carbonate (17 g), and charcoal (121 g). The sample mixture was placed in hollowed-out portion of a 15.24-cm (6 in.)-long and 3.81-cm (1.5 in.)-outside-diameter graphite crucible and heated in an electrically heated tube furnace at 1000 C (1832 F) for 1 hour. The cooled mixture was first leached with 0.1 liter (100 cc) of 10 percent Na_2CO_3 solution and then washed with 1 liter (1000 cc) of hot water. The settling test was performed on the leached residue suspended in water. A Davis tube was used to determine the amount of magnetic iron in the residue. The magnetics and nonmagnetics portions were analyzed separately for iron and Al_2O_3 .

Experiment 2 - In the second experiment, pellets 0.64 cm to 1.27 cm (1/4 in. to 1/2 in.) in size were made from the ground bauxite (890 g), sodium carbonate (550 g), calcium carbonate (54.0 g), and coke (200 g) mixture. The pellets were placed in a 11.43-cm (4.5 in.)-long and 7.62-cm

(3 in.)-diameter refractory crucible and fired in an electrically heated muffle furnace at 1000 C (1832 F) for 1-1/2 hours. Fifty grams of the pellets was then crushed, ground, and leached with 200 cc of 10 percent Na_2CO_3 solution. The settling test was performed on the leached solids while suspended in liquor and also in wash water. The Davis tube test was made as before to separate magnetic iron. Analyses of typical products are provided in Tables 21 and 22.

The material balances for the two experiments are listed in Table 23. In the second experiment, emphasis was placed on the settling behavior of solids in pregnant liquor and the leaching of the sample was not completed.

The chemical analyses of the head bauxite sample and other samples obtained at each stage of the sintering process are given in Tables 21 and 22. The overall test data indicated approximately 85 percent recovery of the total available alumina.

Figure 14 shows the settling-rate curves for the mud obtained in the present sinter method test and the red mud obtained in the conventional Bayer Process supplied by the Kaiser plant. Data for the settling rates and percent solids obtained in the sludge for the two muds are given in Table 24.

Note that the settling rate of the mud obtained from the roasted ore experiment is approximately four times higher than that of the conventional red mud. However, the compaction of the mud as measured by the percent solids in the sludge after 24 hours showed no increment in either case.

In general, the preliminary investigations indicated that the soda-lime-sinter process may offer limited potential to reduce the severity of the red-mud problem. The recovery of iron in a magnetic concentrate was only about 30 percent of the iron content of the bauxite. Moreover, the magnetic concentrate was not sufficiently high in iron to be used in ironmaking furnaces. These aspects, however, may be improved with study.

Such a procedure, however, would entail significantly higher energy costs and possibly a need to pelletize the feed to prevent excessive dusting. Moreover, the amount of caustic required may be more than that required for the conventional system. It is not likely that such front-end processing could be implemented without a major change in existing Bayer Process plants.

TABLE 21. CHEMICAL ANALYSES OF PRODUCTS OBTAINED BY THE REDUCTIVE ROASTING OF BAUXITE (EXPERIMENT 1)

| Product | Weight percent | | | |
|-----------------------|--------------------------------|-------|------------------|------------------|
| | Al ₂ O ₃ | Fe | SiO ₂ | TiO ₂ |
| Head sample (bauxite) | 54.10 | 12.20 | 0.64 | 2.44 |
| Sintered mixture | -- | 8.20 | 0.98 | -- |
| Leached liquor | 4.91 ^(a) | -- | -- | -- |
| Iron concentrate | 21.40 | 41.40 | 4.40 | -- |
| Nonmagnetic residue | 10.60 | 18.70 | 3.96 | 3.60 |

(a) Grams/liter.

TABLE 22. CHEMICAL ANALYSES OF PRODUCTS OBTAINED BY THE REDUCTIVE ROASTING OF BAUXITE (EXPERIMENT 2)

| Product | Weight percent | | | |
|-----------------------|--------------------------------|-------|------------------|------------------|
| | Al ₂ O ₃ | Fe | SiO ₂ | TiO ₂ |
| Head sample (bauxite) | 54.10 | 12.20 | 0.64 | 2.44 |
| Sintered pellets | 43.40 | 11.10 | 1.36 | 2.52 |
| Leached liquor | 15.78 ^(a) | -- | -- | -- |
| Iron concentrate | 33.90 | 26.00 | 1.70 | 5.30 |
| Nonmagnetic residue | 32.30 | 19.00 | 1.76 | 4.21 |

(a) Grams/liter.

TABLE 23. METALLURGICAL WEIGHT BALANCE FOR IRON AND Al_2O_3 OBTAINED IN REDUCTIVE ROASTING OF BAUXITE

| Experiment | Sample | Weight of sample, g | Assays (total weight) | |
|------------|------------------------------------|---------------------|-----------------------|---------------|
| | | | Fe, g | Al_2O_3 , g |
| I | Head sample mixture ^(a) | 25 | 2.05 | 6.27 |
| I | Magnetic concentrate | 0.5 | 0.2 | 0.10 |
| I | Nonmagnetic concentrate | 5.3 | 1.0 | 0.57 |
| I | Leached liquor | -- | -- | 5.40 |
| I | Accountability, % | | 63.0 | 96.8 |
| I | Recovery, % | | 10.0 | 86.0 |
| II | Head sample pellets ^(b) | 50 | 5.55 | 21.7 |
| II | Magnetic concentrate | 6.4 | 1.64 | 2.15 |
| II | Nonmagnetic concentrate | 19.2 | 3.65 | 6.45 |
| II | Leached liquor | -- | -- | 8.80 |
| II | Accountability, % | | 95.0 | 80.0 |
| II | Recovery, % | | 30.0 | 40.0 |

(a) Sample was taken from a 576-g mixture of bauxite (270 g), solution carbonate (168 g), calcium carbonate (17 g), and charcoal (121 g).

(b) Sample was taken from a 1690-g mixture of bauxite (890 g), sodium carbonate (550 g), calcium carbonate (540 g), and coke (200 g) pellets.

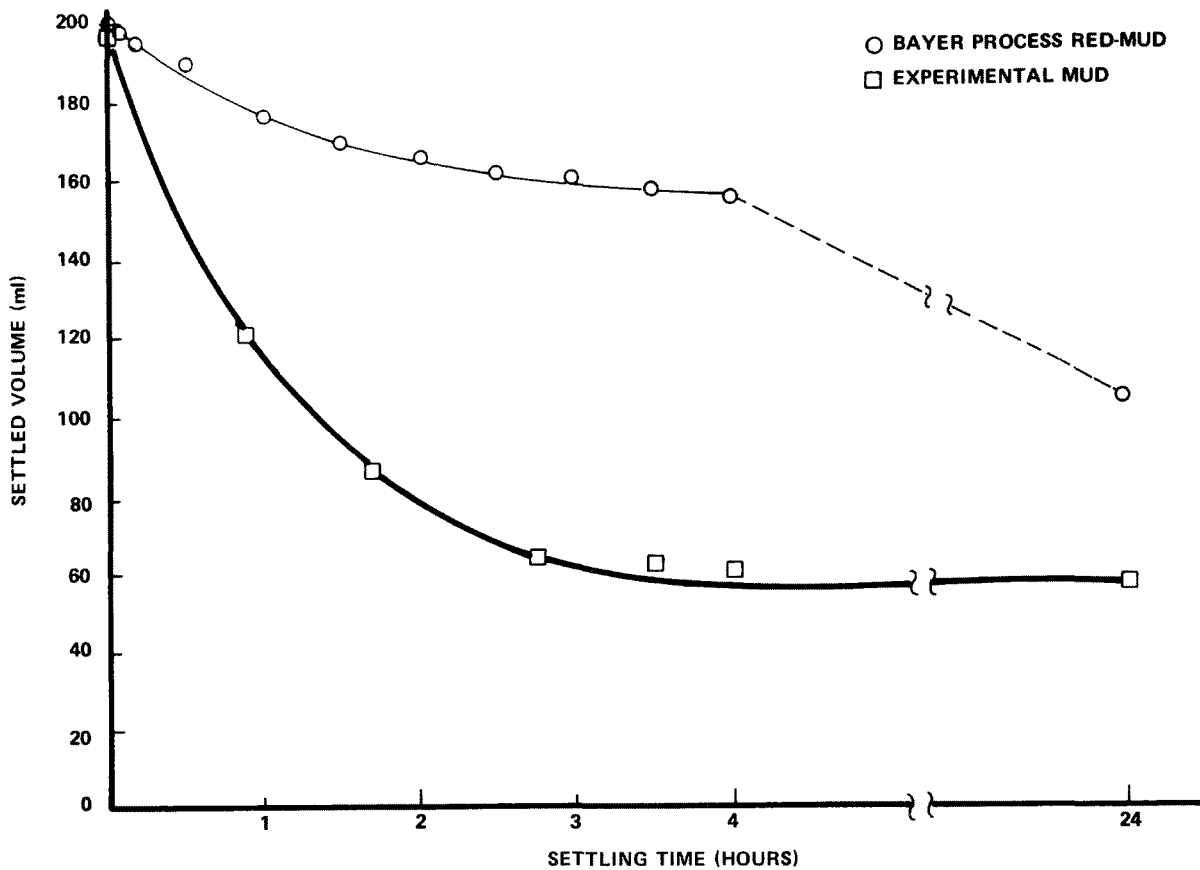


Figure 14. Settling rate curves for the reductive roasting of bauxite process mud (9.7% solids) and the Jamaican Red Mud (11.7% solids) slurries (no flocculant added)

TABLE 24. SETTLING RATE TESTS DATA FOR THE REDUCTIVE ROASTING PRODUCT MUD AND THE JAMAICAN RED MUD

| Mud type | Settling rate, cm/hr | Initial percent solids in slurry | Final percent solids in sludge after 24-hr settling |
|------------------------------------|----------------------|----------------------------------|---|
| Conventional Bayer Process red mud | 3.43 | 11.71 | 22.20 |
| Sinter method experimental mud | 14.63 | 9.70 | 28.50 |

SECTION VII

LITERATURE CITED

- (1) Development Document for Effluent Limitations Guidelines and New Source Performance Standards for "Bauxite Refining Subcategory of the Aluminium Segment of the Nonferrous Metals Manufacturing," EPA Report EPA-440/1-74-019C, March, 1974.
- (2) Rushing, J. C. Alumina Plant Tailings Storage, Vol. II -Light Metals 1973, Proceed. of Sessions 102nd AIME Annual Meeting, Chicago, Illinois, A. V. Clark, Editor, 1973.
- (3) Vogt, M. F. and D. L. Stein, Dewatering of Large Volume Aqueous Slurries; Sand Bed Filtration of Bauxite Residue, paper to be presented at Annual AIME Meeting, Las Vegas, Nevada, February, 1976.
- (4) Vogt, M. F. Development Studies on Dewatering Red Mud, paper presented at the 103rd Annual Meeting of the AIME, February, 1974, Dallas, Texas.
- (5) Fulda, W. Preparation of Pure Alumina From Solutions of Bauxite in Dilute NaOH. Metall. 1948:397-9, 1948.
- (6) Takemoto, M. and S. Kishimoto. Continuous Extraction of Alumina. Japan 3963, July 24, 1951.
- (7) Maricic, S. and M. Mihalic. Extractibility of Bauxite by the Bayer Process and the Solubility of the Aluminum Components. Arhiv Kem. (25):241-9, 1953.
- (8) Holder, G. Alumina From Bauxite. Ger. 1,022,572, January 1958.
- (9) Dunn, R. C. Extraction of Alumina From Its Ores. U.S. 2,785,956, March 19, 1957.
- (10) Manufacture of Aluminum by the Bayer Process. Societe d'electrochimie, d'electrometallurgie et des acieries electriques d'Ugine. Fr. 1,010,384, June 10, 1952.
- (11) Plass, L. Leaching of Bauxite With Aqueous Sodium Hydroxide. Ger. Offen. 2,307,922, August 29, 1974.

- (12) Soudan, P. and H. Mercier. Continuous Digestion of European Bauxite in Alkaline Solutions. U.S. 3,095,280, June 25, 1963.
- (13) Juhasz, A., L. Nagy, I. Ottohal, I Penzes, G. Sigmond, J. Steine, L. Vetek, F. Vidovszky and K. Wentzely. Continuous Digestion of Bauxite With Sodium Hydroxide. Hung. 149,514, June 15, 1962.
- (14) Vol'f, F. F. and A. M. Rozenberg. Polytherms of the Lixiviation of the "Kransnaya Shapochka" Bauxite Deposits and Investigations of the Low Moduli of Aluminate Solutions. Trudy Vsesoyuz. Nauch.-Issledovatel. Inst. Issledovaniyu i Proektirovaniyu Alyuminievoi i Elektrodnoi Prom. 1940 (20):16-21, 1940.
- (15) Bauermeister, G. and W. Fulda. The Bayer Process (for Purification of Bauxite). Aluminum (25):97-100, 1943.
- (16) Mal'ts, N. S. Advantages of Increasing the Bauxite Leaching Temperature in the Bayer Process. Tsvet. Metal. (USSR). 44(7):34-7, 1971.
- (17) Bauermeister, G. Determination of the Stability Limits of NaAlO_2 Solutions Between 74° and 94° . Aluminium (23):205-8, 1941.
- (18) Mooney, C. L. Recovery of Alumina From Alumina-Containing Ores. U.S. 2,559,653, July 10, 1951.
- (19) Maricic, S. and M. Mihalic. The Degree of Extraction of Bauxite in the Bayer Process and the Solubility of the Aluminum Component. Arhiv Kem. (25):241-9, 1953.
- (20) Scholder, R. Alumina From Bauxite, U.S. 2,181,669, November 28, 1940.
- (21) Antipin, P. F., M. N. Smirnov, and A. I. Svistunov. Aluminum Oxide. U.S.S.R. 67,916, February 28, 1947.
- (22) Malyshev. M. F., N. N. Tikhonov, M. N. Smirnov, G. A. Panasko, and A. B. Bykova. Preparation of Aluminum Oxide From Bauxite. U.S.S.R. 196,751, May 31, 1967.
- (23) Belyaev. A. I. and M. A. Kolenkova. Leaching Bauxite at High Pressures. Sbornik Nauch. Trudov, Moskov. Inst. Tsvetnykh Metal. i Zolota im. M. I. Kalinina. (26):120-31, 1957.
- (24) Wolf, N. H. Leaching Alumina From Its Ores With Alkali and a Boron Compound. U.S. 3,094,378, June 18, 1963.

- (25) Bernshtein, V. A. and E. A. Matsenok. Leaching of Boehmitic Bauxite With Lime Addition and Peculiarities of Slime Sedimentation. Tr. Vses. Nauchn. -Issled. Alyumin. -Magnievyi Inst. (46):24-30, 1960.
- (26) Kompaneets, M. F., K. A. Pustovalova, R. A. Sabitov, V. N. Dement'ev, and M. A. Smyshlyaeva. Lowering the Loss of Alkali With Red Mud. U.S.S.R. 161,494, March 19, 1964.
- (27) Starostina, K. M. and V. A. Pazukhin. The Effect of Calcining Bauxite Upon the Recovery of Alumina by the Autoclave Method. Sbornik Nauch. Trudov Moskov. Inst. Tsvetnykh Metal. i Zolota. (24):104-16, 1954.
- (28) Coles, H. L. Production of Alumina From Bauxite. U.S. 2,283,849, May 19, 1942.
- (29) Yasuo, K. An Improvement on the Preparation of Alumina by the Bayer Process. Japan 2227, May 8, 1951.
- (30) Derevyankin, V. A. and S. I. Kuznetsov. Utilization of Lignin Additives in the High-Temperature Leaching of Bauxite (250° and Higher). Khim. i Tekhnol. Glinozema, Inst. Met. i Obogashch., Akad. Nauk Kozakh. SSR, Tr. Vses. Soveshch., Alma-Ata. 23-4, 1959.
- (31) Commonwealth Aluminum Corp. Ltd. Extraction of Aluminum Oxide. Neth. 6,408,485, February 1, 1965.
- (32) Gebefuegi, I. Aluminum Hydroxide From Bauxite. Fr. 1,475,776, April 7, 1967.
- (33) Svejda, Z., P. Klan, and I. Poduskova. Hydrothermal Decomposition of Bauxites. Czech. 131,481, March 15, 1969.
- (34) Poduskova, I. and P. Klan. Alumina From Diasporic Bauxites. Czech. 142,638, September 15, 1971.
- (35) Feher, I., M. Orban, Z. Osvald, K. Solymar, I. Voros, and J. Zambo. Reducing or Compensating for Sodium Hydroxide Loss Produced During Alumina Manufacture. Fr. Demande 2,166,188, September 14, 1973.
- (36) Alumina Manufacture From Bauxite. Montecatini Societa generale per L'industria mineraria e chimica. Ital. 580,979, August 18, 1959.
- (37) Water-Soluble Aluminates From Aluminum Ore Such as Bauxite, "Montecatini." Societa Generale per l'industria Mineraria e chimica. Brit. 884,671, December 13, 1961.

- (38) Soudan, P. Alumina. Pechiney-Compagnie des Produits chimiques et Electrometallurgiques. Ger. 1,115,725, February 10, 1959.
- (39) Klan, P. Production of Alumina by Alkaline Digestion at High Temperatures and Pressures. Bauxite, Alumina, Alum., Proc. Int. Symp. ICSOBA, 2nd 1969. (Pub. 1971).
- (40) Orban, Mrs. F., F. Orban, T. Pinter, G. Sigmond, P. Siklosi, K. Solymar, P. Toth, and J. Zambo. Processing Bauxites Containing Goethite. Hung. Teljes 6,758,28, August, 1973.
- (41) Gould, R. F. Alumina From Low-Grade Bauxite. Ind. Eng. Chem. (37):796-802, 1945.
- (42) Skobeev, I. K. Extracting Alumina From Low-Quality Bauxite. Nauchn. Tr. Irkutskogo Politekhn. Inst. (19):218-28, 1963 (Russ).
- (43) Flint, E. P., W. F. Clarke, E. S. Newman, L. Shartsis, D. L. Bishop, and L. S. Wells. Extraction of Alumina From Clays and High-Silica Bauxites. J. Research Natl. Bur. Standards. (36):63-106, 1946.
- (44) Grigor'eva, G. D. and N. I. Eremin. Effect of the Reducing Agent on Bauxite Cake Properties. Tr. Vses. Nauch.-Issled. Proekt. Inst. Alyum., Magn. Elek. Prem. (Russ). (73):43-6, 1970.
- (45) Lileev, I. S., V. S. Volkov, and V. A. German. Producing Alumina From Bauxites by Fusion With Soda. Sbornik Rabot Lab. Gosudarst. Inst. Prikladnoi Khim. (32):179-99, 1940.
- (46) Dobos, D. Further Technological Development of Bayer Alumina Production with the Simultaneous Extraction of Iron. Tsvet. Metal. (Russ). 41(5):60-7, 1968.
- (47) Calhoun, W. A. and H. E. Powell, Jr. Investigation of Low-Grade Bauxites as Potential Sources of Aluminum by Caustic Desilication and Alumina Extraction. U.S. Bur. Mines, Rept. Invest. 5042, 23 pp, 1954.
- (48) Devereux, W. C. and W. E. Prytherch. Alumina From Aluminous Materials. Brit. 515,000, May 6, 1942.
- (49) Barlot, J. Alumina Extraction From Bauxites or Silicate Materials. Fr. 1,251,226, September 30, 1957.
- (50) Lanyi, B. Continous Processing of Bauxite. Femipari Kutalo Intezet Kozlemenyei. 5-28, 1956.

- (51) Schrader, R., H. Rump, R. Kressner, and K. Hoffmann. Alumina From Bauxite and Bauxite-Like Minerals. Ger. (East) 50,059, October 15, 1966.
- (52) VEB Chemiewerk "Albert Zimmermann". Alumina Production. Fr. 1,494,483, September 8, 1967.
- (53) Solymar, K. and S. Zsindely. The Effect of Organic Matter When Manufacturing Al_2O_3 With the Bayer Process. Freiburger Forschungsh. 103B:61-80, 1965 (Ger).
- (54) Matyasi, J. and K. Nemeth. Decreasing the Organic-Matter Content of Alumina Manufacturing Plant Liquors. Femipari Kutato Intezet Kozlemenyei. 4:83-92, 1961.
- (55) Matthes, F. and H. Bach. Organic Substances in Bauxite and Effects on the Bayer Process. Chem. Tech. (Berlin). 14(10):610-13, 1962.
- (56) Oku, T., K. Yamada, T. Harato, and H. Kato. Removal of Organic Compounds in Bauxite. Japan Kokai 72 21,395, October 3, 1972.
- (57) Kobayashi, S. Roasting Bauxite for Removal of Organic Matters. Japan Kokai 73 39,317, June 9, 1973.
- (58) Korotich, V. I. and V. V. Mikhailov. Agglomeration of Sulfur-Bearing Bauxites. Trudy Ural. Politekh. Inst. im. S. M. Korova. (73):5-22, 1958.
- (59) Tkacheva, Z. S. The Use of Sodium Sulfate in the Production of Alumina. Materialy Vsesoyuz. Soveshchaniya po Khim. i Tekhnol. Glinozema, Akad. Nauk SSSR, Sibir, Otdel., Novosibirsk. 195-203, 1958.
- (60) James, W. A. Alumina. Can. 461,024, November 15, 1949.
- (61) Leiteizen, M. G., A. A. Bitner, and P. Ya. Kiselev. Removal of Silica From a Bauxite Pulp Before Leaching. U.S.S.R. 190,359, December 29, 1966.
- (62) Archibald, F. R. Extraction of Alumina. U.S. 2,604,379, July 22, 1952.
- (63) Mariassy, M. Methods for the Elimination of Salt Contaminants in the Manufacture of Alumina. Kohnszati Lapok. 90:126-9, 1957.
- (64) Juhasz, A. Removal of Salt Impurities in Alumina Manufacture by the Bayer Process. Kohaszati Lapok. 91:161-8, 1958.

- (65) Perezel, A. and I. Miklos. Effects of the Zinc Content in Bauxite on the Products of Alumina Manufacture by the Bayer Process and on the Aluminum (Produced Therefrom). *Femipari Kutato Intezet Kozlemenyei*. 4:103-15, 1960.
- (66) Pickens, R. A. Bauxite Beneficiation. *Brit.* 563, 015, July 27, 1944.
- (67) Prasad, S. S. and S. B. Rao. Beneficiation of Bauxite. Recent Develop. Nonferrous Metals Technol., Pap. Discuss. Symp. 1968. 1:38-40 (Eng).
- (68) Ishchenko, V. V., V. M. Korus, and F. F. Fedyaev. Physicochemical Interaction of Bauxite-Forming Minerals With Flotation Reagents. *Nauch.-Tekh. Konf. Ural. Politekh. Inst.* (1):10-11, 1973 (Russ).
- (69) Clemmer, J. B., B. H. Clemmons, and R. H. Stacy. Preliminary Report on the Flotation of Bauxite. U. S. Bur. Mines, Rept. Investigations 3586, 26 pp, 1941.
- (70) Fedyaev, F. F., V. M. Korus, and A. A. Golovin. Gravitation-Magnetic Beneficiation of Bauxites. *Nauch.-Tekh. Konf., Ural. Politekh. Inst.*, 4th. (1):11-12, 1973 (Russ).
- (71) Kuznetsov, V. P., E. N. Gulin, and G. G. Balashova. Photometric Beneficiation of Kaolinite-Hydragillite Bauxites. *Tsvet. Metal.* (2):75-6, 1973 (Russ).
- (72) Parker, V. I., E. P. Sekharova, L. G. Simakova, and V. E. Lifirenko. Efficient System for Producing Alumina From Highly Ferruginous Bauxites. *Tsvetn. Met.* (12):65-9, 1974 (Russ).
- (73) Blake, H. E., Jr., O. C. Fursman, A. D. Fugate, and L. H. Banning. Adaptation of the Pedersen Process to the Ferruginous Bauxites of the Pacific Northwest. U.S. Bur. Mines, Rept. Invest. 6939, 21 pp, 1967.
- (74) Miller, J. and A. Irgens. Alumina Production by the Pedersen Process, History and Future. *Light Metals, Proc.*, 103d AIME Annu. Meet. 1974. (3):789-99 (Eng).
- (75) Fursman, O. C., H. E. Blake, Jr., and J. E. Mauser. Recovery of Alumina and Iron From Pacific Northwest Bauxites by the Pedersen Process. U.S. Bur. Mines, Rept. Invest. No. 7079, 22 pp. 1968.
- (76) Aluminum Laboratories Ltd. Improvements in the Production of Alumina. *Brit.* 642, 943, September 13, 1950.

- (77) Graefe, J., C. Kelch, and H. Roederer. Flocculants for Red Mud. (Deutschi Maizena Werk G.m.b.H.) Ger. Offen. 2, 158, 130, November 24, 1971.
- (78) Hollo, J., J. Szejtli, E. Laszlo, G. S. Gantner, Zs. Toth, J. Huszar, and A. Lux. The Importance and Degradation of Starch in the Bayer Process. I. The Action of the Starch. Tech. Univ., Budapest, Hung. Staerke. 16(4):118-22, 1964.
- (79) Hollo, J., E. Laszlo, J. Szejtli, and A. Lux. Importance and Degradation of Starch in the Bayer Process. III. Distribution of Starch and Its Degradation Products. Staerke. 17(2):36-40, 1965.
- (80) Nemeth, K., J. Matyasi, and F. Orban. Effect of Flour Solutions, Prepared in Alkaline or Alkali-Free Medium, on the Sedimentation of Red Sludge (in Alumina Manufacture). Kohiszati Lapok. 94:97-100, 1961.
- (81) Buravlev. T. T., A. A. Lyashenko, I. T. Slyusarov, and A. I. Golubova. Precipitation of Red Slime From Aluminate Solutions by the Bayer Method. III. Zh. Prikl. Khim. 40(3):487-92, 1967.
- (82) Wolf, F., H. Kramer, and L. Eckert. Modifying the Rate of Sedimentation of Red Mud in the Bayer Process. Chem. Tech. (Leipzig). 22(9):550-2, 1970.
- (83) Silina, E. I., T. M. Zlokazova, and M. G. Zolotareva. Research and Industrial Study of Polyacrylamide Flocculant in the Production of Alumina. Tsvetn. Metal. 37(12):44-6, 1964.
- (84) Sibert, F. J. Alumina. (Nalco Chemical Co.) S. African 68 02, 757. 15 pp. October, 1968.
- (85) Sullivan, E. J. Alumina. (Dow Chemical Co.) Ger. 1, 177, 626. 3 pp. September 10, 1964.
- (86) Atlas Chemical Industries, Inc. High-Molecular-Weight Sodium Acrylate Polymers Containing a Major Proportion of Water-Soluble Polymer. Brit. 1, 260, 206, 6 pp. January 12, 1972.
- (87) Ismatov, Kh. R., A. A. Rakhimov, and T. P. Rasulov. Use of Reagents K-4 and K-6 in Settling of Red Mud. Tsvet. Metal. 39(9): 63-4, 1966.
- (88) Werner, P. E. Settling Red Mud From Suspensions of Bauxite in Caustic Solutions. (Rohm and Haas Co.) S. African 67 01, 885. 12 pp. August 20, 1968.

- (89) Tsukawaki, M. and Y. Inamoto. Refining Alumina by Alkali Treatment of Minerals. (Kao Soap Co., Ltd.) S. African 71 05, 673. 17 pp. March 22, 1972.
- (90) Skobeev, I. K. Adaptation of Coagulants During a Thickening of Red Mud. Nauchn. Tr. Irkutskogo Politekhn. Inst. (19):121-35, 1963.
- (91) Sibert F. J. Improved Separation Rate of Dispersed Red Mud From Dissolved Alumina. (Nalco Chemical Co.) U.S. 3, 445, 187. 3 pp. May 25, 1966.
- (92) Sibert, F. J. Rapid Method of Removing Red Muds During Alumina Preparation. (Nalco Chemical Co.) S. African 69 02, 471. 15 pp. October 15, 1969.
- (93) Novozhenov, V. M. and S. I. Kuznetsov. Settling of Red Mud in Alumina Production. Tsvet. Metal. 39(9):58-62, 1966.
- (94) Novozhenov, V. M., S. I. Kuznetsov, and V. A. Derevyankin. Settling of Red Muds. Khim. Tekhnol. Glinozema, Tr. Vses. Soveshch. (Russ) (4):445-9, 1965.
- (95) Vasil'ev, V. N., A. S. German-Galkina, and G. A. Chemezova. Effect of the Clay Fraction of Bauxite on the Precipitation of Red Mud. Tr. Inst. Met. Obogashch., Akad. Nauk Kaz. SSR (USSR). 1970(37): 62-4, 1970.
- (96) Chu, Y. and Ping Tung Wang. Effect of Calcium Oxide on Aluminum Ore Roasting and Red Mud Sedimentation. (Taiwan Alum. Corp., Taiwan) Taiwan Lu Yeh Ku Fen Yu Ilsten Kung Szu Yen Chun Chan Kung Tso Pao Kao. 55-64, 1974.
- (97) Makary, I., P. Nagy, and T. Pinter. Rapid Settling of Red Mud From Sodium Aluminate Lye. Hung. Teljes 4004. 8 pp. April 28, 1972.
- (98) Gol'dman, M. M., I. A. Yakubovich, N. P. Paskhin, V. N Vasil'ev, B. S. Povazhnyi, G. P. Poenebesnyi, and L. V. Bunchuk. Pilot Plant Test on Densification of Red Mud by Polyacrylamide. Tr. Inst. Met. Obogashch. Akad. Nauk Koz. SSR (USSR). 41:65-60, 1971.
- (99) Oida, H., M. Miki, and T. Hasegawa. Treatment of Red Mud Suspensions. (Sumitomo Chemical Co., Ltd.) Japan 69 24, 892. 3 pp. October 21, 1969.
- (100) Kobayashi, S., M. Ichiki, M. Ishii, and T. Sato. Separating the Solid and Liquid of a Red Mud Suspension. (Mitsui Mining and Smelting Co., Ltd.) Japan 74 18, 558. 3 pp. May 10, 1974.

- (101) Derevyankin, V. A., V. M. Novozhenov, E. M. Il'yashevich, and S. I. Kuznetsov. Effect of Washing on the Settling Rate of Red Mud in Alumina Production. *Tsvetn. Metal.* 38(9):55-8, 1965.
- (102) Takemoto, M. Separation of Red Mud From Sodium Aluminate. (Nisson Chemical Industries Co.) Japan 501, February 13, 1951.
- (103) Maier, A. A., N. S. Mal'ts, A. A. Lapin, and P. V. Yashchunin. Coagulating Red Mud. U.S.S.R. 323, 364, December 10, 1971.
- (104) Cook, G. W. Rapid Settling of Mud Impurities From Sodium Aluminate Solutions. (Reynolds Metals Co.) U.S. 3, 127, 239. 5 pp. March 31, 1964.
- (105) Murphy, J. M. and P. W. Bolmer. Freezing and Melting Treatment of Red Mud Slurries to Aid Solid Separation. (Kaiser Aluminum and Chemical Corp.) U.S. 3, 714, 792. 5 pp. February 6, 1973.
- (106) Dumay, S. The Influence of the Processing Temperature on the Settling of the Red Mud. *Femipari Kutato Intezet Kozlemenyei.* 29-66, 1956.
- (107) German-Galkina, A. S., T. M. Zlokazova, V. P. Mel'nikova, and V. V. Sidorenko. The Use of Hydrocyclones Together With Thickeners for Separation of Solids in Leaching Alumina-Bearing Sinter. *Tsvetnye Metally* 34:52-4, 1961.
- (108) Good, P. C. and O. C. Fursman. Centrifugal Dewatering of Jamaican Red Mud. U.S. Bur. of Mines, R. I. 7140, June, 1968.
- (109) Polyakov, L. N. and I. K. Skobeev. Filtration of Red Muds (Bayer Process). *Obogashch. Met. Polez. Iskop.* 27-9, 1970.
- (110) Kaempf, F. Experience With the Use of Drum Filters for the Filtration of Red Mud. *Int. Leuhtmetalltag.*, 5th. 356-60, 1968.
- (111) Plaetschke, H. Separation of Red Mud With Rotary Filters. *Bauxite, Alumina, Alum.*, Proc. Int. Symp. ICSOBA, 2nd (1969) 3:181-5, 1971.
- (112) Konig, P. Filtering Red Mud in Alumina Plants With a Vacuum Drum Filter With a Stripping Cylinder. *Banyasz. Kohasz. Lapok, Kohasz.* 106(6):282-5, 1973.
- (113) Martine, J. L., Jr. Filtration of Alkali Metal Aluminate Solutions. (Aluminum Co. of America) U.S. 2, 822, 091, February 4, 1958.

- (114) Fursman, O. C., J. E. Mauser, M. O. Butler and W. A. Stickney. Utilization of Red Mud From Alumina Production. U. S. Bur. Mines, Report Invest. 7454, November, 1970.
- (115) Calhoun, W. A., and T. E. Hill, Jr. Metallurgical Testing of Hawaiian Ferruginous Bauxites. Concluding Report U. S. Bur. Mines, Report Invest. 6944, 1967.
- (116) Colombo, U., and G. Sironi. Iron Sponge From Bayer Process Red Slurry. U.S. 3,295,961. 6 pp. January 3, 1967.
- (117) Kamlet, J. Processing of Ferruginous Aluminum Ores. U.S. 2,964,383, December 13, 1960.
- (118) Guccione, E. Red Mud, A Solid Waste Can Now Be Converted to High-Quality Steel. Eng. Mining J. 172(9):136-8, September, 1971.
- (119) Papp, Elemer. Possibilities of Recovery of Rare Elements From Bauxites During Alumina Production by the Bayer Process. Freiburger Forschungsh. B67, 117-30, 1962.
- (120) Friedrich, V. Production of Vanadium Slag From Bauxite Red Mud. Tech. Dig. 9(7):443-4, 1967.
- (121) Gerisch, S., H. Martens and S. Ziegenbalg. Winning of Vanadium From By-Product of Bauxite Treatment. Neue Huette. 14(4):204-10, April, 1969.
- (122) Urvacya, G. D. Slurry Wastes in the Metallurgical Industry and Their Utilization. Khim.-Met. Inst., 62-114, 1964.
- (123) Beisher, R. V. Use of the Tikhvin Alumina Plant Bauxite Mud in Highway Construction. Inzh.-Stroit. Inst., 8-17, 1968.
- (124) Mitsugi, T. Fluidizing Calcination of Red Mud. Tohoku Daigaku Senko Seiren Kenyusho Iho, 18, 61-73, 1962.
- (125) Katayama, S. and Yoshikaya Horiguchi. Utilization of Red Mud. I-Effects of Red Mud on the Properties of Cements. Rika Gaku Kenkyusho Hokoku, 37, 101-105, 1961.
- (126) Katayama, S. and Yoshikoya Horiguchi. Utilization of Red Mud. II-Effects of the Addition of Red Mud on the Properties of Cements. Rika Gaku Kenkyusho Hokoku, 39, 407-410, 1963.
- (127) Katayama, S. Utilization of Red Mud. V. Physical Tests of Cements Blended With Calcined Red Mud. Rika Gaku Kenkyusho Hokoku, 40, 194-202, 1964.

- (128) Horiguchi, Y. and S. Katayama. High Early-Strength Blended Cement. Japan 16, 984, 2 pp. October 20, 1962.
- (129) Szekely, Istvan. Cement Production by Using the Red Sludge of the Bauxite Industry, *Epitoanyag*, 12, 28-37, 1960.
- (130) Szekely, I. Ore Cements From Red Mud. Proc. Conf. Silicate Inds., 6th. Budapest, 399-408, 1961.
- (131) Bayer, G., E. Cherdron, M. Haerter, and E. Hecht. Bricks From Red Mud. Ger. 2, 063, 028, June 29, 1972.
- (132) Tauber, E., R. K. Hill, D. N. Crook, and M. J. Murray. Red Mud Residues From Alumina Production as a Raw Material for Heavy Clay Products. J. Aust. Ceram. Soc., 7, 12-17, 1971.
- (133) Hegenbarth, R. Experiments in the Utilization of Red Mud. Aluminum 48, 748-750, 1972.
- (134) Ishihara M., K. Takada, and Y. Yamanashi, Synthetic Lightweight Aggregate. Japan, 74, 60, 324, June 12, 1974.
- (135) Expanded Clay, Kloeckner-Humboldt: Deutz A.G. Fr. 1, 503, 121, November 24, 1967.
- (136) Wargalla, Gerhard. Use of Red Mud in the Production of Cement and Expanded Clay. *Erzmetall* 26(1): 18-20 (1973).
- (137) Tacken, J., Production of Porous Clay Ceramics. Ger. 1, 224, 655, September 8, 1966.
- (138) Hayashi, S. and K. Kato. Lightweight Concrete With High Mechanical Strength. Japan, 74 52, 213, May 21, 1974.
- (139) Funke, Armin, H. Wetzels, and G. Buhler. Rubber Fillers From Red Mud. Ger. (East) 19, 854, September 20, 1960.
- (140) Filler for Rubber Compositions. Fr. 978, 108, April 10, 1951.
- (141) Ketomo, A. G. Treating Natural and Synthetic Rubber. Swiss 274, 574, July 2, 1951.
- (142) Foerster, Herbert. Concrete Color Composition. Ger. (East), 57, 543, August 20, 1967.

- (143) Hahnel, K. O. Red Mud as Raw Material for Colored Glass. Glasstech. Ber. 76, 174-175, 1953.
- (144) Ramanujam, S. Bauxite Residues as (Corrosion) Inhibitive Primers. Paintiudia 12, 22-34, 1962.
- (145) Oda, N. Agricultural Pesticide. Japan 5650 (51), September 21, 1951.
- (146) Motte and Pomot. Protecting Insecticides Against the Action of Light. Fr. 848,974, November 9, 1939.
- (147) Whittaker, C. W., W. H. Armiger, P. P. Chichilo, and W. M. Hoffman. Brown Mud From the Aluminum Industry as a Soil Liming Material. Soil Sci. Soc. Amer., Proc., 19, 288-292, 1955.
- (148) Ramanujam, S. and R. V. Saluja. Primers Based on Red Mud. Indian 81, 431, April 11, 1964.
- (149) Worzella, Gerhard. Bituminous Mixtures Containing Treated Bauxite Residues. Brit. V1110168, April 18, 1968.
- (150) Kasai, J. and K. Fukurr. Surface Treated Quicklime. Japan 74, 49, 899, May 15, 1974.
- (151) Watanabe, T. Zeolitic Potassium Fertilizer From Red Mud. Japan 12, 622, September 3, 1960.
- (152) Hofmann, H., K. H. Reisner, S. Meyer, E. Friedrich, and E. Guenther. Treating Red Mud. Ger. (East) 67, 721, July 5, 1969.
- (153) Retezar, A., L. Pechy, and G. Gardos. Leaching of the Red Sludge. Veszpremi Vegyipari Egyetem Kozlemenyei, 2, 213-217, 1958.
- (154) Karpenko, Z. S., Kh. N. Nurmagambetov, Yu. Khaliullin, and V. D. Ponomarev. Regeneration of Alkali From Bayer Red Slime of Turgai Bauxites. Met. i Obogashch., 1, 3-7, 1965.
- (155) Sudzilovskaya, M. S. and E. V. Robozheva. Kinetics of Destructive Hydrogenation of Coal. VNIGI, 6, 30-45, 1959.
- (156) Tabuchi, K. Sulfide Catalyst for Obtaining Ethane and Ethylene From Mixed Gases. Japan 72 08,012, March 8, 1972.
- (157) Suzuki, N. Refractory Cement Additives. Japan 73 38, 609, November 19, 1973.

- (158) Machlet, A. W. Surfacing Metallic Articles. U.S. 2, 551, 957, May 8, 1951.
- (159) Edward II, Ellis. Chlorinated Copper as Treatment of Sewage at Kingston-on-Thames. Surveyor, 106, 195-196, 1947.
- (160) Hayashi, S. and Matsui, F. Hardenable Foam-Generating Compositions. Japan, 73 36, 941, November 8, 1973.
- (161) Heyd, Ferdinand. Use of Sludge From Alumina Production From Iron-Containing Bauxite in Coke Manufacture. Czech. 93, 355, January 15, 1960.
- (162) Land, G. W. Controlling Sulfur Dioxide Emissions From Coal Burning. Nat. Eng. 73(1):6-8, 1969.
- (163) Myers, J. G., and J. H. Field. Absorbent for Removing Sulfur Oxides From Gases. U.S. 3, 580, 702. 6 pp. May 25, 1971.
- (164) Shultz, F. G. and J. S. Berber. Hydrogen Sulfide Removal From Hot Producer Gas With Sintered Absorbents. J. Air Pollut. Contr. Ass. 20(2):93-6, 1970.
- (165) Kazantsev, E. I., E. K. Stepanenko, and A. N. Gerasimenko (USSR). Removal of Arsenic From Waste Waters by Sorption. Tsvet. Metal. 45(1):18-20, 1972 (Russ).
- (166) Bayer, G., and E. Cherdron. Red Mud Flocculant for Waste Water Treatment. Ger. Offen. 2, 242, 811. 9 pp. March 14, 1974.

SECTION VIII

GLOSSARY

ALUMINA

Any of several forms of aluminum oxide, Al_2O_3 , occurring naturally as corundum, in a hydrated form in bauxite, and with various impurities as ruby, sapphire, and emery.

BAYER PROCESS

Process in which impure alumina in bauxite is dissolved in a hot, strong, alkali solution, normally NaOH , to form sodium aluminate which upon diluting and cooling hydrolyzes, forming a precipitate of pure aluminum hydroxide.

BAUXITE

A commercial ore for alumina, which is an impure mixture of earthy hydrous aluminum oxides and various metal oxides, e.g., iron, titanium, rare earths, etc.

BROWN MUD

The final solid waste remaining after the alumina is leached from the calcined red mud in the combination process.

CALCINATION

The roasting or burning of any substance to bring about physical or chemical changes.

CAUSTIC SODA

The sum of free NaOH and the NaOH combined as NaAlO_2 , expressed as Na_2CO_3 .

CENTIMETER (cm)

0.3937 inch.

CLEAR WATER LAKE

Nominally the lake relatively free of alkalinity and other dissolved solids used as a fresh-water reservoir for a bauxite refinery.

COMBINATION PROCESS

Variation of Bayer Process used for high silica ores, in which the red mud from the first-stage Bayer Process is calcined with soda ash and lime and leached to recover additional alumina.

CONTINUOUS COUNTERCURRENT DECANTATION (CCD)

A continuous system of washing finely divided solids, such as red muds, to free them from liquids containing dissolved substances. In practice, the fresh water and the solids slurry start at opposite ends and move counter-currently to each other, so that the fresh water contacts the solid to remove soluble substances away from it.

DEWATERING

Physical separation of water from sludge by the application of an external force.

DIGESTER

Pressure vessel or autoclave in which the alumina is dissolved from the bauxite.

FRENCH DRAIN

An underground passageway (through gravity) for liquid through the interstices of sand and gravel layer and collected in perforated pipes.

FILTER CAKE

The solids collected on a mechanical filter surface when a solids suspension is filtered.

FLOC

Collections of smaller particles agglomerated into larger, more easily settleable particles through chemical or physical treatment.

FLOCCULANT

A reagent which induces flocculation of suspended solids.

FLOCCULATION

The agglomeration of suspended solids by adding a flocculant, thereby forming larger aggregate flocs that are easily removed by sedimentation.

FLOTATION

A process for separating suspended particles from a solution by introducing air bubbles which carry the particles to the surface where they are removed.

GPM

Gallons per minute.

GREEN LIQUOR

The aluminum-bearing solution from the bauxite digesters before further processing.

HINDERED SETTLING (Sedimentation)

Sedimentation that is affected by interactions among suspended particles at high concentrations or between particles and vessel walls.

IMPOUNDMENT

A natural or artificial, usually open, body of water from which surface water could be reused.

JAR TEST

A laboratory procedure for evaluating flocculation and sedimentation processes in a series of parallel comparisons.

LITER

1000 cubic centimeter.

MAGNETIC SEPARATION

A physical treatment process for removing magnetic suspended solids from a liquid by applying a magnetic field.

MICRON

0.0001 cm (10^{-6} meter).

mg/l

Milligrams per liter. Nearly equivalent to parts per million concentration.

MUD LAKE

The diked reservoir (tailing pond) used to impound mud.

pH

A measure of the alkalinity or acidity of a solution, in terms of the negative logarithm of the hydrogen-ion $\langle H^+ \rangle$ concentration (mol/l); neutral = pH 7 = 10^{-7} mol $\langle H^+ \rangle$ /l; acidic pH < 7; basic pH > 7.

POLYMER

Any synthetic organic compound having a high molecular weight and composed of repeating chemical units (monomer).

ppm

Parts per million, a unit of concentration.

PRECIPITATION

The conversion of dissolved solids into suspended solids.

PREGNANT LIQUOR

Solution containing the metal values prior to their removal and recovery.

PROCESS LAKE

Reservoir used for process water; often in closed circuit with part of process; not used for mud disposal.

RECYCLE

To return water after some type of treatment for further use, generally implying a closed system.

RED MUD

The final solid waste remaining after the alumina is leached from the bauxite.

SAND FILTER

A bed of sand through which liquid is passed to remove fine suspended particles from it.

SEDIMENT

Any solid phase settling out of a liquid phase.

SEDIMENTATION

Solid-liquid separation resulting from the application of an external force, usually under the force of gravity.

SLUDGE

Any solid material containing entrained water.

SLURRY

Suspension of solids in a liquid.

SUPERNATANT

The liquid remaining above the settled sludge after sedimentation.

TURBIDITY

Any suspended solids imparting a visible haze or cloudiness to water.

APPENDIX A: LITERATURE REFERENCES BY CATEGORY

BAUXITE REFINING

Bayer Process

- A-1. Vol'f, F. F. and A. M. Rozenberg. Polytherms of the Lixiviation of the "Krasnaya Shapochka" Bauxite Deposits and Investigations of the Low Moduli of Aluminate Solutions. Trudy Vsesoyuz. Nauch. - Issledovatel. Inst. Issledovaniyu i Proektirovaniyu Alyuminievoi i Elektrodnoi Prom. 1940. (20):16-21, 1940.
- A-2. Scholder, R. Alumina From Bauxite, Etc. U.S. 2,181,669, November 28, 1940.
- A-3. Bauermeister, G. Determination of the Stability Limits of NaAlO_2 Solutions Between 74° and 94° . Aluminium (23):205-8, 1941.
- A-4. Bauermeister, G. and W. Fulda. The Bayer Process (for Purification of Bauxite). Aluminium (25):97-100, 1943.
- A-5. Antipin, P. F., M. N. Smirnov, and A. I. Svistunov. Aluminum Oxide. U.S.S.R. 67,916, February 28, 1947.
- A-6. Fulda, W. Preparation of Pure Alumina From Solutions of Bauxite in Dilute NaOH. Metall. 1948:397-9, 1948.
- A-7. Mooney, C. L. Recovery of Alumina From Alumina-Containing Ores. U.S. 2,559,653, July 10, 1951.
- A-8. Takemoto, M. and S. Kishimoto. Continuous Extraction of Alumina. Japan 3963, July 24, 1951.
- A-9. Sugimoto, S., et al. Extraction of Alumina. Japan 2228, May 8, 1951.
- A-10. Maricic, S. and M. Mihalic. Extractibility of Bauxite by the Bayer Process and the Solubility of the Aluminum Components. Arhiv Kem. (25):241-9, 1953.
- A-11. Maricic, S. and M. Mihalic. The Degree of Extraction of Bauxite in

- the Bayer Process and the Solubility of the Aluminum Components. Arhiv Kem. (25):241-9, 1953.
- A-12. Kosugi, C. and T. Nakamura. Alumina. Japan 2474, June 2, 1953.
- A-13. Holder, G. Alumina from Bauxite. Ger. 1,022,572, January 16, 1958.
- A-14. Dunn, R. C. Extraction of Alumina From Its Ores. U.S. 2,785,956, March 19, 1957.
- A-15. Alumina From Bauxite. Societe d'electrochimie, d'electrometallurgie et des acieries electriques d'Ugine. Fr. 1,010,385, June 10, 1952.
- A-16. Vol'pin, P. I. and N. S. Mal'ts. Alumina. U.S.S.R. 132,208, October 5, 1960.
- A-17. Manufacture of Aluminum by the Bayer Process. Societe d'electrochimie, d'electrometallurgie et des acieries electriques d'Ugine. Fr. 1,010,384, June 10, 1952.
- A-18. Soudan, J. and P. Soudan. Dissolving Alumina from Bauxites. Fr. 1,280,009, April 6, 1962.
- A-19. Carr, A. R. Chemical Engineering Operations in the Production of Alumina. Proc. Symp. Chem. Eng. Met. Ind., Edinburgh (Eng). 65-70, 1963.
- A-20. Malyshev, M. F., N. N. Tikhonov, M. N. Smirnov, G. A. Panasko, and A. B. Bykova. Preparation of Aluminum Oxide From Bauxite. U.S.S.R. 196,751, May 31, 1967.
- A-21. Oprea, Fl., M. Ienciu, and N. Panait. Processing of Bauxites by Alkaline Methods. Rev. Chim. (Bucharest). 22(6):342-6, 1971.
- A-22. Mal'ts, N. S. Advantages of Increasing the Bauxite Leaching Temperature in the Bayer Process. Tsvet. Metal. (USSR) 44(7):34-7, 1971.
- A-23. Plass, L. Leaching of Bauxite with Aqueous Sodium Hydroxide. Ger. Offen. 2,307,922, August 29, 1974.
- A-24. Coles, H. L. Production of Alumina from Bauxite. U.S. 2,283,849, May 19, 1942.
- A-25. Yasuo, K. An Improvement on the Preparation of Alumina by the Bayer Process. Japan 2227, May 8, 1951.

- A-26. Schonfelder, H. and H. Ginsberg. Alumina From High-Silica Bauxite. U.S. 2,939,765, June 7, 1960.
- A-27. Donaldson, D. J. Alumina. U.S. 2,946,658, July 26, 1960.
- A-28. Belyaev, A. I. and M. A. Kolenkova. Leaching Bauxite at High Pressures. Sbornik Nauch. Trudov. Moskov. Inst. Tsvetnykh Metal. i Zolota im. M. I. Kalinina. (26):120-31, 1957.
- A-29. Starostina, K. M. and V. A. Pazukhin. The Effect of Calcining Bauxite Upon the Recovery of Alumina by the Autoclave Method. Sbornik Nauch. Trudov Moskov. Inst. Tsvetnykh Metal. i Zolota. (24):104-16, 1954.
- A-30. Derevyankin, V. A. and S. I. Kuznetsov. Utilization of Lignin Additives in the High Temperature Leaching of Bauxite (250° and Higher). Khim. i Tekhnol. Glinozema, Inst. Met. i Obogashch., Akad. Nauk Kozakh. SSR, Tr. Vses. Soveshch., Alma-Ata. 23-4, 1959.
- A-31. Wolf, N. H. Leaching Alumina From Its Ores With Alkali and a Boron Compound. U.S. 3,094,378, June 18, 1963.
- A-32. Soudan, P. and H. Mercier. Continuous Digestion of European Bauxite in Alkaline Solutions. U.S. 3,095,280, June 25, 1963.
- A-33. Bernshtein, V. A. and E. A. Matsenok. Leaching of Boehmitic Bauxite With Lime Addition and Peculiarities of Slime Sedimentation. Tr. Vses. Nauchn.-Issled. Alyumin.-Magnievyi Inst. (46):24-30, 1960.
- A-34. Timfoldgyar, A. Continuous Digestion of Bauxite With Sodium Hydroxide. Hung. 149,514, June 15, 1962.
- A-35. Sato, H., T. Mitsugu, and T. Hamada. Extraction of Alumina From Bauxite. Japan 26,154, December 11, 1963.
- A-36. Commonwealth Aluminum Corp. Ltd. Extraction of Aluminum Oxide. Neth. 6,408,485, February 1, 1965.
- A-37. Kompaneets, M. F., K. A. Pustovalova, R. A. Sabitov, V. N. Dement'ev, and M. A. Smyshlyaeva. Lowering the Loss of Alkali With Red Mud. U.S.S.R. 161,494, March 19, 1964.
- A-38. Gebefuegi, I. Aluminum Hydroxide From Bauxite. Fr. 1,475,776, April 7, 1967.

- A-39. Dobos, D. Further Technological Development of Bayer Alumina Production with the Simultaneous Extraction of Iron. *Tsvet. Metal.* (Russ). 41(5):60-7, 1968.
- A-40. Svejda, Z., P. Klan, and I. Poduskova. Hydrothermal Decomposition of Bauxites. *Czech.* 131,481, March 15, 1969.
- A-41. Poduskova, I. and P. Klan. Alumina From Diasporic Bauxites. *Czech.* 142,638, September 15, 1971.
- A-42. Osvald, Z. and K. Solymar. Processing Bauxites Containing Diaspore. *Hung. Teljes* 2177, July 2, 1971.
- A-43. Abramov, V. Ya., T. A. Dudko, N. A. Makarov, N. M. Kontorovich, and G. G. Pestova. Increased Effectiveness of the Flow-Type Leaching of Bauxite Sinter Cakes. *Tsvet. Metal. (USSR).* 45(4):32-4, 1972.
- A-44. Johnson, A. F. Alumina From Bauxite. U.S. 3,632,310, January 4, 1972.
- A-45. Yamada, Y., Y. Takenaka, and M. Watanabe. Dissolving Bauxite. *Japan. Kokai* 72 18,797, September 16, 1972
- A-46. Feher, I., M. Orban, Z. Osvald, K. Solymar, I. Voros, and J. Zambo. Reducing or Compensating for Sodium Hydroxide Loss Produced During Alumina Manufacture. *Fr. Demande* 2,166,188, September 14, 1973.
- A-47. Vislyakova, L. F., G. G. Zav'yalova, and A. I. Savchenko. Increase in the Extraction of Alumina From Bauxites. *Tsvet. Metal. (Russ).* (2):44-5, 1974.
- A-48. Schepers, B., W. Meusel, R. Haerberlein, and H. Loos. Aluminum Oxide From Bauxite by Modified Bayer Process. *Ger. Pend.* 2,329,547, January 2, 1975.

Lime-Soda Sinter Process

- A-49. de Vecchis, I., and O. E. Ramuz. Treatment of Bauxites. U.S. 2,637,628, May 5, 1953.
- A-50. Ponomarev, V. D., L. P. Ni, and V. S. Sazhin. Combined Method of Complex Treatment of Titanium-Bearing High-Silica and High-Iron Bauxites. *Tsvetnye Metally* 33(5):44-8, 1960.

- A-51. Mansurova, Z. R. Processing Low-Quality Bauxites Into Alumina. Tr. Sredneaziat. Nauch. -Issled. Inst. Geol. Miner. Syr'ya. (7):208-12, 1966 (Russ).
- A-52. Gould, R. F. Alumina From Low-Grade Bauxite. Ind. Eng. Chem. (37):796-802, 1945.
- A-53. Flint, E. P., W. F. Clarke, E. S. Newman, L. Shartsis, D. L. Bishop, and L. S. Wells. Extraction of Alumina From Clays and High-Silica Bauxites. J. Research Natl. Bur. Standards (36):63-106, 1946.
- A-54. Howat, D. D. Production of Alumina. Mine & Quarry Eng. (12):41-6, 1946.
- A-55. Mazel, V. A., M. P. Sokolovskii, and B. Kh. Shvartsman. Production of Alumina From Bauxite by the Sintering Method. Legkie Metally, Leningrad, Sbornik. (4):33-7, 1957.
- A-56. Rozentreter, R. G., N. S. Berseneva, and A. A. Goryunova. Sintering and Leaching of Sinters Obtained by Reductive Toasting of Bayer Slimes. Tr. 3-go (Tret'ego) Vses. Soveshch. po Khim. i Tekhnol. Glinozema, Erevan. 111-20, 1964 (Russ).
- A-57. Skobeev, I. K. Extracting Alumina From Low-Quality Bauxite. Nauchn. Tr. Irkutskogo Politekhn. Inst. (19):218-28, 1963 (Russ).
- A-58. Pavlov, L. N. Leaching Bauxite Sinter. Tsvetn. Metal. 37(8):47-9, 1964 (Russ).
- A-59. Lecis, P., and A. Guidi. Pyrogenic Attack on Bauxite. Ext. Met. Aluminum (1):231-49, 1963.
- A-60. Goloduoi, O. V., N. I. Eremin, M. M. Zorikov, V. A. Mazel, P. I. Sokolov, V. Ya. Tumarinson, Yu. G. Khavkin, E. I. Khodorov, and V. R. Sapiro. Preparation of Aluminate Cake From Alumina-Containing Charges. U.S.S.R. 213,004, March 12, 1958. Izabret., Prom. Obraztsy, Tovarnye Zuaki. 45(10):27, 1968.
- A-61. Grigor'eva, G. D., and N. I. Ermin. Effect of the Reducing Agent on Bauxite Cake Properties. Tr. Vses. Nauch. -Issled. Proekt. Inst. Alyum., Magn. Elek. Prom. (Russ). (73):43-6, 1970.
- A-62. Fedyaev, F. F., G. P. Mededev, S. I. Kuznetsov, and V. F. Stepanova. Effect of Some Iron Minerals on the Sintering of Bauxite With Limestone and Soda. Izv. Vyssh. Uchebn. Zaved., Tsvetn. Metall. (Russ). (1):135-8, 1975.

- A-63. Manoilov, K. E. Properties of Porous Aluminate Briquets and Their Diffusion Leaching. *Tsvetnye Metal.* (7):79-85, 1940.
- A-64. Lileev, I. S., V. S. Volkov, and V. A. German. Producing Alumina From Bauxites by Fusion With Soda. *Sbornik Rabot Lab. Gosudarst. Inst. Prikladnoi Khim.* (32):179-99, 1940.
- A-65. Yamaguchi, T. The Production of Alumina by the Sintering Process in The Rotary Kiln. I. Mixing Ratio of Soda and Lime and the Sintering Temperature. *Prov. Faculty Eng., Keiogijuki Univ.* 1(1):1-12, 1948.
- A-66. Lecis, P. Complex Utilization of Hungarian Bauxites, Pyrogenic Processing of Bauxite. *Industrial Procedures. Comments. Femip. Kut. Intez. Kozlem (Italy)* (9):69-75, 1971.
- A-67. Skobeev, I. K. The Problem of Extracting Aluminum Oxide From Low-Quality Bauxites. *Nauchn. Tr. Irkutskogo Politekhn. Inst.* (19):218-28, 1963.
- A-68. Ponomarev, V. D., L. P. Ni, V. S. Sazhin, M. N. Smirnov, P. V. Strel'nikov, K. Z. Vydrevich, A. E. Montvid, A. I. Krvm, M. F. Purits, and A. A. Agranovskii. Aluminum From Highly Siliceous Bauxite. U.S.S.R. 116,775, January 19, 1959.
- A-69. Bernshtein, V. A. The Process of Leaching Diaspore Bauxites With Soda and Lime. *Trudy Vsesoyuz. Nauch. -Issledovatel. Alyumin. -Magn. Inst.* (39):75-86, 1957.
- A-70. Cservenjak, F. J., J. Ruppert, and D. E. Garen. Extraction of Alumina From High-Iron Bauxites. U.S. Bur. Mines, Rept. Invest. 4299, 29 pp, 1948.

Pedersen Method

- A-71. Diettrich, O. Recovery of Alumina From Alumina- and Silica-Containing Materials. *Ger.* 824,197, December 10, 1951.
- A-72. Blake, H. E., Jr., O. C. Fursman, A. D. Fugate, and L. H. Banning. Adaptation of the Pedersen Process to the Ferruginous Bauxites of the Pacific Northwest. U.S. Bur. Mines, Rept. Invest. 6939, 21 pp, 1967.
- A-73. Aluminum Laboratories Ltd. Improvements in the Production of Alumina. *Brit.* 642, 943, September 13, 1950.
- A-74. Miller, J., and A. Irgens. Alumina Production by the Pedersen

Process, History and Future. *Light Metals, Proc.*, 103rd AIME Annu. Meet. 1974. (3):789-99.

- A-75. Fursman, O. C., H. E. Blake, Jr., and J. E. Mauser. Recovery of Alumina and Iron From Pacific Northwest Bauxites by the Pedersen Process. U.S. Bur. Mines, Rept. Invest. 7079, 22 pp, 1968.

Bauxite Beneficiation

- A-76. Runke, S. M., and R. G. O'Meara. Beneficiation of Arkansas Bauxite. *Am. Inst. Mining Met. Engrs.*, Tech Pub. No. 1698, 9 pp, 1944.
- A-77. Pickens, R. A. Bauxite Beneficiation. *Brit.* 563,015, July 27, 1944.
- A-78. Clemmer, J. B., B. H. Clemmons, and R. H. Stacy. Preliminary Report on the Flotation of Bauxite. U.S. Bur. Mines, Rept. Invest. 3586, 26 pp, 1941.
- A-79. Laurie, A. P., and P. Spence & Sons Ltd. Separation of Alumina From Silica and Silicates. *Brit.* 672,216, May 14, 1952.
- A-80. Prasad, S. S., and S. B. Rao. Beneficiation of Bauxite. Recent Develop. Non-Ferrous Metals Technol., Pap. Discuss. Symp. 1968. 1:38-40.
- A-81. Fedyaev, F. F., V. M. Korus, and A. A. Golovin. Gravitation-Magnetic Beneficiation of Bauxites. *Nauch. -Tekh. Konf., Ural. Politekh. Inst.*, 4th. (1):11-12, 1973 (Russ).
- A-82. Kuznetsov, V. P., E. N. Gulin, and G. G. Balashova. Photometric Beneficiation of Kaolinite-Hydragillite Bauxites. *Tsvet. Metal.* (2):75-6, 1973 (Russ).
- A-83. Ishchenko, V. V., V. M. Korus, and F. F. Fedyaev. Physicochemical Interaction of Bauxite-Forming Minerals With Flotation Reagents. *Nauch. -Tekh. Konf. Ural. Politekh. Inst.* (1):10-11, 1973 (Russ).
- A-84. Fedyaev, F. F., V. M. Korus, and V. I. Fedoseev. Magnetic Beneficiation of Bauxites in Aluminate Solutions. *Tsvet. Metal.* (10):61-2, 1973 (Russ).
- A-85. Lyushnya, L. M., P. I. Andreev, Yu. A. Bykov, N. M. Anishchenko, and A. A. Safonova. Beneficiation of Unconditioned Ukrainian Bauxites. *Obogashch. Polez. Iskop.* (13):3-9, 1973.

- A-86. Kuznetsov, V. P., and Yu. F. Sokolov. Bauxites Which Need Beneficiation. *Tsvet. Metal.* (6):73-5, 1974 (Russ).
- A-87. Fedyaev, F. F., V. M. Korus, S. I. Kuznetsov, G. P. Medvedev, and A. A. Golovin. Concentration Capability of Hydrargillite Bauxites According to the Gravitation-Magnetic Scheme of the Ural Polytechnic Institute. *Izv. Vyssh. Uchebn. Zaved., Tsvetn. Metall.* 17(4):16-22, 1974 (Russ).
- A-88. Parker, V. I., E. P. Sekharova, L. G. Simakova, and V. E. Lifirenko. Efficient System for Producing Alumina From Highly Ferruginous Bauxites. *Tsvetn. Met.* (12):65-9, 1974 (Russ).

Alternative (New) Methods

- A-89. Devereux, W. C., and Wm. E. Prytherch. Alumina From Aluminous Materials. *Brit.* 515,000, May 6, 1942.
- A-90. Barlot, J. Alumina Extraction From Bauxites or Silicate Minerals. *Fr.* 1,251,226, September 30, 1957.
- A-91. Delyannis, Mrs. E. Alkaline Treatment of Diasporic Bauxites. Bauxite, Alumina, Alum., *Proc. Int. Symp. ICSOBA, 2nd 1969.* (3):69-76, 1971 (Eng).
- A-92. Suzuki, Y., and T. Yutaka. Treatment of Aluminum Ores. *Japan* 130,975, July 7, 1939.
- A-93. Fink, C. G., and V. S. De Marchi. Treating Aluminous Material Such as Impure Bauxites for the Production of Alumina. *U.S.* 2,238,103, April 15, 1940.
- A-94. Nickelsen, D. Aluminum Oxide. *Norw.* 63,969, September 29, 1941.
- A-95. Haff, R. C. Recovery of Alumina From Alumina-Bearing Ores. *U.S.* 2,551,944, May 8, 1951.
- A-96. Menegoz, D., and Pl Belon. A New Process for Making Aluminum: The Loevenstein Process. *J. four elec.* (61):79-82, 1952.
- A-97. Seailles, J. C., and Societe des ciments francais. Calcium Aluminates and Alumina. *Fr.* 978,019, April 9, 1951.
- A-98. Pechiney-Compagnie de produits chimiques et electrometallurgiques. Aluminum Production. *Brit.* 717,481, October 27, 1954.

- A-99. Smirnov, M. N. Means of Increasing the Extraction of Aluminum Oxide in the Process of Leaching of Difficult-to-Strip Diaspore Bauxites. Trudy Vsesoyuz. Nauch. -Issledovated. Alyumin. -Magn. Inst. (39):36-43, 1957.
- A-100. Vereinigte Aluminium-Werke A. -G. Treatment of Bauxite With Caustic Soda Solution. Brit. 757,825, April 27, 1954.
- A-101. Shvartsman, B. Kh., and N. S. Volkova. Production of High-Grade Alumina on Treatment of Bauxites by Sintering. Tsvetnye Metally 33(4):48-51, 1960.
- A-102. Khodak, L. P., and A. I. Ivanov. Complex Treatment of Alumina Iron Ores and Highly Ferrous Bauxites. Trudy Vostochno-Sibir. Filiala, Akad. Nauk S. S. S. R. (13):237-41, 1958.
- A-103. Kamlet, J. Processing of Ferruginous Aluminum Ores. U.S. 2,964,383, December 13, 1960.
- A-104. Ponomarev, V. D., and L. P. Ni. The Sulfide-Caustic Method of Processing Bauxites Into Alumina. Trudy Vostochno-Sibir. Filiala, Akad. Nauk S. S. S. R. (13):232-6, 1958.
- A-105. Lanyi, B. Continuous Processing of Bauxite. Femipari Kutalo Intezet Kozlemenyei. 5-28, 1956.
- A-106. Alumina Manufacture From Bauxite, Montecatini Societa generale per l'industria mineraria e chimica. Alumina Manufacture From Bauxite. Ital. 580,979, August 18, 1959.
- A-107. "Montecatini" Societa Generale per l'Industria Mineraria e Chimica. Water-Soluble Aluminates From Aluminum Ore Such as Bauxite. Brit. 884,671, December 13, 1961.
- A-108. Commonwealth Scientific and Industrial Research Organization. Alumina. Brit. 883,311, August 19, 1959.
- A-109. Pechiney-Compagnie des Produits Chimiques et Electrometallurgiques. Alumina. Ger. 1,115,725, August 5, 1959.
- A-110. Scott, T. R. Alumina by Acid Extraction. J. Metals (14):121-5, 1962.
- A-111. Sumitomo Chemical Co., Ltd. Alumina From Bauxite Containing Large Amounts of Silicate. Japan 18,156, November 20, 1962.

- A-112. Showa Denko K. K. Alumina From Bauxite. Japan 8257, July 14, 1962.
- A-113. Lecis, P., and A. Guidi. Alumina From Bauxite by Pyrogenic Attack, in Agglomeration Plants, Either Under Suction or Pressure. U.S. 3,057,683, October 9, 1962.
- A-114. Japan Light Metal Co., Ltd. Extraction of Alumina From Bauxites. Japan 5804, May 13, 1963.
- A-115. Yawata Iron & Steel Co., Ltd. Extraction of Alumina From Slag Containing Alumina. Japan 9254, June 15, 1963.
- A-116. Ni, L. P., and E. U. Daulbaev. Leaching of High-Silica Hydrargillite Bauxites by a Non-Autoclave Method. Tsvet. Met. Nauch. - Tekh. Byul. (1):36-8, 1967 (Russ).
- A-117. Eremin, N. I., A. V. Bogdanov, and I. V. Ravdonikas. Preparation of Alumina. U.S.S.R. 192,768, March 2, 1967.
- A-118. Schrader, R., H. Rump, R. Kressner, and K. Hoffmann. Alumina From Bauxite and Bauxite-Like Minerals. Ger. (East) 50,059, October 15, 1966.
- A-119. Molnar, L., and K. Solymar. Removal of Fe From Bauxite With NH_4Cl . Freiburger Forschungsh 103B, 7-8, 1965 (Ger).
- A-120. Molnar, L., and K. Solymar. The Recovery of the Iron Content From Bauxites by Treatment With Ammonium Chloride. Femip. Kut. Int. Kozlmeny. 7:29-45, 1965 (Hung).
- A-121. Perieres, R., and Y. Debard. Purification of Bauxite. Fr. 1,495,002, September 15, 1967.
- A-122. VEB Chemiewerk "Albert Zimmermann". Alumina Production. Fr. 1,494,483, September 8, 1967.
- A-123. Amano, C. K., and M. L. Taylor. Selective Extraction of Alumina From Bauxite With Nitrogen Peroxide and Water at High Temperature and Pressure. U.S. 3,387,921, June 11, 1968.
- A-124. Tusche, K. J. Continuous Extraction of Bauxite in a Tubular Reactor. U.S. 3,497,317, February 24, 1970.
- A-125. Tusche, K. J. Continuous Digestion of Bauxite. Brit. 1,186,389, April 2, 1970.

- A-126. Klan, P. Production of Alumina by Alkaline Digestion at High Temperatures and Pressures. Bauxite, Alumina, Alum., Proc. Int. Symp. ICSOBA, 2nd 1969. (3):163-73, 1971.
- A-127. Vereinigte Aluminum-Werke A. -G. Apparatus for Continuously Extracting Bauxite. Fr. Demande 2,121,277, October 27, 1972.
- A-128. Kobayashi, S. Treatment of Gibbsite-Type Bauxite. Japan Kokai 73 45,498, June 29, 1973.
- A-129. Orban, Mrs. F., F. Orban, T. Pinter, G. Sigmond, P. Siklosi, K. Solymer, P. Toth, and J. Zambo. Processing of Bauxites Containing Goethite. Hung. Teljes 6,758, August 28, 1973.
- A-130. Kampf, F., and H. G. Kaltenberg. Apparatus for Continuously Extracting Bauxite With Sodium Aluminate Liquor. Brit. 1,327,162, August 15, 1973.
- A-131. Derevyankin, V. A., V. Ya. Chuprakov, and V. B. Chernyshov. Conditioning of Bauxites. Tsvet. Metal. (10):26-7, 1973 (Russ).
- A-132. Maieir, A. A., M. N. Smirnov, V. M. Sizyakov, I. G. Gorelik, and A. A. Bitner. Alumina. U.S.S.R. 431,111, June 5, 1974.
- A-133. Poppleton, H. O., and T. T. Campbell. Desilication of Minerals With Sulfur and Carbon. U. S. Bur. Mines, Rept. Invest. 7950, 8 pp, 1974.
- A-134. Sekulovic, V., R. Vracar, and E. Krotin. Design of a Bayer-Process-Type Laboratory Tube Reactor for Combined Heating and Leaching of Bauxite. Hem. Ind. 28(9):403-9, 1974 (Serbo-Croatian).
- A-135. Reisner, K. H. Alumina From Aluminum Silicates. Ger. (East) 105,795, May 12, 1974.
- A-136. Othmer, D. F. Chlorinating Ores for Separation of Aluminum and Iron. U.S. 3,856,508, December 24, 1974.
- A-137. Othmer, D. F. Aluminum Metal Directly From Ore. U.S. 3,861,904, January 21, 1975.
- A-138. Solymer, K., J. Zambo, Mrs. F. Orban, E. Bujdoso, I. Feher, Z. Osvald, I. Voros, T. Ferenczi, P. Toth, et al. Processing Bauxites Containing Goethite. Hung. Teljes 8,559, July 7, 1973.

- A-139. Kampf, F., and H.-G. Kaltenberg. Method and Apparatus for the Continuous Extraction of Bauxite. Ger. 134,145, February 8, 1972.
- A-140. Calhoun, W. A., and H. E. Powell, Jr. Investigation of Low-Grade Bauxites as Potential Sources of Aluminum by Caustic Desilication and Alumina Extraction. U.S. Bur. Mines, Rept. Invest. 5042, 23 pp, 1954.
- A-141. Plaetschke, H. Extractable Alumina and Phase Transformation of Bauxites in the Bayer Process. Digestibility of Bauxites in the Bayer Process. Comments. Femip. Kut. Intez. Kozlem. (9):100-3, 1971 (Eng).
- A-142. Ni, L. P., and E. U. Daulbaev. Complex Treatment of High-Silica Hydrargillitic Bauxites. Tr. Inst. Met. Obogashch., Akad. Nauk Kaz. SSR. (37):57-61, 1970 (Russ).
- A-143. Uzkikh, Yu. F., and G. P. Podnebesnyi. Treatment of Hydrargillitic Bauxites With Various Silica to Alumina Ratios. Tr. Inst. Met. Obogashch., Akad. Nauk Kaz. SSR. (37):53-6, 1970 (Russ).
- A-144. Grzymek, J., and J. Macias. The Importance of pH in the Extraction of Aluminum Oxide From Basic Sinters. Rudy Metale Niezelazne. 8(5):164-7, 1963.
- A-145. Tamise, L., and J. Millet. Continuous Attack of Bauxite by Sodium Hydroxide and Sodium Aluminate Solutions. Fr. 1,523,302, May 3, 1968.
- A-146. Ginsberg, H. Current Problems in the Digestion of Bauxite of the United Aluminum Works A. G. Reichsamt Wirtschaftsbaus Chem. Ber. Prof-Nr. 93:193-6, 1941.
- A-147. Aimé, R. The Alkaline-Earth Aluminates and the Production of Alumina. Ann. chim. 12(3):271-315, 1948.
- A-148. Datar, D. S. Alumina Low in Iron. Indian 41,932, November 1, 1950.
- A-149. Lowenstein, H. M., and A. M. Lowenstein. Alumina Production. S. African 73 05, 996, November 21, 1974.

Miscellaneous

- A-150. Vereinigte Aluminium-Werke A.-G. Decomposing Bauxite. Brit. 506,885, June 6, 1939.

- A-151. Litchfield, L., Jr. Bauxite. I, II. Chem. Industries. (48):154-9, 290-5, 1941.
- A-152. Brown, R. W. Extracting Alumina Values From Ores. U.S. 2,280,998, April 28, 1942.
- A-153. Bugarev, L. A., and V. S. Cheinodanov. Extraction of Alumina. U.S.S.R. 64,954, July 31, 1945.
- A-154. Sherwin, R. S. Extractive Metallurgy of Aluminum. J. Metals 188, Trans. 661:(6), 1950.
- A-155. Cundiff, W. H. Extraction of Alumina From Aluminous Ores. U.S. 2,522,605, September 19, 1950.
- A-156. Sugimoto, S., and S. Klyomiya. Extraction of Alumina. Japan 6('51), January 9, 1951.
- A-157. Gedeon, T. The Processing of Sulfurous Bauxite by the Bayer Method. Aluminium (Budapest). (2):154-7, 1950.
- A-158. Kompaniets, M. F. The Influence of the Mineralogical Composition and of the Structural Characteristics of Bauxites on Their Behavior in the Bayer Process. Tsvetnye Metally 31(8):50-2, 1958.
- A-159. Matthes, F., and H. Bach. Organic Substances in Bauxite and Effects on the Bayer Process. Chem. Tech. (Berlin). 14(10):610-13, 1962.
- A-160. Gebefuegi, I. Kneading Pretreatment of Ground Bauxite Before Digestion With Hot Alkali Under Pressure for Producing Pure Aluminum Hydroxide. U.S. 3,357,792, December 12, 1967.
- A-161. Gol'dman, M. M., and L. P. Ni. Behavior of Iron Minerals in the Bayer Process. Tr. Inst. Met. Obogashch., Akad. Nauk Kaz. SSR. (44):96-101, 1972 (Russ).
- A-162. Guenter, W., and W. Gruhl. Aluminum. Raw Materials, Extraction, and Refining. Chem. Ztg. 97(6):311-20, 1973 (Ger).
- A-163. Wittig, R. The Tower Process for the Extraction of Alumina From Bauxite. Chem. Ing. Tech. (22):81-4, 1950.
- A-164. James, W. A. Alumina. Can. 461,024, November 15, 1949.

- A-165. Reese, K. M., and W. H. Cundiff. Alumina. *Ind. Eng. Chem.* 47:1672-80, 1955.
- A-166. Soudan, P., and J. Breton. Treating Alumina Ores With Soda Recovery. U.S. 2,992,893, July 18, 1961.
- A-167. Garing, M. L., F. E. Adkins, Jr., and G. E. Branigan. Sodium Aluminum Fluoride and Sulfuric Acid. U.S. 3,207,575, September 21, 1965.
- A-168. Regnier, J. Continuous Digestion of Monohydrate Bauxites. *Ext. Met. Aluminum.* 1:251-64, 1963.
- A-169. Riesel, W., and R. Peters. Removal of Silica From Bauxites With a High-Content of Silica. *Ger.* 1,171,888, June 11, 1964.
- A-170. Leiteizen, M. G., A. A. Bitner, and P. Ya. Kiselev. Removal of Silica From a Bauxite Pulp Before Leaching. U.S.S.R. 190,359, December 29, 1966.
- A-171. Lundquist, R. V., and N. Chardoul. Desilication of Caustic Leach Liquors Containing Alumina. U.S. Bur. Mines, Rept. Invest. 6100, 18 pp, 1962.
- A-172. Johnson, A. F. Separation of Alumina From Bauxite. U.S. 3,241,910, March 22, 1966.
- A-173. Tikhonov, N. N., A. B. Bykova, and M. N. Smirnov. Expediency of Using Mixed Solutions of Potassium and Sodium Hydroxides for Leaching Bauxites. *Tsvet. Metal.* 41(4):58-9, 1968 (Russ).
- A-174. Campelo, V. The Classification and Method of Separation of Aluminum From Bauxites as Silicates With Silica. *Rev. soc. brasil. quim.* 14:261-83, 1945.
- A-175. Howat, D. D. Production of Alumina. II. New Advances and Developments. *Mine & Quarry Eng.* 12:73-9, 1946.
- A-176. Ervin, G., Jr., D. D. Blue, and J. E. Conley. Control of Gelation in Extraction of Alumina From Lime-Soda-Clay Sinters. U.S. Bur. Mines, Rept. Invest. 3923, 16 pp, 1946.
- A-177. Prytherch, W. E., M. L. R. Harkness, and W. D. Spencer. Production of Alumina by the Lime-Soda Process. III. Acid and Alkaline Processes. *Chem. Age (London)* 56:339-43, 1947.

- A-178. Archibald, F. R. Extraction of Alumina. U.S. 2,604,379, July 22, 1952.
- A-179. Ni, L. P., V. D. Ponomarev, Kh. N. Nurmagambetov, and V. S. Sazhin. Alumina From High-Silica Bauxites. U.S.S.R. 132,206, October 5, 1960.
- A-180. Lainer, A. I., V. I. Pauker, and E. F. Vegman. Sintering of a Bauxite Charge by Combined Heating. Izv. Vyssh. Ucheb. Zaved., Tsvet. Met. 14(4):30-4, 1971 (Russ).
- A-181. Bartha, L. The Manufacture of Alumina. Aluminium (Budapest) 1:208-14, 221-4, 1949.
- A-182. Varga, J., and K. Polinszky. Dehydration of Hungarian Bauxites. Magyar Kem. Lapja. 4:589-92, 1949.
- A-183. Mariassy, M. Methods for the Elimination of Salt Contaminants in the Manufacture of Alumina. Kohnszati Lapok. 90:126-9, 1957.
- A-184. Dunay, S. The Stepwise Mild Digestion of Hungarian Bauxites. Femipari Kutato Intezet. Kozlemenyei. (2):5-12, 1958.
- A-185. Calhoun, W. A., and T. E. Hill, Jr. Metallurgical Testing of Hawaiian Ferruginous Bauxites. U.S. Bur. Mines, Rept. Invest. 6003, 43 pp, 1962.
- A-186. Magyarossy, I., M. Mariassy, and J. Uveges. Hungarian Sulfur-Containing Bauxites. Femipari Kutato Intezet. Kozlemenyei. 4:7-25, 1960.
- A-187. Papp, E. Sodium Hydroxide Losses in the Bayer Alumina Process. Freiburger Forschungsh. B82:5-15, 1964.
- A-188. Zambo, J. Complex Treatment of Low-Grade Hungarian Bauxites. Symp. Bauxites, Oxides, Hydroxides, Aluminium, Zagreb. 3:63-74, 1963 (Russ).
- A-189. Logomerac, V. Smelting of Low-Grade Bauxite. Tehnika (Belgrade) 26(3):165-70, 1971 (Croat).
- A-190. Ni, L. P., and B. E. Medvedkov. Conversion of Belinsk Bauxites Into Alumina. Tr. Inst. Met. Obogashch., Akad. Nauk Kaz. SSR (47):38-43, 1972 (Russ).

- A-191. Dobos, Gy. Complex Utilization of Hungarian Bauxites. Femip. Kut. Intez. Kozlem. 9:61-9, 1971 (Eng).
- A-192. Steiner, R. Pretreatment of Bauxite. Hung. 139,207, January 3, 1949.
- A-193. Oku, T., K. Yamada, T. Harato, and H. Kato. Removal of Organic Compounds in Bauxite. Japan Kokai 72 21,395, October 3, 1972.
- A-194. Kobayashi, S. Roasting Bauxite for Removal of Organic Matters. Japan Kokai 73 39,317, June 9, 1973.
- A-195. Li, Yi-Yen, Y. Chu, and P. Chu. High-Temperature Fast Digestion of Aluminum Ore. Tai-Wan Lu Yeh Ku Fen Yu Hsien Kung Szu Yen Chiu Fa Chan Kung Tso Pao Kao. 70-82, 1970 (Ch).
- A-196. Mal'ts, N. S., and E. A. Matsenok. Feasibility of Temperature Decrease During Countercurrent Washing of Red Mud. Tr. Vses. Nauch.-Issled. Proekt. Inst. Alyum., Magn. Elektrod. Prom. (81):75-80, 1972 (Russ).
- A-197. Bardossy, Gy. Extractable Alumina and Phase Transformations of Bauxites in the Bayer Process. Comments. Femip. Kut. Intez. Kozlem. (9):103-4, 1971 (Eng).
- A-198. Mercier, H., and M. Noble. Optimization of the Alkaline Treatment of Different Bauxite Varieties. Light Metals, Proc., 103rd AIME Annu. Meet. (3):777-86, 1974 (Eng).
- A-199. Yamada, K., T. Harato, and Y. Furumi. Removal of Iron Compounds From the Bayer Liquor. Light Metals, Proc., 103rd AIME Annu. Meet. (3):713-22, 1974 (Eng).
- A-200. Mal'ts, N. S., L. F. Berbov, and M. D. Uspenskii. Mechanism of Bauxite Leaching. Tr. Vses. n.-i. i proekt. in ta alyumin., magn. i elektrod. prom-sti. (85):33-40, 1973 (Russ).
- A-201. Lath, R. P., and P. M. Menon. Modern Trends in the Preparation of Alumina. Trans. Indian Inst. Metals. 22(4):39-48, 1969 (Eng).
- A-202. Maier, A. A., et al. Hydrochemical Processing of a Cake in a Variant of the Bayer Sintering System. Tr. Inst. Met. Obogashch., Akad. Nauk Kaz. SSR. 28:90-5, 1969 (Russ).
- A-203. Plaetschke, H. Extractable Alumina and Phase Transformation of Bauxites in the Bayer Process. Comments. Digestibility of

Bauxites in the Bayer Process. Proc. Res. Inst. Non-Ferrous Metals 100-3, 1971 (Eng).

- A-204. Mitani, H., and H. Nagai. Direct Reduction of Bauxite by a Plasma Jet. Keikinsoku. 21(12):789-95, 1971 (Japan).
- A-205. Pervushin, N. G., and V. A. Derevyankin. Conversion of High-Silicon Sulfidized Bauxites to Alumina. Nauch.-Tekh. Konf., Ural. Politekh. Inst., 4th. (1):5, 1972 (Russ).
- A-206. Krasnokucki, A. Review of Aluminum Oxide Production Methods. Rudy Metale Niezelazne. 7(5):216-23, 1962.
- A-207. Shneerov, M. S., and Yu. A. Dodonov. Leaching of Alumina Cake in a Continuous Apparatus. U.S.S.R. 193,466, March 13, 1967.
- A-208. Smirnov, V. S. Addition of Lime During the Autoclave Leaching of Bauxites. U.S.S.R. 186,410, October 3, 1966.
- A-209. Solymar, K., and S. Zsindely. The Effect of Organic Matter When Manufacturing Al_2O_3 With the Bayer Process. Freiburger Forschungsh. 103B:61-80, 1965 (Ger).
- A-210. Mercier, H. Aluminum Extraction From Bauxites. Rev. Ind. Miner. 50(5):389-96, 1968 (Fr).
- A-211. Bagaev, A. S. Optimum Technological Parameters During the Leaching of Bauxites. Tsvet. Metal. 41(9):54-5, 1968 (Russ).
- A-212. Juhasz, A. Improvement of Technology of Alumina Production. Tsvetnye Metally. 33(9):58-61, 1960.
- A-213. Korotich, V. I., and V. V. Mikhailov. Agglomeration of Sulfur-Bearing Bauxites. Trudy Ural. Politekh. Inst. im. S. M. Kirova. (73):5-22, 1958.
- A-214. Bernshtein, V. A., and E. A. Matsenok. Composition of Sodium Aluminosilicate During Autoclave Leaching of Bauxite. Trudy Vsesoyuz. Alyumin.-Magnievyi Inst. (44):5-12, 1960.
- A-215. Tkacheva, Z. S. The Use of Sodium Sulfate in the Production of Alumina. Materialy Vsesoyuz. Soveshchaniya po Khim. i Technol. Glinozema, Akad. Nauk S.S.S.R., Sibir, Otdel., Novosibirsk. 195-203, 1958.

- A-216. Uveges, J. Effects of Roasting Bauxite on the Caustic Soda Consumption in the Manufacture of Alumina by the Bayer Process. Femipari Kutato Intezet Kozlemenyei. 4:27-35, 1960.
- A-217. Perezel, A., and I. Miklos. Effects of the Zinc Content in Bauxite on the Products of Alumina Manufacture by the Bayer Process and on the Aluminum (Produced Therefrom). Femipari Kutato Intezet Kozlemenyei. 4:103-15, 1960.
- A-218. Matyasi, J., and K. Nemeth. Decreasing the Organic-Matter Content of Alumina Manufacturing Plant Liquors. Femipari Kutato Intezet Kozlemenyei. 4:83-92, 1961.
- A-219. Buhler, G. E. Dachzelt, and E. Dietsch. Removal of Silica From Bauxites by Sodium Hydroxide-Containing Lyes. Ger. (East) 20, 120, October 13, 1960.
- A-220. Bracewell, S. Bauxite, Alumina, and Aluminum. Overseas Geol. Surv., Mineral Resources Div. 1-235, 1962.
- A-221. Porter, J. L. Preventing Carbonate Accumulation in Caustic Solutions Used for Extracting Alumina From Bauxite. U.S. 3, 120, 996, February 11, 1964.
- A-222. Labutin, G. V., and R. I. Melamed. The Behavior of Potassium in the Production of Alumina. Trudy Vsesoyuz. Nauch. -Issledovatel. Alyumin. -Magn. Inst. (40):144-50, 1957.
- A-223. Juhasz, A. Removal of Salt Impurities in Alumina Manufacture by the Bayer Process. Kohaszati Lapok. 91:161-8, 1958.
- A-224. Dachzelt, E., G. Buhler, and E. Dietsch. Removal of Silica From Bauxite and the Accompanying Problems. Chem. Tech. (Berlin). 12:482-9, 1960.
- A-225. Magyarosy, E., M. Mariassy, and A. Perezel. Causes of Alumina Losses After Digestion in the Bayer Process. Acta Tech. Acad. Sci. Hung. 21:275-89, 1958 (French).
- A-226. Matysai, J., and K. Nemeth. Effects of Lime Addition on the Digestibility of Bauxites. Kohaszati Lapok. 92:313-16, 1959.
- A-227. Matyasi, J., and Mrs. F. Orban. Effects of the Organic Matter Content of Aluminate Liquors on the Alumina Manufacturing Process by the Bayer Method. Kohasz. Lapok. 95:310-15, 1962.

- A-228. Societe d'Electrochimie, d'Electrometallurgie et des Acieries Electriques d'Ugine. Improvement of Bauxite Prior to Treatment by the Bayer Process. Fr. 1,248,529, March 8, 1961.
- A-229. Beneslavskii, S. I. The Problem of Bauxite Enrichment. Tr. Vses. Nauchn. -Issled. Alyumin. -Magnievyi Inst. (47):12-22, 1961.
- A-230. Pearson, T. G. The Chemical Background of the Aluminum Industry. Roy. Inst. Chem. Lectures, Monographs and Repts. (3):103 pp, 1955.
- A-231. Druzhinina, N. K. The Role of Lime in the Leaching of Bauxites. Trudy Vsesoyuz. Nauch. -Issledovatel. Alyumin. -Magn. Inst. (39):62-71, 1957.
- A-232. Shvartsman, B. Kh. Flow Leaching of Bauxite Sinter in Diffusers. Trudy Vsesoyuz. Nauch. -Issledovatel. Alyumin. -Magn. Inst. (40):48-81, 1957.
- A-233. Smirnov, M. N. Activating Effect of Certain Organic Substances in the Process of Leaching of Diaspore Bauxites. Trudy Vsesoyuz. Nauch. -Issledovatel. Alyumin. -Magn. Inst. (39):44-51, 1957.
- A-234. Smirnov, M. N. Activating Effect of Lime and Certain Other Compounds in the Process of Leaching of Diaspore Bauxites. Trudy Vsesoyuz. Nauch. -Issledovatel. Alyumin. -Magn. Inst. (39):52-61, 1957.
- A-235. Gewecke, F. Problems in the Extraction of Bauxite at the Martin Works. Reichsamt Wirtschaftsausbau Chem. Ber. Prof-Nr. 93 (PB52009). 197-200, 1941.
- A-236. Ruter, H. The Decomposition of Bauxite With Sodium Sulfate and Coal. Reichsamt Wirtschaftsausbau Chem. Ber. Prof-Nr. 93 (PB52009). 201-8, 1941.
- A-237. Szekeres, J. and M. Mariassy. The Role of Sodium Carbonate Dissolved in Alkalies in the Processing of Bauxite. Aluminium (Budapest) 1:141-3, 1949.
- A-238. Maricic, S. and I. Dvornik. The Decomposition of Bauxite According to Bayer and the Economy of the Process. Tehnicki pregled (Zagreb), Poseban Inst. lake metale (Special issue Inst. Light Metals). 16-19, October 1952.
- A-239. Herrmann, E., I. Dvornik, O. Korelic, S. Maricic, and S. Ferjancic. The Processing of Bauxite From Mostar. Ibid. 12-15, October 1952.

- A-240. Vachtl, J. Bauxite - Raw Material for Aluminum. Urania (Germany) 18:138-41, 1955.
- A-241. Furui, T. and K. Sakai. Silica Removal From Alumina. Japan. 14, 700('67), August 17, 1967.
- A-242. Fulda, W. and H. Ginsberg. Tonerde und Aluminium. Walter de Gruyter & Co., Berlin, 1964.
- A-243. Gerard, G. and P. T. Stroup. Extractive Metallurgy of Aluminum, Volume 1, Alumina, Interscience Publishers, New York, 1963.
- A-244. Valeton, Ida. Bauxites. Elsevier, New York, 1972.
- A-245. Aluminate Solutions for Aluminum Production Prepared by Precipitation of Iron and Sulfur From Solution With Copper Oxides. Ural Polytechnic Institute. Soviet 385,920, April 9, 1971.
- A-246. Modified Bayer Procedure for Processing of Bauxite. Hungarian 3586, March 3, 1970.
- A-247. Romanov, L. G., B. S. Povazhnyi, B. Sh. Dzhumabaev, and M. G. Zolotareva. Behavior and Role of Phosphorus During the Treatment of Bauxites by the Bayer Method. Tr. Inst. Met. Obogashch., Akad. Nauk Kaz. SSR, 44, 102, 1972.

RED-MUD DEWATERING

- B-1. Stewart, R. F. Separation of Red Mud From Solutions. Brit. 522,691, June 25, 1940.
- B-2. Dvornik, I. and E. Hermann. The Mechanism of the Aggregating Effect of Flour of Starch on the Disperse System of Red Sludge in Aluminate Solution. Kolloid Z. 128, 75-86, 1952.
- B-3. Porter, J. L. Purification of Caustic Aluminate Liquors (Kaiser Aluminum & Chemical Corp.). U.S. 2,981,000, April 25, 1961.
- B-4. Lux, A., E. Laszlo, J. Muszal, G. S. Gantner, and H. Hollo. Importance and Degradation of Starch in the Bayer Process. V. Replacement of Starches by Other Polysaccharides (Inst. Landwirtschaftlich-Chem. Technol. Budapest, Hung.). Staerke 19(5):129-34, 1967 (Ger).
- B-5. Graefe, J., C. Kelch, and H. Roederer. Flocculants for Red Mud (Deutsche Maizena Werk G.m.b.H.). Ger-Offn. 2, 158, 130. 7 pp. June 14, 1973.

- B-6. Hollo, J., J. Szejtli, E. Laszlo, G. S. Gantner, Zs. Toth, J. Huszar, and A. Lux. The Importance and Degradation of Starch in the Bayer Process, I. The Action of Starch (Tech. Univ. Budapest, Hung.). *Staerke* 16(4):118-22 (1964).
- B-7. Hollo, J., E. Laszlo, J. Szejtli, and A. Lux. Importance and Degradation of Starch in the Bayer Process, III. Distribution of Starch and Its Degradation Products (Tech. Univ. Budapest, Hung.). *Staerke* 17(2):36-40 (1965) (Ger.). cf. CA 61, 6667h.
- B-8. Dow Chemical Co. Alumina Manufacture. Fr. 1,342,576. 9 pp. November 8, 1963.
- B-9. Silina, E. I., T. M. Zlokazova, and M. G. Zolotareva. Research and Industrial Study of Polyacrylamide Flocculant in the Production of Alumina. *Tsvetn. Metal.* 37(12):44-6, 1964 (Russ).
- B-10. Sullivan, E. J. Alumina (Dow Chemical Co.). Ger. 1,177,626. 3 pp. September 10, 1964.
- B-11. Silina, E. I. Synthesis of Flotation Reagents and Improvements in the Technology of Their Production. *Tr. Nauch. Issled. Proekt. Inst. Obogashch. Mekh. Obrab. Polez. Iskop Uralmekhanobr.* No. 12, 273-87, 1965 (Russ).
- B-12. Ismatov, K. R., A. A. Rakhimov, and T. P. Rasulov. Use of Reagents K-4 and K-6 in Settling of Red Mud. *Tsvet. Metal.* 39(9):63-4, 1966 (Russ).
- B-13. Sibert, F. J. Alumina Recovery From Bauxite by Using Acrylic Polymers (Nalco Chemical Co.). U.S. 3,390,959. 3 pp. July 2, 1968.
- B-14. Sibert, F. J. Alumina (Nalco Chemical Co.). S. African 6,802,757. 15 pp. October 1, 1968.
- B-15. Nagase, Kunihiro, Kahei Sakaguchi, Osamu Shogi, and Takayoshi Kachi. Separation of Red Mud in Alumina Manufacture (Kao Soap Co., Ltd.). Japan 70 17,893. 4 pp. June 19, 1970.
- B-16. Wolf, F., H. Kramer, and L. Eckert. Modifying the Rate of Sedimentation of Red Mud in the Bayer Process (Bereich Tech. Chem., Martin-Luther-Univ. Halle-Wittenberg, Halle Saale, Ger.). *Chem. Tech. (Leipzig)* 22(9):550-2, 1970 (Ger).

- B-17. Gol'dman, M. M., L. P. Ni, V. D. Ponomarev, I. A. Yakubovich, M. P. Vilyanskii, E. N. Bespalov, Yu. F. Uzkikh, and V. N. Vasil'ev. Clarification of Red Mud Pulps. U.S.S.R. 285, 912, November 10, 1970.
- B-18. Wolf, F., H. Kramer, and L. Eckert. Increasing the Sedimentation Rate of Red Mud Resulting From the Bayer Process. Ger. (East) 82, 122. 3 pp. May 20, 1971.
- B-19. Mal'tseva, N. N., V. V. Rybakov, V. I. Sharkov, and N. I. Kuibina. Precipitation of Red Muds (All-Union Scientific Research and Planning Institute for Mechanical Processing of Minerals). U.S.S.R. 307, 065, June 21, 1971.
- B-20. Gol'dman, M. M., V. N. Vasil'ev, L. P. Ni, I. A. Yakubovich, M. P. Vilyanskii, and N. P. Pashkin. Use of New Synthetic High-Molecular-Weight Compounds for Precipitation of Red Mud (U.S.S.R.). Tr. Inst. Met. Obogashch. Akad. Nauk Kaz. S.S.R. (41):48-55, 1971 (Russ).
- B-21. Atlas Chemical Industries, Inc. High-Molecular Weight Sodium Acrylate Polymers Containing a Major Proportion of Water-Soluble Polymer. Brit. 1, 260, 206. 6 pp. January 12, 1972.
- B-22. Tsukawaki, Masahiro and Yoshiaki Inamoto. Refining Alumina by Alkali Treatment of Minerals (Kao Soap Co., Ltd.). S. African 71 05, 673. 17 pp. March 22, 1972.
- B-23. Palmer, E. W. and F. McIntyre. Recovering Red Mud From Aluminum Oxide Solutions (Nalco Chemical Co.). Ger. Offen. 2, 251, 261. 21 pp. July 26, 1973.
- B-24. Korus, V. M., O. G. Perederii, and A. A. Golovin. Dehydration of Clayey Bauxite Pulps (USSR). Nauch. -Tekh. Konf. Ural. Politekh. Inst., 4th 1972 (Pub. 1973), No. 1, 9-10 (Russ).
- B-25. Skobeev, I. K. Adaptation of Coagulants During a Thickening of Red Mud. Nauchn. Tr. Irkutskogo Politekh. Inst. (19), 121-35, 1963.
- B-26. Werner, P. E. Settling Red Mud From Suspensions of Bauxite in Caustic Solutions (Rohm and Haas Co.). S. African 67 01, 885. 12 pp. August 20, 1968.
- B-27. Sibert, F. J. Improved Separation Rate of Dispersed Red Mud From Dissolved Alumina (Nalco Chemical Co.). U.S. 3, 445, 187. 3 pp. May 20, 1969.

- B-28. Sibert, F. J. Rapid Method of Removing Red Mud During Alumina Preparation (Nalco Chemical Co.). S. African 69 02,471. 15 pp. October 15, 1969.
- B-29. Sibert, F. J. Red Mud Removal From Aqueous Caustic Solutions of Alumina (Nalco Chemical Co.). U.S. 3,681,012. 5 pp. August 1, 1972.
- B-30. Jones, D. A. and L. F. Elmquist. Starch Graft Polymers, III. Preparation of Graft and Polymers Containing Acrylamide, Acrylic Acid, and B. (Methacryloyloxy) Ethyltrimethylammonium Monoethyl Sulfate and Evaluation as Flocculant for Bauxite Ore Red Mud Suspensions (Polym. Dev. Dep. Gen. Mills Chem. Inc., Minneapolis, Minn.). Staerke 25(3):83-9, 1972 (Eng).
- B-31. Schumann, G. and W. Vollmer. Flocculation of Red Mud From Alumina Manufacture (Vereinigte Aluminium-Werke Akt. -Ges.). Ger. 1,009,210, May 29, 1957.
- B-32. Novozhenov, V. M. and S. I. Kuznetsov. Settling of Red Mud in Alumina Production. Tsvetn. Metal. 39(9):58-62, 1966 (Russ).
- B-33. Novozhenov, V. M., S. I. Kuznetsov, and V. A. Derevyankin. Settling of Red Mud. Khim. Tekhnol. Glinozema, Tr. Vses. Soveshch., 4th 1965 (Pub. 1971), (Russ.), 445-9, Edited by Logvinenko, A. T. "Nauka", Sr. Otd.: Novosibirsk, USSR.
- B-34. Vasil'ev, V. N., A. S. German-Galkina, and G. A. Chemezova. Effect of the Clay Fraction of Bauxite on the Precipitation of Red Mud. Tr. Inst. Met. Obogashch. Akad. Nauk Kaz. SSR 37:62-4, 1970 (Russ).
- B-35. Nepokrytykh, T. A., S. I. Kuznetsov, and F. F. Fedyaev. Effect of Iron Sulfide Minerals Contained in SUBR Bauxites on the Settling of Red Mud During Alumina Production by the Bayer Process (Ural Politekh. Inst., Sverdlovsk, USSR). Izv. Vyssh. Uchebn. Zaved. Tsvetn. Metall. 17(5):42-4, 1974 (Russ).
- B-36. Chu, Yuan and Wang Ping Tung. Effect of Calcium Oxide on Aluminum Ore Roasting and Red Mud Sedimentation. Tai-wan Lu Yek Ku Fen Yu Hsien Kung Szu Yen Chiu Fa Chan Kung Tso Pao Kao 55-64, December 1974 (Ch).
- B-37. Papp, E., I. Magyarosy, and A. Hejja. Sedimentation of Red Mud in the Bayer Process (Met. Research Inst., Budapest). Acta. Tech. Acad. Sci. Hung. 13, 33-52, 1955 (Eng).

- B-38. Oku, Tsurumi, Kaichi Yamada, Tatsuo Harato, and Yoshinon Furumi. Separation of Red Mud (Sumitomo Chemical Co., Ltd.). Japan Kokai 73 102,097. 5 pp. December 21, 1973.
- B-39. Letebvre, M.J. Certain Phenomena Relative to the Flocculation and Decantation of Bayer Process Residual Muds. Symp. Bauxites, Oxides, Hydroxides Aluminum. Zagreb, 3, 7-53, 1963 (Pub. 1965, France).
- B-40. Osvald, Z. Effects of Expansion on the Sedimentation of the Red Sludge [in Alumina Manufacture by the Bayer Process]. Research Inst. Metal. Ind., Budapest, Hung., Femipari Kutato Intezet Kozlemenyei 4, 77-81, 1960.
- B-41. Nemeth, K., J. Matyasi, and F. Orban. Effects of Flour Solutions, Prepared in Alkaline or Alkali-free Medium, on the Sedimentation of Red Sludge (in Alumina Manufacture). Kohaszati Lapok 94, 97-100, 1961.
- B-42. Buravlev, T. T., A. A. Lyashenko, I. T. Slyusarov, and A. I. Golubova. Precipitation of Red Slimes From Aluminate Solutions by the Bayer Method, III (V. Ya. Chubar Zaporozhe Mashinostr. Inst. Zaporozhe). Zh. Prikl. Khim. 40(3):487-92, 1967 (Russ).
- B-43. Gol'dman, M. M., I. A. Yakubovich, N. P. Paskhin, V. N. Vasil'ev, B. S. Povazhnyi, G. P. Podnebesnyi, and L. V. Bunchuk. Pilot-Plant Test on Densification of Red Mud by Polyacrylamide (USSR). Tr. Inst. Met. Obogasch. Akad. Nauk Kaz. SSR. (41):56-60, 1971 (Russ).
- B-44. Makray, Istvan, Peter Nagy, and Tihamer Pinter. Rapid Settling of Red Mud From Sodium Aluminate Lye (Alutrev Aluminiumipari Tervezo Vallalat). Hung. Teljes 4004. 8 pp. April 28, 1972.
- B-45. Oida, H., M. Miki, and T. Hasegawa. Treatment of Red Mud Suspensions (Sumitomo Chemical Co. Ltd.). Japan 69 24,892. 3 pp. October 21, 1969.
- B-46. Kobayashi, Shigehiko, Minoru Ichiki, Masato Ishii, and Toshikazu Sato. Separating the Solid and Liquid of a Red Mud Suspension (Mitsui Mining and Smelting Co., Ltd.). Japan. 69 24,892. 3 pp. May 10. 1974.
- B-47. Marsany, Josef and Peter Nagy. Removal of Suspended Red Mud From Sodium Aluminate. Ger. Offen. 2,322,643. 6 pp. November 15, 1973.
- B-48. Korus, V. M., O. G. Perederii, F. F. Fedyaev, A. A. Golovin, and S. I. Kuznetsov. Use of Reagents TZhK and ANP to Accelerate Settling of Slimes (USSR). Tsvet. Metal. (1):42-3, 1974 (Russ).

- B-49. Lloyd, D. J. Flocculation in Bauxite Mining (Love, N. B. Industries Pty. Ltd.). Ger. Offen. 2,432,497. 18 pp. January 23, 1974.
- B-50. Takemoto, M. Separation of Red Mud From Sodium Aluminate (Nisson Chemical Industries Co.). Japan. 501, February 13, 1951.
- B-51. Cook, G. W. Rapid Settling of Mud Impurities From Sodium Aluminate Solutions (Reynolds Metals Co.). U.S. 3,127,239. 5 pp. March 31, 1964.
- B-52. Dereryankin, V. A., V. M. Novozhenov, E. M. Il'yashevich, and S. I. Kuznetsov. Effect of Washing on the Settling Rate of Red Mud in Alumina Production. Tsvetn. Metal. 38(9):55-8, 1965.
- B-53. Zambo, J. and A. I. Belyaeva. Leaching of Hungarian Bauxites and Settling of Mud in Alumina Production by the Bayer Method. Sbornik Nauch. Trudov. Moskov. Inst. Tsvetnykh Metal. i Zolota (31):64-79, 1958.
- B-54. Murphy, J. M. and P. W. Bolmer. Freezing and Melting Treatment of Red Mud Slurries to Aid Solid Separation (Kaiser Aluminum and Chemical Corp.). U.S. 3,714,792. 5 pp. February 6, 1973.
- B-55. Maier, A. A., N. S. Mal'ts, A. A. Lapin, and D. V. Yashchunin. Coagulating Red Mud. U.S.S.R. 323,364, December 10, 1971.
- B-56. German-Galkina, A. S., T. M. Zlokazova, V. P. Mel'nikova, and V. V. Sidorenko. The Use of Hydroclones Together With Thickeners for Separation of Solids in Leaching Alumina-Bearing Sinter. Tsvetnye Metally 34, 52-4, 1971.
- B-57. Dunay, Sander. The Influence of the Processing Temperature on the Settling of the Red Mud. Femipari Kutato Intezet Kozlemeneyei 29-66, 1956.
- B-58. German-Galkina, A. S., V. P. Mel'nikova, and V. V. Sidorenko. Intensification of Thickening of Red Mud. Tsvetnye Metally 33(2):49-55, 1960.
- B-59. Ponomarev, V. D. and M. I. Erdenbaeva. Densification and Washing of Black and Red Mud Obtained After Leaching of Alumina From Bauxite Under 15 Atmosphere. Trudy Inst. Met. i Obogashcheniya, Akad. Nauk Kazakh. S.S.R. 2, 24-31, 1960.
- B-60. Buravlev, T. T. and I. T. Slyusarov. Precipitation of Red Mud From Aluminate Solutions. Zhur. Priklad. Khim. 33, 2627-32, 1960.

- B-61. Kaempf, F. Experience With the Use of Drum Filters for the Filtration of Red Mud (Schwandorf, Ger.). Int. Leuhtmetalltag, 5th (Pub 1969), 350-60, 1968 (Ger).
- B-62. Konig, P. Filtering Red Mud in Alumina Plants With a Vacuum Drum Filter With a Stripping Cylinder (Aluminiumipari Tervezo Vallalat, Hung.). Bonyasz. Kohasz. Lapok. Kohasz 106(6):282-5, 1973 (Hung).
- B-63. Konig, P. Filtration of Red Mud on a Vacuum Filter With a Pickup Roll. Tsvetn. Met. (9):25-8, 1974 (Russ).
- B-64. Kaempf, F. and J. Tusche. Experience on Filtration of Red Mud by Rotary Filters (Ver. Aluminium-Werke A.-G., Bonn, Ger.). Z. Erzbergbau Metallhuettenw. (2019), 402-9, 1967 (Ger).
- B-65. Kaempf, F. Tests on Rotary Filters for the Filtration of Red Mud. Aluminum 45(8):473-6, 1969 (Ger).
- B-66. Plaetschke, H. Separation of Red Mud With Rotary Filters (Ver. Aluminiumwerke A.-G., Bonn. Ger.). Bauxite, Alumina, Alum., Proc., Int. Symp. ICSOBA 2nd 1969, 3, 181-5, 1971.
- B-67. Martin, J. L., Jr. Filtration of Alkali Metal Aluminate Solutions (To Aluminum Co. of America). U.S. 2,822,091, February 4, 1958.
- B-68. Polyakov, L. N. and I. K. Skobeev. Filtration of Red Muds (Bayer Process). Obogasch. Met. Polez. Iskop. 27-9, 1970 (Russ).
- B-69. Schwalbach, W. History of Continuous Red Mud Filtration and Methods of Aluminate Liquor Clarification and Hydrate Separation (Dorr-Oliver G.m.b.H. Wiesbaden, (Ger.). Bauxite, Alumina, Alum., Proc. Int. Symp. ICSOBA, 2nd 1969 (Pub. 1971) 3, 187-200, 1971.
- B-70. Ihevnovaty, A. I. Effect of Physical Factors on the Filtration of Suspensions of Alumina Production (USSR). Tsvet. Metal. (1), 37-9, 1973 (Russ).
- B-71. Good, P. C. and O. C. Fussman. Centrifugal Dewatering of Jamaican Red Mud. U.S. Bureau of Mines, R.I. 7140, June 1968.
- B-72. Vogt, M. F. and D. L. Stein. Dewatering of Large Volume Aqueous Slimes; Sand Bed Filtration of Bauxite Residue, paper presented at Annual AIME Meeting, Las Vegas, Nevada, February 1976.
- B-73. Vogt, M. F. Development Studies on Dewatering Red Mud, paper presented at the 103rd Annual Meeting of the AIME, Dallas, Texas, February 1976.

RED MUD UTILIZATION

Recovery of Alumina

- C-1. Lainer, A. I., and I. N. Kitler. Red Sludge as an Additional Source of Raw Material for the Alumina Industry. *Tsvetnye Metal.* 19(6):54-8, 1946.
- C-2. Nagai, S., and Y. Nakamura. Utilization of "Al residual Ash". IV. *J. Electrochem. Soc. Japan.* 14:12-15, 1946.
- C-3. Papuashvili, S. N., M. E. Shishinashvili, and M. V. Pirtskhalava. Preparation of Aluminum Oxide From the Red Earth. *Trudy Inst. Khim. im. P. G. Melikishvili, Akad. Nauk Gruzin. S.S.R.* 11:61-70, 1953.
- C-4. Takahashi, T. Sodium Hydroxide and Alumina Recovery From a Residue From Alumina Manufacture From Bauxite. Showa Electric Industry Co., Inc. Japan 4867-('60), May 10, 1960.
- C-5. Khodak, L. P., N. N. Varlamova, and G. N. Kozhevnikov. The Removal of Alumina and Alkali From the Slags Obtained on Reduction Fusion of Red Mud. *Ural Branch Acad. Sci. U.S.S.R., Sverdlovsk. Izv. Sibirsk. Otd. Akad. Nauk SSR.* (7):64-70, 1962.
- C-6. Voros, I., Z. Pais, L. Bunda, P. Nagy, and Mrs. Z. Toth. Recovery of Sodium Hydroxide and Alumina from Red Mud. *Hung.* 149,730, August 31, 1962.
- C-7. Ni, L. P., V. D. Ponomarev, and E. F. Osipova. Combined Hydrochemical Treatment of Red Mud and Nepheline. *Tr. 3-go [Tret'ego] Vses. Sovesch. po Khim. i Tekhnol. Glinozema, Erevan.* 145-55, 1964.
- C-8. Vosyka, J. Recovering Soda and Aluminum Oxide From Bauxite Waste Material in the Production of Aluminum Oxide. *Czech.* 120,273. 2 pp. October 15, 1966.

- C-9. Mukhymbekova, M. K., K. B. Bekshebaeva, and A. R. Rakhimov. Simultaneous Leaching of Aluminosilicate Slags With Red Mud. Tr. Khim. -Met. Inst., Akad. Nauk Kaz. SSR. (11):3-8, 1969.
- C-10. Egorova, I. V., and E. I. Khazanov. Treatment of Red Muds of Diaspore Bauxites. Izv. Nauch. -Issled. Inst. Nefte-Uglekhim. Sin. Irkutsk. Univ. (12):124-5, 1970.
- C-11. Bereza, L. V., N. F. Pecherskaya, and L. P. Ni. Use of an Experiment Planning Method During the Leaching of an Alumina-Containing Charge. Tr. Inst. Met. Obogashch., Akad. Nauk Kaz. SSR. (49):31-6, 1973.
- C-12. Lainer, A. I., L. G. Simakova, and V. I. Pauker. Extraction of Alumina From Highly Ferruginous Red Mud. Izv. Vyssh. Ucheb. Zaved., Tsvet. Met. 17(2):58-61, 1974.

Recovery of Iron

- C-13. Bejna, F. Agglomeration of Powdered Ores and Preparation of Ores Rich in Silica and Poor in Iron. Banydsz. Kohasz. Lapok. 77:181-90, 1944.
- C-14. Budavideki Vasgyar, R. T. Recovery of Iron From Muds Containing Iron Oxides. Hung. 132,574, February 15, 1944.
- C-15. Compagnie de produits chimiques et electrometallurgiques Alais, Froges & Camargue. The Metallurgical Treatment of Red Slimes and Residues From the Residues From the Refining of Aluminum. Fr. 897,608, March 27, 1945.
- C-16. Ibid. Separation of "Red Muds" in the Manufacture of Alumina by the Bayer Process. Brit. 592,324, September 15, 1947.
- C-17. Seailles, J. C. Recovering Alumina and a Residue Rich in Iron Out of Bauxites. Brit. 616,103, January 17, 1949.
- C-18. Yasumasa, H. Direct Reduction of Red Mud. J. Electrochem Soc. Japan. 15:64-6, 1947.
- C-19. Stirling, B. Availability of Roasted Pyrite and of Red Silt Obtained in the Working Up of Bauxite Ores for Iron Metallurgic Purposes. Banydszati es Kohaszati Lapok. (81):135-41, 1948.
- C-20. Guidi, A. Cast Iron From "Red Muds" of the Bauxite Bayer Process. Ital. 461,988, February 21, 1951.

- C-21. Gerdemann, J. H. Manufacture of Slag Wool. Ger. 823,425, December 3, 1951.
- C-22. Mukoyama, M. Simultaneous Production of Calcium Carbide and Iron in the Electric Furnace. Japan 5980, October 8, 1951.
- C-23. Sugimoto, S. Refining of Iron From Bauxite. Nippon Light Metals Co. Japan. 4308, October 22, 1952.
- C-24. Heck, C. Iron Powder From Bayer Process Wastes. Ger. 894,843, October 29, 1953.
- C-25. Heck, C. Ferromagnetic Substances From Bayer Process Red Mud. Ger. 917,726, September 9, 1954.
- C-26. Horvatn, Z., N. Wieder, and A. Horvath. Reduction in Coal Gas of High-Iron and High-Silica Bauxite of Scöc, Hungary. Magnetic Separation of Red Mud Obtained by the Bayer Method. Acta Tech. Acad. Sci. Hung. (11):363-404, 1955.
- C-27. Riesel, W., and R. Peters. Processing of Red Mud From Bauxite. Ger. (East) 11,379, March 17, 1956.
- C-28. Akt.-Ges., M. Thomas Steel. Brit. 797,838, July 9, 1958.
- C-29. Viens, G. E., R. A. Campbell, and R. R. Rogers. Experimental Electric Smelting of Ores and Related Materials at the Department of Mines and Technical Surveys, Ottawa. Trans. Can. Inst. Mining Met. 60 (in Can. Mining Met. Bull. No. 538:70-7, 1957).
- C-30. Kippe, O. Beneficiating Low-Grade Iron Ores by Adding the Red Sludge Residue From the Bauxite Treatment. U.S. 2,842,434, July 8, 1958.
- C-31. Watanabe, T., and E. Yuki. Fine Powders From High-Purity Reduced Iron. Japan 13,202, September 10, 1958.
- C-32. Rozentreter, R. G., N. S. Berseneva, and A. A. Goryunova. Sintering Bayer Muds With Calcium Carbonate and Reducing Substances. Khim. i Tekhnol. Glinozema, Inst. Met. i Obogashch., Akad. Nauk Kaz. SSR, Tr. Vses. Soveshch., Alma-Ata. 72-82, 1959.
- C-33. Zalesskaya, S. V. Sintering of Red Sludge in the Presence of Lime. Trudy Gor'kovsk. Politekh. Inst. 15(5):63-9, 1959.

- C-34. Rouaux, M. E. Rotary Furnace for Reduction of Metallic Ores With Hydrogen-Containing Gases. U.S. 2,964,309, December 13, 1960.
- C-35. Samarin, A. M., A. V. Rudneva, and S. V. Zaleskaya. Effect of Phase Compn. of Slags on Gravitational Separation of Pig Iron During the Reductive Smelting of Agglomerates of Red Sludge. Izvest. Vysshikh. Ucheb. Zavedenii, Chernaya Met. (6):20-6, 1961.
- C-36. Herzog, E., and L. Backer. Extraction of Iron From Rich Residues Containing High Percentages of Sodium, Silicon, and Aluminum. Fr. 1,301,964. 6 pp, August 24, 1962.
- C-37. Molnar, L., J. Zambo, Z. Osvald, and K. Solymar. Treatment of Iron-Containing Ores, Particularly Bauxites. Hung. 150,471. 10 pp, April 3, 1962.
- C-38. Magyarosi, I., and E. Skuteczky. Preparation of the Red Sludge in Alumina Manufacture for Smelting. Femip. Kut. Int. Kozlemen. (6):91-8, 1962.
- C-39. Cartoux, H., and F. Dubrous. Cast Iron or Steel From Ferrosilicon. Fr. 1,325,801. 12 pp, May 3, 1963.
- C-40. Kaltenbach, R. Magnetic Separation of Metal Ores. Fr. 1,330,166. 9 pp, June 21, 1963.
- C-41. Bychin, A. I., and B. Z. Kudinov. Perspectives of Rational Metallurgical Treatment of Red Mud. Tsvetn. Metal. 36(2):49-52, 1963.
- C-42. Zaleskaya, S. V. Viscosity of Slags Produced During Reducing Melting of Sinters of Red Mud. Izv. Vysshikh Uchebn. Zavedenii, Chern. Met. 7(1):38-40, 1964.
- C-43. Miller, V. Ya., and A. I. Ivanov. Rational Utilization of Red Mud. Tsvetn. Metal. 36(2):45-9, 1963.
- C-44. Magyarosy, I. Preparatory Methods of the Smelting of Hungarian Red Muds and a Comparison of Their Economics. Femip. Kut. Int. Kozlemeny. 7:135-42, 1964.
- C-45. Arkhipov, O. A. Electrosmelting Characteristics of an Agglomerate of Red Mud. Tr. Inst. Met. Gos. Kom. po Chern. i Tsvetn. Met. pri Gosplane SSSR. (10):122-8, 1964.

- C-46. Miller V. Ya., A. I. Ivanov, and V. A. Utkov. Behavior of Sulfur and Alkali in Sintering Red Muds. *Zh. Prikl. Khim.* 38(11):2407-10, 1965.
- C-47. Visnyovszky, L. Production of Crude Iron From Red Mud. *Symp. Bauxites, Oxydes Hydroxydes Aluminum, Zagreb.* (3):142-6, 1963.
- C-48. Dobos, G., and G. Horvath. Laboratory Studies for Determining the Optimum Mixture Composition for the Processing of Red Mud According to the Krupp-Renn Process. *Femip. Kut. Intez. Kozlem.* (8):55-61, 1966.
- C-49. Majercak, S., V. Mihalic, N. Konopljova, V. Maly, and M. Zoricak. Utilizing Red Mud in Pig Iron Production. *Hutnicke Listy.* 21(8):515-17, 1966.
- C-50. Kudinov, B. Z., A. I. Bychin, L. I. Leont'ev, V. A. Kiselev, and V. B. Fetisov. Pilot-Plant Tests of Flow-Sheet for Metallurgical Treatment of Red Mud in Rotary Furnaces. *Tsvet. Metal.* 40(1):63-5, 1967.
- C-51. Colombo, U., and G. Sironi. Iron Sponge From Bayer Process Red Slurry. U.S. 3,295,961. 6 pp, January 3, 1967.
- C-52. Dobos, G., L. Bartha, Z. Felfoldy, G. Kaptay, Z. Osvald, and K. Solymar. Processing of Red Mud by Reducing Heat Treatment. *Hung.* 154,125. 15 pp, November 22, 1967.
- C-53. Novak, J., Z. Ruzickova, and P. Vejnar. Pelletization of Powdered Iron Ores. *Czech.* 129,262. 2 pp, October 15, 1968.
- C-54. Bowden, J. J. By-Products of Aluminum Production as Fluxes for Steel. U.S. 3,320,052. 3 pp, May 16, 1967.
- C-55. Kudinov, B. Z., A. I. Bychin, V. A. Kiseiev, and L. I. Leont'ev. Results of Pilot-Plant Experiments for Treating Red Muds in a Two-Stage Rotary Furnace. *Tr. Inst. Met., Sverdlovsk.* (14):94-8, 1967.
- C-56. Baktubaeva, S. S., R. S. Kaheva, A. R. Rakhimov, and V. K. Gruzinov. Production of Fluxed Pellets From Lisakov Calcination-Magnetic Concentrates Containing Additions of Red Mud. *Tr. Khim.-Met. Inst., Akad. Nauk Kaz. SSR.* (6):8-12, 1969.
- C-57. Kalieva, R. S., S. S. Baktubaeva, R. D. Simbinov, and V. K. Gruzinov. Effect of Red Mud Additions on the Softening Point of Lisakov Concentrate Fluxed Pellets. *Tr. Khim.-Met. Inst., Akad. Nauk Kaz. SSR.* (6):13-18, 1969.

- C-58. Raizman, V. L., L. P. Ni, V. G. Kazakov, M. Ya. Yakovlev, V. R. Udalov, and V. D. Ponomarev. Pilot-Plant Tests of the Autoclave Leaching of Red Muds by a Hydrochemical Method. *Tr. Inst. Met. Obogashch., Akad. Nauk Kaz. SSR.* (28):82-9, 1969.
- C-59. Gyula, H., and K. Sztrokay. Production of Magnetite and Sponge Iron From Red Mud. *Banyasz. Kohasz. Lapok, Kohasz.* 103(5):193-9, 1970.
- C-60. Hatarascu, O., F. Schieber, E. Stoicovici, and V. Mitran. Metallurgical Utilization of Red Mud [From Aluminum Manufacture]. *Metalurgia (Bucharest).* 22(4):253-6, 1970.
- C-61. Kudinov, B. A., L. I. Leont'ev, A. I. Chernogolov, and S. N. Gushchin. Scheme of Rotary Furnace Installations for Converting Red Muds and Organization of its Heating Operation. *Tr. Inst. Met., Sverdlovsk.* (22):50-5, 1970.
- C-62. Drugalev, S. M., B. Z. Kudinov, and L. I. Leont'ev. Red Muds, Valuable Industrial Raw Material. *Tr. Inst. Met., Sverdlovsk.* (22):56-62, 1970.
- C-63. Fursman, O. C., J. E. Mauser, M. O. Butler, and W. A. Stickney. Utilization of Red Mud Residues from Alumina Production. U.S. Clearinghouse Fed. Sci. Tech. Inform., PB Rep. 1970, No. 196608. 37 pp (Eng).
- C-64. Steintveit, G. Precipitation of Iron From Sulfate Solutions From Zinc Leaching. *Ger. Offen.* 2,117,584. 11 pp, April 6, 1972.
- C-65. Bayer, G. Economic Removal of Red Mud. *Erzmetall.* 25(9):454-7, 1972.
- C-66. Horvath, G., Z. Felfoldi, Z. Oswald, K. Solymar, A. Juhasz, G. Dobos, and G. Kaptay. Dressing of the Red Mud From the Alumina Manufacture. *Ger. Offen.* 2,218,464. 20 pp, November 2, 1972.
- C-67. Sugiyama, Y., and S. Sasaki. Flux in Steel Refining. *Ger. Offen.* 2,306,804. 6 pp, September 6, 1973.
- C-68. Kapolyi, L., F. Lazar, B. Galauner, L. Dzisda, G. Vamos, L. Wagner, and A. Pogany. Processing of Red Mud. U.S. 3,776,717. 4 pp, December 4, 1970.
- C-69. Murakami, K., K. Fukuro, and S. Matsumura. Basic Slag-Forming Agent. *Ger. Offen.* 2,205,633. 10 pp, July 12, 1973.

- C-70. Sho, K. Flux Made of Acid-Treated Red Mud. Japan Kokai 74 09,417. 4 pp, May 26, 1972.
- C-71. Horvath, Gy. Test of Red Mud Smelting by Thermal Analysis. Aluminum (Duesseldorf). 50(3):221-7, 1974 (Eng).
- C-72. Utkov, V. A., N. A. Vatolin, V. V. Kashin, P. S. Kondrashova, and G. I. Chufarov. Strengthening of a Sinter With Red Mud. Stal'. (5):397-400, 1974 (Russ).
- C-73. Sasaki, S. Slag-Forming Agent for Steel Refining. Japan Kokai 74 74,611. 5 pp, July 18, 1974.
- C-74. Srb, J., and Z. Ruzickova. Steel Casting Additive. Czech. 154, 441. 2 pp, August 15, 1974.

Recovery of Titania

- C-75. Das-Gupta, P. C., and H. N. Das-Gupta. Recovery of Titania From Bauxite Wastes. J. Indian Chem. Soc., Ind. & News Ed. 4. 4:15-20, 1941.
- C-76. Desai, R. D., and F. R. Peermahomed. Recovery of Alumina and Titania From Bauxite Sludge. J. Indian Chem. Soc., Inc. & News Ed. 8. 8:9-13, 1945.
- C-77. Bhatnagar, S. S., S. Parthasarathy, G. C. Singh, and A. L. Sundara Rao. Pilot Plant for the Recovery of Titanium Dioxide From Bauxite Sludge. J. Sci. Ind. Research (India). 4:375-81, 1945.
- C-78. Logomerac, V. The Production of Titanium Compounds and Ferrotitanium From Red Mud. Teknicki preglev (Zagreb). 5:3-9, 1953.
- C-79. Imai, H., and S. Kadota. Treatment of Bauxite Red Earth for Extraction of Titanium. Japan 1825('54). April 7, 1954.
- C-80. Centre national de la recherche scientifique. Concentrating Titanium Dioxide From Red Mud and Recovery of Titanium. Fr. 1,142,679, September 20, 1957.
- C-81. Orliac, M., and L. Capdecemme. Titanium Oxide Concentrates from Bauxite Red Mud. Fr. 1,152,128, February 12, 1958.

- C-82. Achs, M. Preparation of Titanium Dioxide From Hungarian Bauxites and Red Sludge for the Manufacture of Ferrotitanium. Kohaszati Lapok. 91:157-8, 1958.
- C-83. Aradi, A. Utilization of Fused Slags From Red Sludge (Originating From the Alumina Manufacture by the Bayer Method). Femipari Kutato Intezet Kozlemenyei. (2):48-63, 1958.
- C-84. Ponomarev, V. D., L. P. Ni, and V. S. Sazhin. Treating Titanium-Containing Red Mud. U.S.S.R. 117,646, February 6, 1959.
- C-85. Marcarovici, C. Gh., L. Czegledi, H. Roth, and I. Soos. Preparation of Titanium Dioxide From the Residual Red Muds of Alumina Manufacture. Acad. rep. populare Romine, Filiala Cluj, Studii cercetari stiint., Ser. 1, Stiinte mat., fiz., chim. si tehnice. 6(3-4):87-109, 1955.

Recovery of Iron and Alumina

- C-86. Gillemot, L. Improved Utilization of Bauxites. Aluminum (Budapest). (2):25-32, 1950.
- C-87. Lanyi, B. Utilization of the Red Mud Obtained From the Bayer Process. Aluminum (Budapest). (2):40-50, 1950.
- C-88. Seailles, J. C. Aluminum and Iron From Bauxite. Fr. 981,516, May 28, 1951.
- C-89. Sugimoto, S., and Y. Ito. Recovering of Iron and Alumina From Red Earth. Japan. 4454('52), October 31, 1952.
- C-90. Sugimoto, S., and Y. Ito. Recovery of Alumina and Iron From Red Mud. Japan. 2625('54), May 14, 1954.
- C-91. Dobos, G., and K. Solymar. Extraction of Iron and Aluminum From Hungarian (Bayer Process) Red Mud. Symp. Bauxites, Oxydes Hydroxydes Aluminium, Zagreb. (3):132-4, 1963.
- C-92. Hemmann, A. O. Working Up the Wastes of Aluminum Manufacture From Bauxite. Ger. 1,143,529, February 14, 1963.
- C-93. Visnyovszky, L. The Smelting of Bauxite and Red Mud. Vasipari Kutatoint. Evkonyve. 1:24-35, 1963.

- C-94. Dobos, D., J. Zambo, and L. Vishn'ovskii. Utilization of Bayer Process Red Mud for the Production of Iron and Aluminum. *Tsvetn. Metal.* 37(2):36-40, 1964.
- C-95. Dobos, G., G. Kaptay, and Z. Osvald. Recovery of Fe and Al From Hungarian Red Mud. *Freiberger Forschungsh.* 103B:19-33, 1965.
- C-96. Dobos, G., G. Kaptay, and Z. Osvald. Extraction of the Iron and Aluminum Contents From Hungarian Red Slurry. *Kohasz. Lapok.* 98:14-19, 1965.
- C-97. Horiguchi, Y., and S. Katayama. Treatment of Red Mud With Sulfurous Acid. *Keikinzoku.* 15(4):5-10, 1965.
- C-98. Dobos, G. Further Development of the Bayer Method Applied in the Al_2O_3 Industry for the Purpose of Improving Al_2O_3 Output and a Better Use of the Fe Content in Bauxite. *Acta Tech. Acad. Sci. Hung.* 55(3-4):303-26, 1966.
- C-99. Kiselev, V. A., L. I. Leont'ev, B. Z. Kudinov, A. I. Bychin, and G. P. Dubotolkov. Some Parameters for Converting Red Muds Into Cast Iron and Aluminum Oxide. *Tr. Inst. Met., Sverdlovsk.* (14):89-93, 1967 (Russ).
- C-100. Eremin, N. I. Complex Processing of Bauxites. *Bauxite, Alumina, Alum., Proc. Int. Symp. ICSOBA, 2nd.* (3):329-35, 1969.
- C-101. Matyash, V. G., L. I. Leont'ev, and B. Z. Kudinov. Reduction of Iron Oxides in Red Muds. *Tr. Inst. Met., Sverdlovsk.* (22):46-9, 1970.
- C-102. Dobos, G., K. Solymar, and G. Horvath. Complex Processing of Red Mud in Hungary. *Banyasz. Kohasz. Lapok, Kohasz.* 105(9):417-26, 1972.
- C-103. Belsky, M. Decomposition of Red Mud From the Bayer Process. *Ger. Offen.* 2,060,766. 10 pp, June 22, 1972.
- C-104. Dobos, G., Z. Felfodi, G. Horvath, G. Kaptay, Z. Osvald, and K. Solymar. Processing of Red Mud. *Hung. Teljes* 6,759. 14 pp, August 28, 1973.

- C-105. Kunaev, A. M., L. P. Ni, S. M. Kozhakhmetov, B. K. Zhakibaev, L. G. Romanov, E. N. Suleimenov, R. Z. Zhalelev, and B. Sh. Dzhumabaev. Cyclone Smelting of High Iron Bauxites and Red Mud for Their Complex Use. Vestn. Akad. Nauk Kaz. SSR. (1):46-50, 1974 (Russ).
- C-106. Red Mud Processing, Especially the Recovery in One Heat Treatment Operation of the Aluminum and Iron. German 2,328,674, June 6, 1972.

Recovery of Iron and Titania

- C-107. Calhoun, W. A. Titanium and Iron Minerals From Black Sands in Bauxite. U.S. Bur. Mines, Rept. Invest. No. 4621. 16 pp, 1950.
- C-108. Baetz, H. B., and R. C. Lightbourne. Treating Red Mud for Extracting Iron or Titanium. U.S. 3,690,828. 7 pp, September 12, 1972.

Recovery of Different Materials

- C-109. Fleischer, M., K. J. Murata, J. D. Fletcher, and P. F. Narten. Geochemical Association of Niobium and Titanium and Its Geological and Economic Significance. U.S. Geol. Survey Circ. 225. 1-13, 1952.
- C-110. Papp, E. Possibilities of Recovery of Rare Elements From Bauxites During Alumina Production by the Bayer Process. Freiburger Forschungsh. B67:117-30, 1962.
- C-111. Veres, I. Extraction of the V Content of Bauxite During the Production of Al_2O_3 by the Bayer Process. Acta Tech. Acad. Sci. Hung. 41(3-4):259-68, 1962.
- C-112. Bibikova, V. I., and R. V. Ivanova. Production of Metallic Gallium From Aluminum Raw Materials. Freiburger Forschungsh. B82:17-24, 1964.
- C-113. Zazubin, A. I., and A. N. Barshchevskaya. Distribution of Gallium During Treatment of High-Silica Bauxites by Hydrochemical Alkaline Method. Tr. Inst. Met. i Obogashch., Akad. Nauk Kaz. SSR. 9:103-5, 1964.
- C-114. Horak, J., and V. Friedrich. Processing Red Mud in the Manufacture of Aluminum to Obtain Metals, Especially Vanadium. Czech. 114,670. 3 pp, May 15, 1965.

- C-115. Friedrich, V. Production of Vanadium Slag From Bauxite Red Mud. Tech. Dig. 9(7):443-4, 1967.
- C-116. Logomerac, V. G. Distribution of Rare-Earth and Minor Elements in Some Bauxite and Red Mud Produced. Bauxite, Alumina, Alum., Proc. Int. Symp. ICSOBA, 2nd. (3):383-93, 1969.
- C-117. Bhattacharyya, B. N. Recovery of Vanadium From Indigenous Sources Including Bauxite Sludge. Mines Miner. (Nagpur, India). 7(4):119-25, 1970.
- C-118. Kitsugu, N. Firing of a Chromium Ore. Japan. 73 44,606. 3 pp, December 26, 1973.
- C-119. Makhmetov, M. Zh., V. P. Malyshev, L. G. Gorokhova, V. G. Shkodin, A. I. Poluboyarinov, I. A. Golomzik, A. I. Chernobai, I. S. Uzentsev, and V. I. Chuprakov. Conversion of Arsenic-Containing Materials. U.S.S.R. 429,110, May 25, 1974.
- C-120. Castells, L. D. Recovery of By-Products From Chemical Treatment of Bauxites. Span. 198,160, June 15, 1953.
- C-121. Machlet, A. W. Treatment of Ferrous Metals With Red Mud. U.S. 2,683,675, July 13, 1954.
- C-122. Terebesi, L., and J. Kornyei. Chlorination of Red Mud (From the Manufacture of Alumina). Kohaszati Lapok. (90):460-5, 1957.
- C-123. Udy, M. J. Recovery of Iron, Titanium Oxide, and Alumina From Ores and Wastes. U.S. 2,830,892, April 15, 1958.
- C-124. Gregoire, F.A.A., and R. Ricard. Extraction of Metals From Red Mud and Other Residues of Metallurgical Industries. Fr. 1,157,477, May 29, 1958.
- C-125. Miller, V. Ya., and A. I. Ivanov. Characteristics and Means of a Recovery-Complex of Red Mud. Trudy Inst. Met., Akad. Nauk S.S.S.R., Ural. Filial. (2):257-63, 1958.
- C-126. Ni, L. P. The Extraction of Aluminum, Iron, and Sodium Oxide From Red Mud. Izvest. Akad. Nauk. Kazakh. S.S.R., Ser. Met., Obogashchen. i Ogneuporov. (1):21-6, 1960.
- C-127. Colombo, U. Reclaiming Iron, Titanium, and Aluminum From the Red Mud Obtained in the Treatment of Bauxite. Belg. 623,931. 19 pp, April 23, 1963.

- C-128. Mitsubishi Shipbuilding & Engineering Co., Ltd. Metal Recovery From Bauxite Residues. Fr. 1,353,118. 9 pp, February 21, 1964.
- C-129. Cazafura, K., and J. Feges. Principles for the Production of Titanium, Aluminum, and Vanadium From Red Mud Acid Leaches. Rudarsko-Met. Zbornik. (3):225-4, 1964.
- C-130. Logomerac, V. G. Metallurgical Processing of Red Mud to Produce Useful Elements. Symp. Bauxites, Oxydes Hydroxydes Aluminum, Zagreb. 3:153-65, 1963.
- C-131. Gol'dman, M. M., L. V. Bunchuck, O. F. Kuchanskaya, L. P. Ni, and V. D. Ponomarev. Leaching of Red Mud by Hydrogarnets. Tr. Inst. Met. Obogashch., Akad. Nauk Kaz. SSR. 16:111-17, 1966.
- C-132. Zazubin, A. I., A. N. Barshchevskaya, and G. M. Potapova. Complex Reprocessing of Red Mud. Tr. Inst. Met. Obogashch., Akad. Nauk Kaz. SSR. 25:3-7, 1967.
- C-133. Zalesskaya, S. V. Reduction of Some Components in the Smelting of Red Mud Sinter. Izv. Vyssh. Ucheb. Zaved., Chern. Met. 11(9):40-3, 1968.
- C-134. Sai, Z. Recovery of Useful Materials From Red Muds in Alumina-Manufacturing Process. Japan. 70 25,762. 3 pp, August 26, 1970.
- C-135. Tsai, J. H. Separation of Iron Oxide, Sodium Sulfite, Alum, and Silica Gel From Waste Formed During the Production of Alumina by the Bayer Process. Brit. 1,203,950. 3 pp, September 3, 1970.
- C-136. Kudinov, B. Z., A. I. Bychin, V. A. Kiselev, L. I. Leont'ev, A. S. V'yukhina, and L. M. Dmitrieva. Complex Treatment of Red Muds of Alumina Production. Khim. Tekhnol. Glinozema. 399-401, 1971.
- C-137. Kapolyi, L., F. Lazar, B. Glauner, L. Dzsida, G. Vamos, L. Wagner, and A. Pogany. Removal of Sodium From Red Mud. Hung. Teljes 4243. 8 pp, May 27, 1972.
- C-138. Dobos, G., K. Selymar, and G. Horvath. Principles and Technological Problems in the Complex Working-Up of Red Mud. Aluminium (Duesseldorf). 48(12):808-10, 1972.
- C-139. Yang, C. B., R. R. Choe, R. M. Chang, and N. S. Choe. Sintering of Kyanite Bauxite. 1. Choson Minjujuui Inmin Konghu agul. Kivahagwon Tongbo. (6):28-30, 1973.

- C-140. Logomerac, V. G. Complex Processing of Red Mud. Neue Huette. 20(3):145-8, 1974.
- C-141. Lovashi, I., L. P. Ni, A. I. Zazubin, and Yu. N. Evseev. Multiple Treatment of Red Mud. Vestn. Akad. Nauk Kaz. SSR. (1):30-3, 1975.
- C-142. Calhoun, W. A., and T. E. Hill, Jr. Metallurgical Testing of Hawaiian Ferruginous Bauxites. Concluding Report U.S. Bureau of Mines, Rept. Invest. 6944, 1967.
- C-143. Processing of Red Mud-Composition Recovery of Cryolite, Iron, Aluminum and Titanium. French 2, 117, 930, December 10, 1970.
- C-144. Logomerac, V. G. The Distribution of Rare-Earth and Minor Elements in Some Bauxite and Red Mud Produced. Proc. Second Int. Symp., Int. Comm. for Studies of Bauxite, Oxides, Hydroxides of Aluminum (ICSOBA) Research Institute for Nonferrous Metals, Budapest, Vol. 3, 383-393, 1971.
- C-145. Gerisch, S., H. Martens and S. Ziegenbalg. Winning of Vanadium Slag From By-Product of Bauxite Treatment. Neue Huette. 14(4):204-10, 1969.

NONMETALLURGICAL

Cement Material

- D-1. Katayama, S., and Y. Horiguchi. Utilization of Red Mud. II. Effects of Red Mud on the Properties of Cements. Rika Gaku Kenkyusho Hokoku. 39(6):407-10, 1963.
- D-2. Uryvacva, G. D. Slurry Wastes [Slags] in the Metallurgical Industry and Their Utilization. Tverdenie Izvestkovo-Glinyanykh Smesei i Shlamovykh Otkhodov, Akad. Nauk SSSR, Sibirsk. Otd., Khim. -Met. Inst. 62-114, 1964.
- D-3. Beisher, R. V. Use of the Tikhvin Alumina Plant Bauxite [Red] Mud in Highway Construction. Sb. Tr. Melodykh Uch. Mekh. -Avtodorozh. Fak., Leningrad. Inzh. -Stroit. Inst. 8-17, 1968.
- D-4. Pashchenko, A., G. Baklanov, E. Starchevskaya, and E. Myasnikova. Hydration of Cements Using Red Mud. Budiv. Mater. Konstr. (5):41-2, 1972.

- D-5. Mitsugi, T. Fluidizing Calcination of Red Mud. Tohoku Daigaku Senko Seiren Kenkyusho Iho. 18(1):61-73, 1962.
- D-6. Tohei, H., and M. Fujii. Preparation of Refractory Concrete or Mortar. Japan. Kokai 73 31,228. 3 pp, April 24, 1973.
- D-7. Hoguchi, Y., and S. Katayama. Utilization of Red Mud. I. Effects of the Addition of Red Mud on the Properties of Cements. Rika Gaku Kenkyusho flokuku. 37:101-5, 1961.
- D-8. Straszak, S., A. Krasnokucki, W. Stras, H. Wierzbowski, M. Broszewski, and J. Bartecki. Cement Clinker. Pol. 52,050. 2 pp, November 10, 1966.
- D-9. Biancheri, J. A Process for the Treatment of Alumina Muds for Construction Blocks. Fr. 1,469,953. 2 pp, February 17, 1967.
- D-10. Brodtko, A. S., G. M. Baklanov, A. A. Pashchenko, E. M. Pavlotskii, and O. S. Ovcharenko. Mineral Binder. U.S.S.R. 417,386. February 28, 1974.
- D-11. Youth, C. C. Red Mud. Iron Source for the Cement Industry. K'uang Yeh. 17(2):25-7, 1973.
- D-12. Wargalla, G. Use of Red Mud in the Production of Cement and Expanded Clay. Erzmetall. 26(1):18-20, 1973.
- D-13. Gol'dman, M. M., and V. D. Ponomarev. Composition of Solid Phases in Conversion of Red Mud From Alumina Production. Izvest. Akad. Nauk, Kazakh. S.S.R., Ser. Met., Obogashchen. i Ogneuporov. (3):40-9, 1961.
- D-14. Horvath, G. Production of Self-Decomposing Calcium Aluminate Slag From Red Mud. Banyasz. Kohasz. Lapok, Kohasz. 105(10):471-6, 1972.
- D-15. "Licencia" Talalmanyokat Ertekesito Vallalat. Cement Additives. Brit. 975,378. 2 pp, November 18, 1964.
- D-16. Katayama, S., and V. Horiguchi, Utilization of Red Mud. I. Effects of the Addition of Red Mud on the Strength of Cements with Time. 1. Rika Gaku Kenkyusho Hokoku. 39(5):224-5, 1963.
- D-17. Katayama, S. Utilization of Red Mud. V. Physical Tests of Cements Blended With Calcined Red Mud. Rika Gaku Kenkyusho Hokoku. 40(3):194-202, 1964.

- D-18. Karbt, D., M. Matousek, L. Novak, and Z. Vaja. Brown Bauxite Waste Slurry, A New Kind of Admixture for Light Concrete. *Stavivo*. 38:250-3, 1960.
- D-19. Szekely, I. Cement Production by Using the Red Sludge of the Bauxite Industry. *Epiteanyag*. 12:28-37, 1960.
- D-20. Horiguchi, G., and S. Katayama. High Early-Strength Blended Cement. *Japan*. 16,984('62). 2 pp, October 20, 1962.
- D-21. Sugimoto, S., Y. Ito, and H. Kobayashi. Hydraulic Cement Containing Red Mud. *Japan*. 8315('61). 2 pp, June 22, 1961.
- D-22. Guruviah, S., and K. S. Rajagopalaa. Comparative Studies on the Protection Given by Paints Containing Red Mud, Red Mud-Red Oxide, Red Mud-Zinc Chromate Pigments. *Paintindia*. 16(3): 31-2, 34, 1966.
- D-23. Szekely, I. Ore Cements From Red Mud: Are They Fit for Use in the Building Industry? *Proc. Conf. Silicate Ind.*, 6th, Budapest. 399-408, 1961.

Lightweight Aggregate Material

- D-24. Ishihara, M., K. Takada, and Y. Yamanashi. Synthetic Lightweight Aggregate. *Japan*. Kokai 74 60,324. 3 pp, June 12, 1974.
- D-25. Nagasaki, M., and Y. Suzuki. Artificial Aggregate Containing Converter Slag and Red Mud. *Japan*. Kokai 73 49,819. 3 pp, July 13, 1973.
- D-26. Kloeckner-Humboldt-Deutz A. -G. Expanded Clay. *Fr.* 1,503,121. 2 pp, November 24, 1967.
- D-27. Wangalla, G. Use of Red Mud in the Production of Cement and Expanded Clay. *Erzmetall*. 26(1):18-20, 1973.
- D-28. Tacken, J. Production of Porous Clay Ceramics. *Ger.* 1,224,655. 2 pp, September 8, 1966.
- D-29. Hayashi, S., and K. Kato. Lightweight Concrete With High Mechanical Strength. *Japan*. Kokai 74 52,213. 5 pp, May 21, 1974.
- D-30. Utkov, V. A., B. Z. Kudinov, V. V. Kashin, S. G. Pavlyuk, P. S. Rempel, G. I. Chufarov, V. Kh. Vakulenko, M. V. Smetamin, and V. N. Peretyaka, Reinforcement of Agglomerate. *U.S.S.R.* 346,341, July 28, 1972.

- D-31. Pattas, E. Bloated Granules of Red Mud From Bauxite Decomposition. Ger. Offen. 2,033,260, November 25, 1971.
- D-32. Tacken, J. Expanded Granules of Clay. Fr. 1,540,632. 2 pp, September 27, 1968.
- D-33. Sann, R. Vitreous, Cellular Additives for Concrete. Fr. 1,526,207. 5 pp, May 24, 1968.

Construction Material

- D-34. Sugasawa, M. Solidifying Red Mud. Japan Kokai 74 52,766. 2 pp, May 22, 1974.
- D-35. Horioka, K. Building Material From Red Mud. Japan Kokai 74 99,719. 3 pp, September 20, 1974.
- D-36. Hegenbarth, R. Experiments in the Utilization of Red Mud. Aluminium (Duesseldorf). 48(11):748-50, 1972.
- D-37. Bayer, G., E. Cherdron, M. Haerter, and E. Hecht. Red Mud Bricks. Ger. Offen. 2,150,677. 8 pp, April 19, 1973.
- D-38. Tauber, E., R. K. Hill, D. N. Crook, and M. J. Murray. Red Mud Residues From Alumina Production as a Raw Material for Heavy Clay Products. J. Aust. Ceram. Soc. 7(1):12-17, 1971.
- D-39. Bayer, G., E. Cherdron, M. Haerter, and E. Hecht. Bricks From Red Mud. Ger. Offen. 2,063,028. 8 pp, June 29, 1972.
- D-40. Mori, S., and K. Kitsugi. Solidification of Hydrous Red Mud. Japan Kokai 74 69,569. 4 pp, July 5, 1974.
- D-41. Nakanishi, K. Solidification of Red Mud. Japan Kokai 74 45,892. 2 pp, May 1, 1974.
- D-42. Horioka, K. Hardened Products From Red Muds. Japan Kokai 74 99,781. 3 pp, September 20, 1974.
- D-43. Mori, S., and K. Kitsugi. Hydraulic Composition From Red Mud. Japan Kokai 74 69,759. 3 pp, July 5, 1974.
- D-44. Wilkening, S. Lightweight Building Material From Red Mud. Ger. Offen. 2,309,500. 7 pp, September 19, 1974.

- D-45. Horioka, K. Building Materials From Red Mud. Japan Kokai 74 99,781. 3 pp, September 20, 1974.
- D-46. Nudel'man, B. I., and A. T. Tairov. Use of Siliceous Bauxite Processing Wastes in the Production of Silicate Material. Kremnezemistye Shlamy Kislotnogn Razlozheniya Kaolinov Puti Ikh Ispol's. 26'42, 1971.
- D-47. Parimbetov, B. P., I. A. Kroichuk, A. G. Neiman, and N. A. Trebukhina. Physicochemical Principles of the Use of Bauxite Sludge. Strait. Mater. (5):18-19, 1973.
- D-48. Bayer, G., E. Cherdron, M. Haerter, and E. Hecht. Method for Producing Bricks From Red Mud. U.S. 3,886,244, October 10, 1972.
- D-49. Bayer, G., E. Cherdron, M. Haerter, and E. Hecht. Method for Producing Bricks From Red Mud. U. S. 3,886,245, December 21, 1971.
- D-50. Bayer, G., E. Cherdron, M. Haerter, and E. Hecht. Method of Producing Bricks From Red Mud. U.S. Application No. 153,651, October 11, 1972.
- D-51. Intezet, F. K., and E. Intezet. Briquetting Red Mud or Mixtures Containing Red Mud. Hung. 151,998. 10 pp, April 22, 1965.
- D-52. Mori, S., and K. Kitsugi. Solidifying Sludge By Adding Red Mud and Lime or Dolomite. Japan Kokai 74 66,570. 6 pp, June 27, 1974.

Plastic Resin Filler

- D-53. Nagata, T. Utilization of Waste Red Mud From Aluminum Refining. Japan Kokai 73 50,982. 2 pp, July 18, 1973.
- D-54. Machi, S., H. Kurihara, and T. Yagi. Polyolefin Composites Containing Red Mud. Japan Kokai 74 66,721. 5 pp, June 28, 1974.
- D-55. Funke, A., H. Wetzels, and G. Buhler. Rubber Fillers From Red Mud. Ger. (East) 19,854, September 20, 1960.
- D-56. Compagnie de produits chimiques et electrometallurgiques Alais, Froges & Camargue. Filler for Rubber Compositions. Fr. 978,108, April 10, 1951.

- D-57. Ketomo A. -G. Treating Natural and Synthetic Rubber. Swiss 274,574, July 2, 1951.
- D-58. Negata, N. Poly(vinyl Chloride)-Red Mud Composites. Japan Kokai 74 73,438. 4 pp, July 16, 1974.
- D-59. Riesel, W., R. Peters, and H. Weiser. Recovery of Powdered Fillers From the Red Mud Waste Liquors Obtained in the Production of Alumina From Bauxite According to the Bayer Process. Ger. (East) 62,820. 2 pp, July 20, 1968.
- D-60. Funke, A., H. Wetzell, and G. Buhler. Light-Colored Rubber Fillers by Concomitant Use of Red-Mud Extracts. Ger. (East) 19,295, July 22, 1960.
- D-61. Yuan, H. C., W. W. Hsu, U. P. Wang, C. C. Wu, J. S. Shieh, M. L. Chang, and T. D. Kung. Gamma-Ray Induced Polymerization of Unsaturated Polyesters in Red Mud. Large Radiat. Sources Ind. Processes, Proc. Symp. Util. Large Radiat. Sources Accel. Ind. Process. 383-97, 1969.

Pigments

- D-62. Charrin, V. Utilization of the "[Bayer] Red Wastes". Peintures, Pigments, vernis. 28:253, 1952.
- D-63. Charrin, V. Utilization of Some Industrial By-Products. Genie civil. 131:332-4, 1954.
- D-64. Habel, K. O. Red Mud as Raw Material for Colored Glass. Glastechn. Ber. 76:174-5, 1953.
- D-65. Foerster, H. Concrete Color Composition. Ger. (East) 57,543. 2 pp, August 20, 1967.
- D-66. Charrin, V. Bauxite Residues as Source of Pigments. Natl. Paint, Varnish Lacquer Assoc., Sci. Sect., Abstracts Rev. (139):198, 1948.
- D-67. Ramanujam, S. Bauxite Residues as [Corrosion] Inhibitive Primers. Paintindia. 12(5):22-34, 1962.

Coating Material

- D-68. Ramanujam, S., and R. V. Saluja. Primers Based on Red Mud. Indian 81,431. 4 pp, April 11, 1964.
- D-69. Wargella, G., and H. Plaetschke. Bituminous Mixtures Containing Treated Bauxite Residues. Brit. 1110168. 4 pp, April 18, 1968.
- D-70. Wilkening, S., Red Mud for Concrete Coating Materials. Ger. Offen. 2,210,607. 7 pp, September 6, 1973.
- D-71. Begardi, E. Caustification of the Red Mud From the Alumina Plants. Kohaszati Lapok. 90:194-9, 1957.
- D-72. Retezar, A., L. Pechy, and G. Gardos. Leaching of the Lime-Soda Fusion Product of the Red Sludge (From Alumina Manufacture According to the Bayer Process). Veszpremi Vegyipari Egyetem Kozlemenyei. 2:213-7, 1958.
- D-73. Balogh, K., B. Kochis, I. Magyarossy, and O. Polner. Recovery of NaOH From Red Mud. Hung. 152,325. 4 pp, September 22, 1965.
- D-74. Solymar, K., Mrs. J. Steiner, and L. Huszar. Washing and Causticization of Natrolites and Red Muds. Femip. Kat. Int. Kozlemen. 7:47-64, 1964.
- D-75. Karpenko, Z. S., Kh. N. Nurmagambetov, Yu. Khaliullin, and V. D. Ponomarev. Regeneration of Alkali From Bayer Red Slime of Turgai Bauxites. Sb. Statei Aspirantov i Soiskatelei, Min. Vyssh. i Sredn. Spets. Obrazov. Kaz. SSR, Met. i Obogashch. (1):3-7, 1965.
- D-76. Soudan, P., and J. Breton. Recovery of Alkali Solutions From Residues Obtained by the Alkaline Treatment of Bauxite. Ger. 1.061.756, July 23, 1959.

As Catalyst

- D-77. Sudzilovskaya, M. S., and E. V. Robozheva. Kinetics of Destructive Hydrogenation of Coal. Trudy Vsesoyuz. Nauch-Issledovatel. Inst. Iskusst. Zhidkogo Topliva i Gaza (VNIGI). (6):30-45, 1954.
- D-78. Yoshida, R., Y. Maekawa, and G. Takeya. Study of Coals Mildly Treated With Hydrogen Under High Pressure Using High-Resolution Nuclear Magnetic Resonance Spectroscopy. Effect of a Catalyst Composed of Red Mud and Sulfur. Nenryo Kyokai-Shi. 51(12): 1225-32, 1972.

- D-79. Tabuchi, K. Sulfide Catalyst for Obtaining Ethane and Ethylene From Mixed Gases. Japan 72 08,012. 3 pp, March 8, 1972.
- D-80. Brintziager, H., H. W. Ziegler, and A. Scholz. Polymers and Copolymers From Aromatic Compounds With a Halogenated Side Chain by Heterogeneous Catalysis. Angew. Chem. A60:271, 1948.

Fertilizer

- D-81. Matsumoto, E. Indirect Fertilizer. Japan 5767('53), November 10, 1953.
- D-82. Whittaker, C. W., W. H. Armiger, P. P. Chichilo, and W. M. Hoffman. "Brown Mud" From the Aluminum Industry as a Soil-Liming Material. Soil Sci. Soc. Amer., Proc. 19:288-92, 1955.
- D-83. Watanabe, T. Zeolitic Potassium Fertilizer From Red Mud. Japan 12,622 ('60), September 3, 1960.
- D-84. Hofmann, H., K. H. Reisner, S. Meyer, E. Friedrich, and E. Guenther. Treating Red Mud. Ger. (East) 67,721. 3 pp, July 5, 1969.

Various Useful Components

- D-85. Nishimoto, Y. Study on the Recovery of Reusable Components From Red Mud. Tech. Rev., Mitsubishi Heavy Ind. 3(1):59-67, 1966.
- D-86. Autran, L. Treating Red Mud and Utilization of Portions Recovered. Fr. 1,522,562. 3 pp, April 26, 1968.
- D-87. Reisner, K. H., and S. Meyer. Bayer Process, Red Mud By-Product. Ger. (East) 67,107. 2 pp, June 5, 1969.
- D-88. Tsai, J. H. Separation of Useful Compounds From Waste Red-Mud of the Aluminum Industry. U. S. 3,574,537. 2 pp, April 13, 1971.
- D-89. Oku, T., N. Tawara, and K. Yamada. Recovery of Valuable Components from Red Mud Obtained in Production of Alumina. Japan 74 23,115. 3 pp, June 13, 1974.
- D-90. Oku, T., N. Tawara, and K. Yamada. Recovering Valuable Components of Red Mud. Japan 74 25,118. 3 pp, June 27, 1974.

General Usage

- D-91. Motte and Pomot. Protecting Insecticides Against the Action of Light. Fr. 848,974, November 9, 1939.
- D-92. Oda, N. Agricultural Pesticide. Japan 5650('51), September 21, 1951.
- D-93. Machlet, A. W. Surfacing Metallic Articles. U. S. 2,551,957, May 8, 1951.
- D-94. Satalkin, A. V., and V. A. Solntseva. Additives for Injection [Gunitite] Mortars. Sb. Tr. Leningr. Inst. Insh. Zheleznodor. Transp. (200):40-60, 1962.
- D-95. Suzuki, N. Refractory Cement Additives. Japan 73 38,609. 4 pp, November 19, 1973.
- D-96. Beeching, L., and L. Ainsworth. Material for Road Pavement. Ger. Offen. 2,257,535. 23 pp, May 30, 1973.
- D-97. Kasai, J., and K. Fukurr. Surface-Treated Quicklime. Japan Kokai 74 49,899. 2 pp, May 15, 1974.
- D-98. Hayashi, S., and F. Matsui. Hardenable Foam-Generating Compositions. Japan 73 36,941. 4 pp, November 8, 1973.
- D-99. Veretnova, K. I., T. F. Serpeninova, and A. T. Logvinenko. Production of Glass-Ceramics Using a Red Mud From Alumina Production. Izv. Sib. Otd. Akad. Nauk SSSR, Ser. Khim. Nauk. (4):120-3, 1973.
- D-100. Heyd, F. Use of Sludge From Alumina Production From Iron-Containing Bauxite in Coke Manufacture. Czech. 93,355, January 15, 1960.
- D-101. Chowdhry, N. A. Sand and Red Mud Filters: An Alternative Media for Household Effluents. Water Pollution Control. 113(2):17-18, 1975.
- D-102. Horvath, Gy. Test of Red Mud Smelting by Thermal Analysis. Aluminum. 50(3):331-8, March, 1974.
- D-103. Solymar, K., and E. Bujdoso. Properties of Red Mud in Bayer Process and Its Utilization. AIME Annual Meeting, 102nd, Boc. (Light Met. 1973). February, 1973.

- D-104. Yamada, K., T. Harato, and Y. Furumi. Removal of Iron Compounds From the Bayer Liquor. Metal Soc. AIME Pap. A74-66: 713-722, 1974.
- D-105. Thome, R., and G. Wargalla. Strong Filler. Bitum Teere Asphalte Peche. 25(1):91-92, January, 1974.
- D-106. Wargalla, G. Use of Red Muds in Manufacture of Cement and Expanded Clay. Erzmetall. 26(1):18-20, January, 1973.
- D-107. Dobos, G., G. Horvath, and K. Solymar. Theoretical and Practical Problems in the Complex Process of Working the Red Mud. Aluminum. 48(12):808-810, December, 1972.
- D-108. Bayer, G. Possibilities for Economic Disposal of Red Muds. Erzmetall. 25(9):454-457, September, 1972.
- D-109. Guccione, E. "Red Mud", A Solid Waste, Can Now Be Converted to High-Quality Steel. Eng. Mining J. 172(9):136-8, September, 1971.
- D-110. Fursman, O. C., et al. Utilization of Red Mud From Alumina Production. Bureau of Mines, U. S. Bur. Mines, Rept. Invest. 7454, November, 1970
- D-111. Schultheisz, Z., et al. Microscopic Examination of Red Muds Slags Obtained in Krupprenn Process. Freiburger Forschungsh, Reihe. 113:105-22, 1967.
- D-112. Treatment of Red Mud Waste From Bayer Process by Pelletizing and Coating, Tonan Kaihatsu Kogyo Co. Ltd. Japanese 4, 845, 496, October 14, 1971.

EFFLUENT TREATMENT

Adsorption of Sulfur Oxide Compounds

- E-1. Thibon, H. J. Activation of Red Mud From the Bayer Process. U. S. 2, 432, 071, December 2, 1947.
- E-2. Mitsubishi Shipbuilding & Engineering Co., Ltd. Removal of Effluent Sulfur Dioxide With Red Sludge. Fr. 1, 350, 231. 5 pp, January 24, 1964.

- E-3. Field, J. H., J. G. Myers, J. W. Mulvihill, and H. W. Wainwright. Potential Absorbents for Sulfur Oxides Removal From Flue Gas. Amer. Chem. Soc., Div. Petrol. Chem., Preprints 1967. 12(4):A9-A-15, 1967.
- E-4. Land, G. W. Controlling Sulfur Dioxide Emissions From Coal Burning. Nat. Eng. 73(1):6-8, 1969.
- E-5. Land, G. W. Trials of Additives for Sulfur Dioxide Removal in Industrial Plants. Combustion. 41(6):30-3, 1969.
- E-6. Myers, J. G., and J. H. Field. Absorbent for Removing Sulfur Oxides From Gases. U.S. 3,580,702. 6 pp, May 25, 1971.
- E-7. Badeeva, T. I., L. M. Belavinskaya, B. M. Gikht, N. N. Gryazev, K. A. Dmitrieva, L. A. Novoselova, L. E. Ozerskaya, V. P. Perfilova, M. N. Rakhlevskaya, et al. Removal of Organosulfur Compounds From Jet Fuels. Khim. Seraorg. Soedin., Soderzhashchiksy Neft. Nefteprod. (9):424-8, 1972.
- E-8. Sho, K. Adsorbent for Removal and Decolorization of Liquid and Gaseous Sulphur Compounds From Red Mud. Japan Kokai 73 55,888. 4 pp, August 6, 1973.
- E-9. Sho, K. Adsorbent for Removal and Decolorization of Liquid and Gaseous Sulphur Compounds From Red Mud. Japan Kokai 73 55,886 and 73 55,887. 4 and 3 pp, August 6, 1973.
- E-10. Oku, Tsurumi, and T. Fukunaga. Absorbing Sulfur Dioxide From Waste Gases by a Red Mud Slurry. Japan Kokai 74 10,868. 6 pp, January 30, 1974.
- E-11. Grupe, K., E. Kriegel, and P. Schmidt-Mende. Falling-Cloud Reactor for Removal of Sulfur Dioxide From Flue Gas Using Red Mud as Desulfurizing Agent. Desulphurization Fuels Combust. Gases, Proc. Semin. Work. Party Air Pollut. Probl. U.N. Econ. Comm. Eur. Addendum 3:37-42, 1970.
- E-12. Oku, T., T. Fukunaga, and M. Yoshihara. Removal of Sulfur Dioxide in Exhaust Gas With Red Mud Slurry. Japan Kokai 73 102,094. 5 pp, December 21, 1972.
- E-13. Iida, T. Removal of Sulfur Oxides From Stock Gases by Adsorption on Red Mud. Japan Kokai 74 84,978. 4 pp, August 15, 1974.

Adsorption of H₂S

- E-14. Thibon, H., and A. Maillard. The Cold Fixation of Hydrogen Sulfide by Ferric Oxide. II. *Chimie & industrie*. 54:315-20, 1945.
- E-15. Compagnie de produits chimiques et electrometallurgiques Alais, Froges et Camargue. Red Muds. *Brit.* 595,733, December 15, 1947.
- E-16. Ivanovskii, F. P., V. A. Dontsova, and T. A. Semenova. Utilization of the Alumina-Production By-Product, Red Mud, in the Removal of Hydrogen Sulfide From Gas. *Khim. Prom.* 218-22, 1955.
- E-17. Hsu, W., and C. Ma. Red Mud Used as Desulfurizing Agent for Removing H₂S in Gas. *Union Ind. Research Inst. Rept.* (Hsinchu Twian). (13):8 pp, 1956.
- E-18. Kornyei, J. Absorption of Hydrogen Sulfide From Household Gas With Iron-Containing Mixtures. *Magyar Kim. Lapja*. 12:304-6 1957.
- E-19. Shultz, F. G., and J. Berber. Hydrogen Sulfide Removal From Hot Producer Gas With Sintered Absorbents. *J. Air Pollut. Contr. Ass.* 20(2):93-6, 1970.
- E-20. Shultz, F. G. Removal of Hydrogen Sulfide from Simulated Producer Gas at Elevated Temperatures and Pressures. *Air Pollut. Contr. Off. (U.S.) Publ.* AP-109, III-5, 6 pp, 1972.

Coagulant

- E-21. Cochechi, V., A. Martin, P. Samarghitan, and W. Husz. Preparation of Complex, Inorganic Coagulation Agent. I. Preparation of Coagulation Agents From Red Mud Resulting From Aluminum Oxide Manufacture. *Bul. Stint. Tch. Inst. Politeh. Timisoara. Ser. Chim.* 16(2):163-9, 1971.
- E-22. Sawai, S., and K. Baba. Manufacture of a Coagulant Containing Ferric Oxide. *Japan* 72 25,985. 2 pp, July 14, 1972.
- E-23. Fujii, T., Y. Hosoi, C. Nozaki, and S. Ohwada. Acidic Solid for Flocculation. *Japan. Kokai* 73 20,786. 4 pp, March 15, 1973.
- E-24. Miko, S., H. Takahashi, A. Kurata, and A. Kawaminami. Removal of Phosphate and Heavy Metal Ions From Waste Waters Using Red Mud. *Mizu Shori Gijutsu*. 14(8):817-22, 1973.

- E-25. Bayer, G., and E. Cherdron. Red-Mud Flocculant for Waste Water Treatment. Ger. Offen. 2,242,811. 9 pp, March 14, 1974.
- E-26. Takase, H., and Y. Hata. Production of Coagulants From Red Mud. Japan Kokai 74 55,576. 4 pp, May 29, 1974.
- E-27. Sanga, S. Removal of Phosphorus From Sewage With Red Mud Ash. Japan Kokai 74 74,951. 2 pp, July 15, 1974.
- E-28. Ellis, E. H. Chlorinated Copperas Treatment of Sewage at Kingston-on-Thames. Surveyor. 106:195-6, 1947.

Acid Waste Waters

- E-29. Kalinin, L. G. Dry Neutralization of Acid Waste Waters. U.S.S.R. 340,626, June 5, 1972.
- E-30. Kazantsev, E. I., E. K. Stepanenko, and A. N. Gerasimenko. Removal of Arsenic From Waste Waters by Sorption. Tsvet. Metal. 45(1):18-20, 1972.

RED MUD DISPOSAL

- F-1. Kayatz, K. H. Solidification of Red Mud. Ger. Offen. 2,327,789. 6 pp, December 19, 1974.
- F-2. Miller, V. Ya., A. I. Ivanov, and V. A. Utkov. Sintering of Finely Dispersed Hydroscopic Alumina Material. Tr. Inst. Met., Sverdlovsk. (22):92-5, 1970.
- F-3. Dethlefsen, V., and H. Rosental. Problems With Dumping of Red Mud in Shallow Waters. A Critical Review of Selected Literature. Aquaculture. 2(3):267-80, 1974.
- F-4. Nauke, M. Disposal Problems of Red Mud in the North Sea. Meerestech, Mar Tech. 5(5):149-153, October, 1974.
- F-5. Rushing, J. C. Alumina Plant Tailings Storage. AIME Annual Meeting, 102nd Proceedings (Light Metal, 1973). February.
- F-6. Bayer, G. Economic Disposal of Red Muds, Environmental Protection in the Aluminum and Nonferrous Smelting Industry-Symposium", Technicopy Ltd., Stonehouse, Glos., England, 12-20, 53-56, 1973.

APPENDIX B: WORKSHOP SESSIONS

Draft report copies of the project were submitted for review to the U. S. Environmental Protection Agency and aluminum industries of the United States in the month of January, 1976. A workshop on the project was sponsored by the U. S. Environmental Protection Agency. The workshop sessions were held at Battelle on March 30 and 31, 1976, to discuss and receive comments on the report. The workshop was attended by representatives of the U. S. Environmental Protection Agency, four domestic aluminum companies, and Dow Chemical Company. The program and list of the attendees with their title and organization are listed in Table B-1 and Table B-2, respectively.

The present report incorporates many of the comments and recommendations made by the various representatives during the workshop sessions.

TABLE B-1. PROGRAM OF THE WORKSHOP

Tuesday, March 30, 1976

9:00 a.m. Welcome to Battelle
9:10 a.m. Arrangements for Workshop
9:20 a.m. Introductory Comments (EPA, Battelle)
9:30 a.m. Review of the Project and Draft Report (Battelle, Dow)
10:30 a.m. Coffee Break
10:45 a.m. Prepared General Comments by Industry Participants
12:15 p.m. Lunch
1:30 p.m. Workshop Discussions
Topics: Processing, Disposal, and Utilization
3:00 p.m. Coffee Break
3:15 p.m. Demonstration of Advanced Information Processing and Retrieval
Systems
3:45 p.m. Continue Workshop Discussion
4:30 p.m. Adjourn

Wednesday, March 31, 1976

9:00 a.m. Recommended Research and Demonstration Projects (Industry
Participants)
10:45 a.m. Summary of Workshop Results (Battelle)
11:15 a.m. Concluding Remarks by Participants

TABLE B-2. LIST OF THE WORKSHOP ATTENDEES*

| Organization | Name | Title |
|--------------------------------|----------------------|--------------------------------------|
| Kaiser Aluminum ^(a) | Mr. A. E. McLaughlin | Manager, Process Development |
| Kaiser Aluminum | Dr. R. M. Hansen | Environmental Manager |
| Alcoa ^(b) | Mr. J. E. Ralphe | Superintendent - New Project |
| Alcoa | Mr. R. H. Carwile | Environmental Control Engineer |
| Reynolds Metals Company | Mr. M. Handelman | Technical Assistant to Plant Manager |
| Reynolds Metals Company | Mr. F. N. Newchurch | Process Control Leader |
| Reynolds Metals Company | Mr. J. T. Robinson | Senior Process Engineer |
| Reynolds Metals Company | Mr. R. N. Reid | Senior Environmental Engineer |
| Martin-Marietta | Mr. J. A. S. Green | Head, Materials Department |
| U. S. EPA ^(c) | Mr. Donald Wilson | Research Chemist |
| U. S. EPA | Mr. T. G. Newport | |
| Dow Chemical Company | Dr. S. L. Daniels | Research Specialist |

*List does not include names of Battelle's participants.

(a) Kaiser Aluminum and Chemical Corporation

(b) Aluminum Company of America

(c) U. S. Environmental Protection Agency

TECHNICAL REPORT DATA

(Please read instructions on the reverse before completing)

| | | | | |
|---|--|--|--|-------------------------|
| 1. REPORT NO. EPA-600/2-76-301 | | 2. | 3. RECIPIENT'S ACCESSION NO. | |
| 4. TITLE AND SUBTITLE An Assessment of Technology for Possible Utilization of Bayer Process Muds | | | 5. REPORT DATE December 1976 issuing date | |
| | | | 6. PERFORMING ORGANIZATION CODE | |
| 7. AUTHOR(S) Parekh, B. K. Goldberger, W. M. | | | 8. PERFORMING ORGANIZATION REPORT NO. | |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS Battelle Memorial Institute 505 King Avenue Columbus, Ohio 43229 | | | 10. PROGRAM ELEMENT NO. IBB610; 02-01-05A | |
| | | | 11. CONTRACT/GRANT NO. R803760 | |
| 12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Lab. - Cin., OH Office of Research and Development U. S. Environmental Protection Agency Cincinnati, Ohio 45268 | | | 13. TYPE OF REPORT AND PERIOD COVERED Final | |
| | | | 14. SPONSORING AGENCY CODE EPA/600/12 | |
| 15. SUPPLEMENTARY NOTES | | | | |
| 16. ABSTRACT This report concerns a study of the possible utilization of the mud wastes generated in the domestic production of alumina from bauxite ores. The work was done by the Battelle-Columbus Laboratories for the United States Environmental Agency. The program comprised review of technical literature published from 1940 on subjects related to technology of processing bauxite, the dewatering and impoundment of the mud residues and their possible utilization. Mud samples were received from the domestic alumina plants for characterization experiments and dewatering studies at Battelle and at the laboratories of the Dow Chemical Company in Midland, Michigan. It was concluded from the study that there is no possibility for utilization of the muds that could significantly affect the need for impoundment within the near term. However, improved mud dewatering and methods of impoundment appear possible to develop and a program of joint industry-government demonstration and pilot projects is recommended. In addition, a basic research program is recommended to study the mineral surface chemistry controlling the mechanism of dewatering. Investigations of the possible beneficiation of the muds into a raw material supplement in iron making and the possible use of mud as an absorbent in pollution abatement processes are also recommended. | | | | |
| 17. KEY WORDS AND DOCUMENT ANALYSIS | | | | |
| a. DESCRIPTORS | | b. IDENTIFIERS/OPEN ENDED TERMS | | c. COSATI Field/Group |
| Bauxite*, Bayer Process, Coagulation, Composition, Dewatering*, Disposal, Flocculants, Refining* Utilization*, Wastes *Important terms | | Bauxite Refining Bayer Process Muds Effect of Flocculants Method of Dewatering Mud Utilization Brown Mud Red Mud | | 13B |
| 18. DISTRIBUTION STATEMENT Release to Public | | 19. SECURITY CLASS (This Report) Unclassified | | 21. NO. OF PAGES 153 |
| | | 20. SECURITY CLASS (This page) Unclassified | | 22. PRICE |