Information Circular 8958

Cost Estimate of the Bayer Process for Producing Alumina—Based on 1982 Equipment Prices

By Deborah A. Kramer and Frank A. Peters

UNITED STATES DEPARTMENT OF THE INTERIOR
James G. Watt, Secretary

BUREAU OF MINES
Robert C. Horton, Director

Library of Congress Cataloging in Publication Data:

Kramer, Deborah A

Cost estimate of the Bayer process for producing alumina, based on 1982 equipment prices.

(Bureau of Mines information circular ; 8958)

Bibliography: p. 9.

Supt. of Docs. no.: I 28.27:8958.

1. Aluminum industry–United States–Costs. 2. Aluminum–Metallurgy–Economic aspects–United States. 3. Aluminum ores–Economic aspects–United States. I. Peters, Frank A., 1931- . II. Title. III. Series: Information circular (United States. Bureau of Mines) ; 8958.

TN295.U4 [HD9539.A63U49] 622s [669'.722] 83-600317

CONTENTS

ILLUSTRATIONS

TABLES

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

Btu/d	British thermal unit per day	kW•h	kilowatt-hour
°C	degree Celsius	Mgal	thousand gallons
d/wk	day per week	min	minute
d/yr	day per year	pct	percent
°F	degree Fahrenheit	psia	pound per square inch, absolute
ft	foot	ton/d	short ton per day
ft^2	square foot	ton/h	short ton per hour
gal	gallon	ton/yr	short ton per year
h	hour	wt pct	weight percent
h/d	hour per day	yr	year
in	inch		

COST ESTIMATE OF THE BAYER PROCESS FOR PRODUCING ALUMINA-BASED ON 1982 EQUIPMENT PRICES

By Deborah A. Kramer [1] and Frank A. Peters [2]

ABSTRACT

This Bureau of Mines report presents a cost estimate of the Bayer process, which is used for virtually all cell-grade alumina production. The report will serve as a reference point to determine the economic merits of processes that have evolved from Bureau of Mines investigations on technology for producing alumina from domestic nonbauxitic raw materials.

The Bayer process involves dissolving the alumina present in bauxite in a caustic solution at high temperature and pressure. After the undissolved impurities are removed, the solution is seeded to produce an alumina trihydrate precipitate. This precipitate is filtered, washed, and calcined to produce the cell-grade alumina product.

This cost estimate is for a plant producing 1 million tons of alumina per year. The estimated operating cost is approximately $250 per ton of alumina.

[1]Chemist, Avondale Research Center, Bureau of Mines, Avondale, MD.
[2]Chief, Process Evaluation, Avondale Research Center, Bureau of Mines, Avondale, MD.

INTRODUCTION

Since the United States has very limited high-grade bauxite deposits, it is dependent on imported bauxite to supply virtually all its alumina needs. To provide technology that may help reduce this country's dependence on imported bauxite, the Bureau of Mines has conducted research on methods for recovering alumina from domestic raw materials such as clay, anorthosite, alunite, dawsonite, and coal shale and ash.

To determine the relative economic attractiveness of the technology being considered, a reference point is needed. A cost estimate of the Bayer process was prepared to provide the reference point, since this method is used for virtually all commercial alumina production. The same estimating techniques are used in this cost estimate as are being used in the economic studies of proposed processes for producing alumina from nonbauxitic raw materials in order to provide greater confidence in comparing various technologies.

This cost estimate is based on a previous one prepared by the Bureau of Mines (1),[3] incorporating additional technical information to update the technology. This information includes data on current Bayer practice such as a higher digestion temperature and pressure, an increased number of flash stages, impurity removal through bleed stream treatment, and solution composition. Equipment design and costing methods reflect current evaluation techniques.

The Bayer process was patented in 1894 by Karl Josef Bayer (2). Although modifications have been made, the process is basically the original one. Most modifications have centered on leaching and solid-liquid separation conditions that have been required to adapt the process to different bauxite feeds. Jamaican bauxite is used as the feed for the proposed plant in this study.

PROCESS DESCRIPTION

Bauxite is mixed with a caustic leach solution and then pumped to digestion vessels where the temperature and pressure are increased in order to dissolve the alumina. Undissolved impurities are removed from the solution, and alumina trihydrate is precipitated by seeding the solution with fine trihydrate crystals. The trihydrate crystals are separated from the solution and calcined to produce the final alumina product. A basic process flowsheet is shown in figure 1.

New Bayer plants are being built with capacities exceeding 800,000 ton/yr. Large plants can be built without technical risk because of the maturity of the Bayer technology. Therefore, the proposed plant has been designed to produce 1 million tons of alumina per year and to operate 3 shifts per day, 365 d/yr at a gulf coast location. For economic reasons, Bayer plants are designed for continuous operation by adding spare equipment, which allows for downtime for maintenance without reducing plant capacity. For convenience, the plant has been divided into five major sections. The material balance for each section is presented in the appendix. Jamaican bauxite, a mixture of alumina monohydrate and trihydrate, is used as a feed for the proposed plant. An analysis on a dry basis is given in table 1. The bauxite also contains moisture equal to 15 pct of the dry components.

The bauxite handling and crushing facilities consist of one line of equipment; however, the remainder of the plant is designed with three operating lines and spare equipment to insure continuous production when maintenance is required.

[3]Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

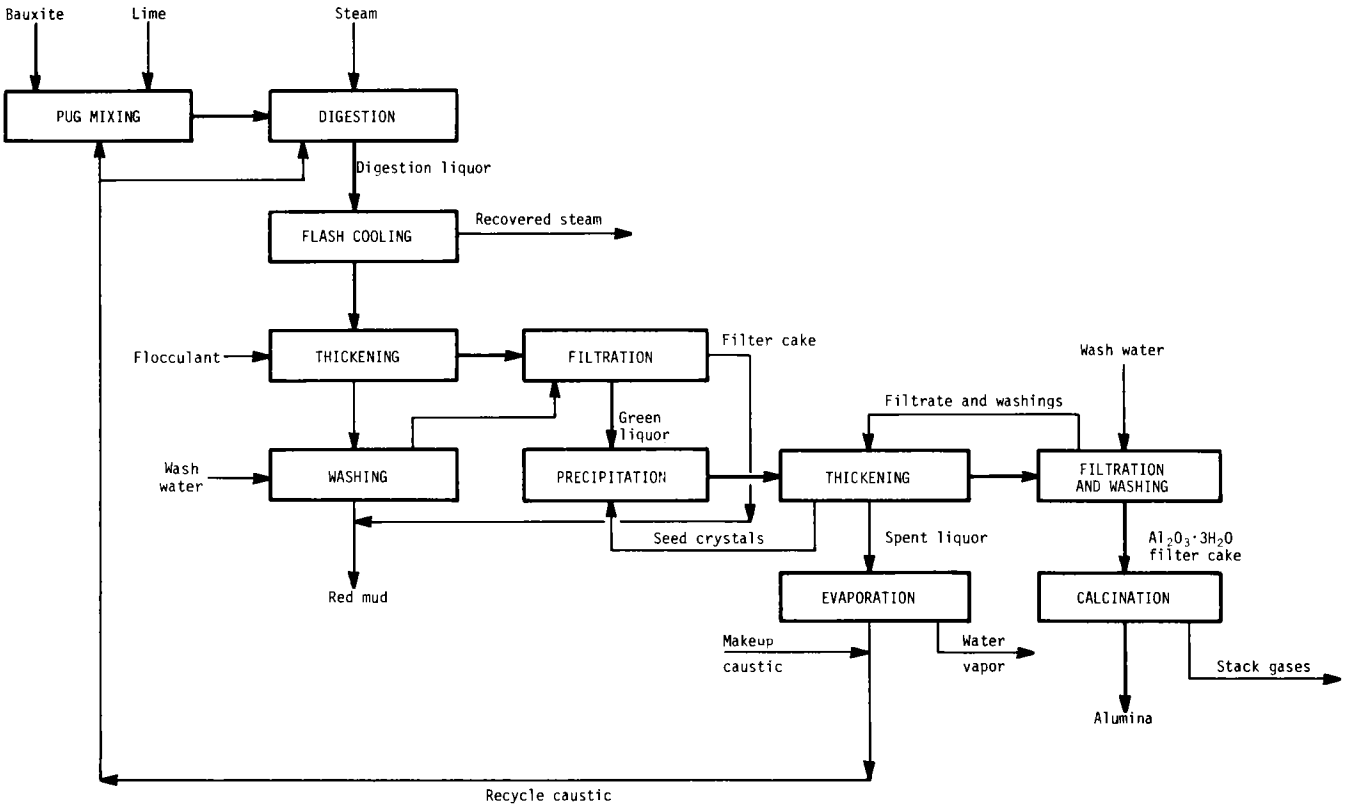

FIGURE 1. - Bayer process flowsheet.

For convenience, only one line of equipment is described in the plant description.

TABLE 1. - Composition of hypothetical bauxite (dry basis)[1]

Component	wt pct
Al_2O_3	49.0
Fe_2O_3	20.0
SiO_2	2.5
TiO_2	2.5
Loss on ignition	25.0
Other	1.0
Total	100.0

[1]Also contains moisture equal to 15 pct of the dry components.

BAUXITE HANDLING AND SLURRY PREPARATION SECTION

Upon delivery to the plant, bauxite is conveyed to a hopper from where it is sent to one of two covered storage buildings, each containing a 30-day supply, or it is fed to an outdoor stockpile containing a 60-day supply. Equipment is included to transport bauxite from the outdoor stockpile into the storage buildings when necessary. Bauxite is withdrawn from a storage building and sent to a hammer mill, where it is crushed from minus 6 in to minus 1 in, and then sent to intermediate storage bins.

Crushed bauxite is conveyed to a rod mill for wet grinding to minus 20 mesh with a portion of the recycle caustic solution. This slurry is then pumped to pug mixers and mixed with lime produced by calcining limestone. The resulting slurry is pumped to storage tanks in the digestion section.

DIGESTION SECTION

Stored slurry is pumped to a line of four digestion vessels, which operate at 243° C (470° F) and 525 psia. The slurry is mixed with the remainder of the recycle caustic solution, and steam is

injected into the tanks to maintain the temperature and to agitate this slurry. Under these conditions, alumina in the bauxite forms soluble sodium aluminate in the following manner:

$$Al_2O_3 \cdot H_2O + 2NaOH \rightarrow 2NaAlO_2 + 2H_2O$$

and

$$Al_2O_3 \cdot 3H_2O + 2NaOH \rightarrow 2NaAlO_2 + 4H_2O.$$

Ninety percent of the alumina is assumed to react in 30 min.

In addition, each ton of silica in the bauxite combines with the dissolved alumina and caustic soda, causing losses in the residue equivalent to 1 ton of alumina and 1 ton of sodium carbonate. The reaction to which these losses are usually attributed is

$$6NaAlO_2 + 5SiO_2 + 5H_2O \rightarrow Na_6Al_6Si_5O_{22} \cdot 5H_2O.$$

A study showing the many compounds found in red mud has been reported in "Extractive Metallurgy of Aluminum" (3). At the same time, carbonate buildup is controlled and the caustic concentration is increased in the system by the following mechanism:

$$Na_2CO_3 + Ca(OH)_2 \rightarrow 2NaOH + CaCO_3.$$

Exiting slurry from the digestion vessels flows to a series of nine flash tanks where the temperature and pressure are gradually reduced. Steam is recovered at the pressures shown in the material balance. The cooled slurry is then pumped to the clarification section. Recovered steam is used to preheat the recycle caustic solution. The equipment required for preheating the solution is detailed in the caustic regeneration section.

CLARIFICATION SECTION

Slurry from caustic digestion is pumped to sand tanks, where the plus 100-mesh particles of red mud are removed. Overflow from the sand tanks is pumped to thickeners, where the remainder of the red mud is removed. Starch is added as a flocculant. Depending on plant location and flocculant cost, flocculants other than starch may be used. Overflow from these thickeners is pumped to filter presses to remove any traces of solids. The underflow, containing 18 pct solids, is pumped to a series of eight wash thickeners, where the red mud is washed to recover soluble alumina and soda. Overflow from the wash thickeners is also pumped to filter presses. Filter cake, containing 40 pct solids, is combined with the underflow from the wash thickeners, reslurried, and pumped to a tailings pond. Green liquor from the filters is pumped to the precipitation and decomposition section.

PRECIPITATION AND DECOMPOSITION SECTION

Green liquor is pumped to 30 precipitators, 30 ft in diameter by 64-ft high. The supersaturated solution is seeded to precipitate the alumina as alumina trihydrate by the following reaction:

$$2NaAlO_2 + 4H_2O \rightarrow Al_2O_3 \cdot 3H_2O + 2NaOH.$$

Seed crystals, equal to 150 pct of the trihydrate produced, are added to the precipitation tanks, and 40 h are allowed for precipitation.

Alumina trihydrate slurry is pumped to primary thickeners, where the overflow containing 9 pct crystals is separated. Underflow from the primary thickeners is pumped to a fluidized-bed calciner system (4). There the solids are filtered, washed, and converted to alumina by the following calcination reaction, which occurs at 950° to 1,050° C (1,740° to 1,920° F):

$$Al_2O_3 \cdot 3H_2O \rightarrow Al_2O_3 + 3H_2O.$$

The alumina product, which contains about 25 pct alpha-alumina, is conveyed to silos with a 60-day storage capacity to await shipment.

Washings from the calciner filters are combined with the overflow from the primary thickener and sent to secondary thickeners. The overflow from the secondary thickeners, containing 1 pct solids, flows by gravity to tertiary thickeners, where the solids are separated in the underflow. Overflow from the tertiary thickeners is pumped to the caustic regeneration section. Underflows from the secondary and tertiary thickeners are combined and recycled to the precipitation tanks to provide the seed crystals.

CAUSTIC REGENERATION SECTION

Clarified solution from the tertiary thickeners is concentrated in a six-effect evaporator and pumped to storage tanks. Water vapor is condensed and recycled to the process. A bleed stream is pumped from the storage tanks to a single-effect evaporator, where concentration allows for the removal and control of organic compounds and other minor impurities in the caustic solution. Water vapor is condensed and returned to the storage tanks along with purified bleed stream.

Concentrated solution is pumped to mixing tanks, where makeup caustic is added to replace process losses. A portion of the recycle caustic solution is pumped to the rod mills; the remainder is preheated in heat exchangers, using some of the steam recovered from flash cooling the digestion liquor. The preheated recycle caustic is pumped to the digestion tanks.

Equipment has been provided for cleaning and removing scale from the heat exchangers. This equipment consists of tanks to hold the solution that is removed from the heat exchangers, tanks containing a sulfuric acid cleaning solution, tanks for the spent acid, and the necessary pumps and feed tanks.

ECONOMICS

The following cost estimate is based on data from literature and other nonpublished sources.

CAPITAL COSTS

The capital cost estimate is of the general type called a study estimate by Weaver and Bauman (5). This type of estimate, prepared from a flowsheet and a minimum of equipment data, can be expected to be within 30 pct of the actual cost for the plant described. Although the degree of confidence in any specific study estimate is not great with respect to the actual cost, greater confidence is justified when comparing a group of similar processes evaluated by identical methods. The estimated fixed capital cost on a fourth quarter 1982 basis (Marshall and Swift (M and S) index of 749.3) for a plant producing 1 million tons of alumina per year is about $820 million as shown in table 2. This translates to a cost of about $820 per annual ton. The plant is designed to operate 3 shifts per day, 7 d/wk. This capital cost is within the range estimated by Hill and Robson (6) in 1980 of $800 to $1,200 per annual metric ton (fourth quarter 1982 equivalent $800 to $1,200 per short ton).

Equipment costs for the process are based on cost-capacity data and manufacturers' costs quotations. Cost data are brought up to date by use of inflation indexes. Capital costs for the fluidized-bed flash calciner are based on a paper by Lussky (4). A lined tailings pond for waste disposal, with a 2-yr life, is included in table 2. Additional cost will be required to construct additional tailings pond capacity during the life of the plant. In developing the plant capital costs, corrosion-resistant materials of construction were used where appropriate. For example, the pressure-digestion vessels and the evaporators are nickel clad in order to withstand the high temperature and high caustic concentration of the solution. An additional line of equipment is included to allow for continuous operation of the plant when maintenance and scale removal are required for the operating equipment.

TABLE 2. - Estimated capital cost[1]

Fixed capital:	
Bauxite handling and slurry preparation section	$28,724,700
Digestion section	87,002,000
Clarification section	64,586,800
Precipitation and decomposition section	107,336,100
Caustic regeneration section	224,700,400
Tailings pond	5,008,400
Steamplant	27,138,500
Subtotal	544,496,900
Plant facilities, 10 pct of above subtotal	54,449,700
Plant utilities, 12 pct of above subtotal	65,339,600
Total plant cost	664,286,200
Land cost	0
Subtotal	664,286,200
Interest during construction period	157,151,000
Fixed capital cost	821,437,200
Working capital:	
Raw material and supplies	8,031,000
Product and in-process inventory	20,609,900
Accounts receivable	20,609,900
Available cash	14,882,600
Working capital cost	64,133,400
Capitalized startup costs	8,214,400
Subtotal	72,347,800
Total capital cost	893,785,000

[1]Basis: M and S equipment cost index of 749.3.

Factors for piping, etc., except for the foundation and electrical factors, are assigned to each section, using as a basis the effect fluids, solids, or a combination of fluids and solids may have on the process equipment. The foundation cost is estimated for each piece of equipment individually, and a factor for the entire section is calculated from the totals. The electrical factor is based on motor horsepower requirements for each section. A factor of 10 pct, referred to as miscellaneous, is added to each section to cover minor equipment and construction costs that are not shown with the equipment listed.

For each section, the field indirect cost, which covers field supervision, inspection, temporary construction, equipment rental, and payroll overhead, is estimated at 10 pct of the direct cost. Engineering cost is estimated at 10 pct, and administration and overhead cost is estimated at 5 pct of the construction cost. A contingency allowance of 15 pct and a contractor's fee of 5 pct are included in the section cost.

The costs of plant facilities and plant utilities are estimated as 10 and 12 pct, respectively, of the total process section costs and include the same field indirect costs, engineering, administration and overhead, contingency allowance, and contractor's fee as are included in the section costs. Included under plant facilities are the costs of material and

labor for auxiliary buildings such as offices, shops, laboratories, and cafeterias, and the cost of nonprocess equipment such as office furniture, together with safety, shop, and laboratory equipment. Also included are labor and material costs for site preparation such as site clearing, grading, drainage, roads, and fences. The cost of water, power, and steam distribution systems is included under plant utilities.

The cost for interest on the capital borrowed for construction is included as interest during construction. Land investment and docking facilities are not included in this estimate. Cost for the plant owner's supervision is not included in the capital cost of the proposed plant.

Working capital is defined as the funds in addition to fixed capital, land investment, and startup costs that must be provided to operate the plant. Working capital, also shown in table 2, is estimated from the following items: (1) Raw material and supplies inventory (cost of raw material and operating supplies for 30 days), (2) product and in-process inventory (total operating cost for 30 days), (3) accounts receivable (total operating cost for 30 days), and (4) available cash (direct expenses for 30 days).

Capitalized startup costs are estimated as 1 pct of the fixed capital, which is shown in table 2.

OPERATING COSTS

The estimated operating costs are based on 365 days of operation per year over the life of the plant. The operating costs are divided into direct, indirect, and fixed costs.

Direct costs include raw materials, utilities, direct labor, plant maintenance, payroll overhead, and operating supplies. The raw material costs, except for bauxite, do not include transportation costs. Electricity, water, fuel oil, and coal are purchased utilities. The temperature of the water from the cooling tower is assumed to be 33° C (92° F). Raw material and utility requirements per ton of alumina are shown in table A-1 (appendix).

The direct labor assignments are shown by sections in table A-2. The direct labor cost is estimated on the basis of assigning 4.2 employees to each position that operates 24 h/d, 7 d/wk. The cost of labor supervision is estimated as 15 pct of the labor cost.

Plant maintenance is separately estimated for each piece of equipment and for the buildings, electrical system, piping, plant utility distribution systems, and plant facilities.

Payroll overhead, estimated as 35 pct of direct labor and maintenance labor, includes vacation, sick leave, social security, and fringe benefits. The cost of operating supplies is estimated as 10 pct of the cost of plant maintenance.

Indirect costs are estimated as 25 pct of the direct labor and maintenance costs. The indirect costs include the expenses of control laboratories, accounting, plant protection and safety, plant administration, marketing, and company overhead. Research and overall company administrative costs outside the plant are not included.

Fixed costs include the cost of taxes (excluding income taxes), insurance, and depreciation. The annual costs of both taxes and insurance are each estimated as 1 pct of the plant construction cost. Depreciation is based on a straight-line, 20-yr period.

The estimated annual operating cost for the proposed plant is about $250 million, or approximately $250 per ton of alumina produced, as shown in table 3. This operating cost would be expected to vary from that in an existing Bayer plant because of several factors. The design of an older Bayer plant generally would be

less efficient, depreciation charges would be less in an older plant, and costs such as raw materials, transportation, and utility rates would differ depending on plant location. In addition, infrastructure costs have not been considered in this evaluation, since they are dependent on the individual plant site.

TABLE 3. - Estimated annual operating cost

	Annual cost	Cost per ton alumina
Direct cost:		
Raw materials:		
Bauxite at $31 per ton	$81,931,900	$81.92
Limestone at $4 per ton	471,600	.47
Sodium hydroxide, 50-pct at $175 per ton	9,900,600	9.90
Starch at $180 per ton	1,248,300	1.25
Replacement rods for grinding at $0.23 per pound	373,200	.37
Chemicals for steamplant water treatment	476,000	.48
Total	94,401,600	94.39
Utilities:		
Electric power at $0.045 per kW·h	9,858,400	9.86
Process water at $0.25 per Mgal	710,400	.71
Coal at $24.50 per ton	11,832,100	11.83
Heavy oil at $0.76 per gallon	14,504,700	14.50
Total	36,905,600	36.90
Direct labor:		
Labor at $13 per hour	4,542,700	4.54
Supervision, 15 pct of labor	681,400	.68
Total	5,224,100	5.22
Plant maintenance:		
Labor	15,039,400	15.04
Supervision, 20 pct of maintenance labor	3,007,900	3.01
Materials	15,039,300	15.04
Total	33,086,600	33.09
Payroll overhead, 35 pct of above payroll	8,145,000	8.14
Operating supplies, 10 pct of plant maintenance	3,308,700	3.31
Total direct cost	181,071,600	181.05
Indirect cost, 40 pct of direct labor and maintenance	15,324,300	15.32
Fixed cost:		
Taxes, 1 pct of total plant cost	6,642,900	6.64
Insurance, 1 pct of total plant cost	6,642,900	6.64
Depreciation, 20-yr life	41,071,900	41.07
Total operating cost	250,753,600	250.72

REFERENCES

1. Peters, F. A., P. W. Johnson, and R. C. Kirby. A Cost Estimate of the Bayer Process for Producing Alumina. BuMines RI 6730, 1966, 23 pp.

2. Bayer, K. J. Process of Making Alumina. U.S. Pat. 515,895, Mar. 6, 1894.

3. Gerard, G. V., and P. T. Stroup. Extractive Metallurgy of Aluminum. Interscience Publishers, New York, v. 1, 1963, 355 pp.

4. Lussky, E. W. Experience With Operation of the Alcoa Fluid Flash Calciner. Light Metals, 1980, pp. 69-79.

5. Weaver, J. B., and H. C. Bauman. Cost and Profitability Estimation. Sec. 25 in Perry's Chemical Engineers' Handbook, ed. by R. H. Perry and C. H. Chilton. McGraw-Hill, 5th ed., 1973, p. 46.

6. Hill, V. G., and R. J. Robson. The Classification of Bauxites From the Bayer Plant Standpoint. Light Metals, 1981, pp. 15-28.

APPENDIX.--UTILITY REQUIREMENTS, EQUIPMENT COST SUMMARIES, AND MATERIAL BALANCES

Raw material and utility requirements per ton of alumina are shown in table A-1, and the direct labor requirements for each section are shown in table A-2. Major items of equipment for each section are shown in table A-3. The equipment costs for each section of the process are contained in tables A-4 to A-8. Material balances are shown for each section in figures A-1 to A-5.

TABLE A-1. - Raw material and utility requirements

	Quantity per ton alumina
Raw materials:	
Bauxite.....ton..	2.643
Limestone.....ton..	.118
Sodium hydroxide, 50-pct.....ton..	.057
Starch.....ton..	.007
Replacement rods for grinding.....lb..	1.622

TABLE A-2. - Direct labor requirements, operators per shift

Section	Shifts per week		
	[1]21	[2]7	[3]5
Bauxite handling and slurry preparation section.....	7	6	0
Digestion section.....	3	0	0
Clarification section.....	4	0	0
Precipitation and decomposition section.....	6	0	3
Caustic regeneration section.....	5	0	0
Steamplant.....	11	0	3
General plant.....	0	2	0
Total.....	36	8	6

[1]3 shifts per day, 7 d/wk.
[2]1 shift per day, 7 d/wk.
[3]1 shift per day, 5 d/wk.

TABLE A-3. - Major items of equipment

Section and item	Quantity	Unit size
Bauxite handling and slurry preparation section:		
Hammer mill.....	1	72 by 70 in.
Rod mills.....	3	7,965 ton/d.
Pug mixers.....	12	85 ton/h.
Digestion section:		
Digestion tanks.....	16	12-ft diam by 37 ft.
Clarification section:		
Thickeners.....	8	100-ft diam.
Wash thickeners.....	32	100-ft diam.
Filter presses.....	32	2,500 ft^2.
Precipitation and decomposition section:		
Precipitation tanks.....	110	30-ft diam by 64 ft.
Primary thickeners.....	12	25-ft diam.
Fluid-flash calciners.....	3	2.9 billion Btu/d.
Secondary thickeners.....	12	55-ft diam.
Tertiary thickeners.....	12	110-ft diam.
Caustic regeneration section:		
Multieffect evaporators.....	3	21,105 ft^2/effect.
Evaporator.....	1	23,833 ft^2/effect.

TABLE A-4.-Equipment cost summary, bauxite handling and slurry preparation section

Item	Cost(1)		
	Equipment	Labor	Total
Belt conveyor	$ 359400.	$ 82800.	$ 442200.
Hopper	16600.	4000.	20600.
Apron feeders	62400.	9400.	71800.
Belt conveyors	320000.	73800.	393800.
Belt conveyor	361600.	81700.	443300.
Apron feeders	41600.	6200.	47800.
Belt conveyors	88600.	11100.	99700.
Belt conveyors	696300.	45800.	742100.
Reclaimer feeders	103100.	15500.	118600.
Belt conveyor	21000.	4200.	25200.
Belt conveyor	60800.	12900.	73700.
Hopper	15400.	3500.	18900.
Apron feeder	39100.	5900.	45000.
Hammer mill	282400.	39500.	321900.
Belt conveyor	147600.	23600.	171200.
Storage bins	940400.	186600.	1127000.
Belt feeders	40400.	6100.	46500.
Belt conveyors	139900.	31200.	171100.
Rod mills	736000.	44200.	780200.
Bridge crane	54200.	1700.	55900.
Pumps	49200.	9200.	58400.
Belt feeders	15500.	2300.	17800.
Belt conveyor	76300.	14400.	90700.
Belt feeder	5200.	800.	6000.
Belt conveyor	27300.	6300.	33600.
Hopper	600.	100.	700.
Belt feeder	5200.	800.	6000.
Lime kiln	297000.	89100.	386100.
Rotary cooler	100200.	16000.	116200.
Bag dust collectors	87800.	800.	88600.
Belt conveyor	54400.	9800.	64200.
Surge tanks	316400.	66400.	382800.
Pumps	29600.	7500.	37100.
Pug mixers	3430000.	128300.	3558300.
Pumps	146900.	26200.	173100.
Bag dust collector	24400.	300.	24700.
Bag dust collector	6200.	200.	6400.
Bag dust collector	22200.	300.	22500.
Bag dust collector	6200.	200.	6400.
Total	9227400.	1068700.	10296100.
Hoppers			(2) 35700.
Limestone unloading hoppers			(2) 53600.
Limestone storage silo			(2) 382000.
Lime storage silo			(2) 188400.
Lime slakers			(2) 131800.
Front-end loaders			300800.
Dump trucks			204200.
Front-end loaders			62000.

TABLE A-4.-Equipment cost summary,
bauxite handling and slurry preparation section
(continued)

Total equipment cost x factor indicated:	
Foundations, x .185	1707300.
Buildings, x .255	2354700.
Structures, x .050	461400.
Instrumentation, x .050	461400.
Electrical, x .055	504900.
Piping, x .050	461400.
Painting, x .030	276800.
Miscellaneous, x .100	922700.
Total	7150600.
Total direct cost	18805200.
Field indirect, 10.0 pct of total direct cost	1880500.
Total construction cost	20685700.
Engineering, 10.0 pct of total construction cost	2068600.
Administration and overhead, 5.0 pct of total construction cost	1034300.
Subtotal	23788600.
Contingency, 15.0 pct of above subtotal	3568300.
Subtotal	27356900.
Contractor's fee, 5.0 pct of above subtotal	1367800.
Section cost	28724700.

(1) Equipment costs are based on the M and S index of 749.3.
(2) Installed cost.

TABLE A-5.-Equipment cost summary, digestion section

Item	Cost(1)		
	Equipment	Labor	Total
Slurry storage tanks	$ 1259200.	$ 261900.	$ 1521100.
Slurry pumps	1943400.	74800.	2018200.
Digestion tanks	19179700.	421600.	19601300.
Flash tanks 1	343900.	38400.	382300.
Flash tanks 2	249100.	24500.	273600.
Flash tanks 3	168600.	17000.	185600.
Flash tanks 4	141000.	14900.	155900.
Flash tanks 5	141000.	14900.	155900.
Flash tanks 6	125200.	12500.	137700.
Flash tanks 7	125200.	12500.	137700.
Flash tanks 8	125200.	12500.	137700.
Flash tanks 9	125200.	12500.	137700.
Pumps	82000.	16600.	98600.
Total	24008700.	934600.	24943300.
Total equipment cost x factor indicated:			
Foundations, x .039			942200.
Buildings, x .004			103000.
Structures, x .100			2400900.
Insulation, x .080			1920700.
Instrumentation, x .180			4321600.
Electrical, x .050			1198100.
Piping, x .700			16806100.
Painting, x .080			1920700.
Miscellaneous, x .100			2400900.
Total			32014200.
Total direct cost			56957500.
Field indirect, 10.0 pct of total direct cost			5695800.
Total construction cost			62653300.
Engineering, 10.0 pct of total construction cost			6265300.
Administration and overhead, 5.0 pct of total construction cost			3132700.
Subtotal			72051300.
Contingency, 15.0 pct of above subtotal			10807700.
Subtotal			82859000.
Contractor's fee, 5.0 pct of above subtotal			4143000.
Section cost			87002000.

(1) Equipment costs are based on the M and S index of 749.3.

TABLE A-6.-Equipment cost summary, clarification section

Item	Cost(1) Equipment	Labor	Total
Pneumatic conveyor	$ 18100.	$ 2000.	$ 20100.
Belt feeder	5200.	800.	6000.
Belt conveyor	37700.	9200.	46900.
Starch storage bin	3500.	1500.	5000.
Belt feeders	10300.	1500.	11800.
Slurry tanks	24900.	8300.	33200.
Pumps	9900.	1200.	11100.
Feed tanks	31400.	4100.	35500.
Pumps	39500.	2800.	42300.
Sand tanks	12800.	9500.	22300.
Pumps	80200.	12400.	92600.
Pumps	20100.	4100.	24200.
Thickeners	2650500.	302900.	2953400.
Pumps	86100.	18000.	104100.
Pumps	116100.	24800.	140900.
Wash thickeners	10601900.	1211700.	11813600.
Pumps	75200.	14900.	90100.
Pumps	40100.	11200.	51300.
Filter presses	4083900.	49700.	4133600.
Belt conveyors	76800.	19500.	96300.
Reslurry tanks	34300.	8900.	43200.
Pumps	50900.	8400.	59300.
Pumps	96200.	13700.	109900.
Total	18205600.	1741100.	19946700.
Starch unloading hopper			(2) 17900.
Starch storage silo			(2) 79600.
Total equipment cost x factor indicated:			
Foundations, x .262			4777100.
Buildings, x .011			196900.
Structures, x .050			910300.
Instrumentation, x .100			1820600.
Electrical, x .028			515500.
Piping, x .600			10923400.
Painting, x .070			1274400.
Miscellaneous, x .100			1820600.
Total			22238800.
Total direct cost			42283000.
Field indirect, 10.0 pct of total direct cost			4228300.
Total construction cost			46511300.
Engineering, 10.0 pct of total construction cost			4651100.
Administration and overhead, 5.0 pct of total construction cost			2325600.
Subtotal			53488000.
Contingency, 15.0 pct of above subtotal			8023200.
Subtotal			61511200.
Contractor's fee, 5.0 pct of above subtotal			3075600.
Section cost			64586800.

(1) Equipment costs are based on the M and S index of 749.3.
(2) Installed cost.

TABLE A-7.-Equipment cost summary, precipitation and decomposition section

Item	Cost(1)		
	Equipment	Labor	Total
Precipitation tanks	$10497200.	$ 2080100.	$ 12577300.
Air compressors	893400.	10000.	903400.
Pumps	950000.	188000.	1138000.
Primary thickeners	952700.	140300.	1093000.
Sumps	2500.	5400.	7900.
Pumps	116300.	21200.	137500.
Belt conveyors	552200.	110200.	662400.
Screw feeders	78600.	11800.	90400.
Secondary thickeners	1824500.	273700.	2098200.
Sumps	3300.	6500.	9800.
Pumps	124900.	24200.	149100.
Tertiary thickeners	3230200.	492600.	3722800.
Sumps	1200.	2900.	4100.
Pumps	80400.	13500.	93900.
Surge tanks	40700.	35500.	76200.
Pumps	149300.	25300.	174600.
Sumps	9200.	12300.	21500.
Pumps	152800.	38700.	191500.
Surge tanks	104400.	63600.	168000.
Total	19763800.	3555800.	23319600.
Fluid-flash calciners			(2)18445900.
Alumina storage silos			(2) 6051500.
Total equipment cost x factor indicated:			
Foundations, x .321			6352600.
Buildings, x .002			47600.
Structures, x .050			988200.
Instrumentation, x .150			2964600.
Electrical, x .062			1229600.
Piping, x .400			7905500.
Painting, x .050			988200.
Miscellaneous, x .100			1976400.
Total			22452700.
Total direct cost			70269700.
Field indirect, 10.0 pct of total direct cost			7027000.
Total construction cost			77296700.
Engineering, 10.0 pct of total construction cost			7729700.
Administration and overhead, 5.0 pct of total construction cost			3864800.
Subtotal			88891200.
Contingency, 15.0 pct of above subtotal			13333700.
Subtotal			102224900.
Contractor's fee, 5.0 pct of above subtotal			5111200.
Section cost			107336100.

(1) Equipment costs are based on the M and S index of 749.3.
(2) Installed cost.

TABLE A-8.-Equipment cost summary, caustic regeneration section

Item	Cost(1)		
	Equipment	Labor	Total
Heat exchangers	$ 2029100.	$ 28500.	$ 2057600.
Solution storage tanks	82200.	30100.	112300.
Acid storage tanks	12100.	8800.	20900.
Pumps	14800.	3900.	18700.
Feed tanks	1700.	2600.	4300.
Pumps	15300.	3900.	19200.
Spent acid storage tanks	12100.	8800.	20900.
Pumps	14800.	3900.	18700.
Pumps	221900.	43900.	265800.
Multieffect evaporators	39094800.	2721900.	41816700.
Pumps	58500.	12400.	70900.
Concentrated caustic tanks	118300.	47100.	165400.
Pumps	8000.	2300.	10300.
Surge tank	3700.	2800.	6500.
Pumps	8800.	2300.	11100.
Evaporator	1564100.	235700.	1799800.
Condensate tank	1300.	1500.	2800.
Pumps	7000.	2000.	9000.
Pumps	5100.	1500.	6600.
Makeup storage tanks	484400.	194400.	678800.
Pumps	79000.	7900.	86900.
Caustic dilution tanks	2300.	4000.	6300.
Pumps	59200.	7400.	66600.
Pumps	68200.	15200.	83400.
Pumps	94900.	26500.	121400.
Heat exchangers	1274000.	42100.	1316100.
Heat exchangers	2475300.	65900.	2541200.
Heat exchangers	1683900.	50800.	1734700.
Heat exchangers	1064000.	37200.	1101200.
Heat exchangers	1693900.	39700.	1733600.
Heat exchangers	2611600.	53200.	2664800.
Heat exchangers	1609200.	34700.	1643900.
Pumps	738400.	221000.	959400.
Acid storage tanks	35700.	23500.	59200.
Pumps	20000.	5500.	25500.
Feed tanks	2500.	3800.	6300.
Pumps	21900.	5500.	27400.
Spent acid storage tanks	35700.	23500.	59200.
Pumps	19700.	5500.	25200.
Pumps	502000.	64500.	566500.
Car puller	3500.	300.	3800.
Total	57852900.	4096000.	61948900.
Caustic storage tanks			(2) 5701600.
Solution storage tanks			(2) 266900.
Cooling tower			(2) 885600.

TABLE A-8.-Equipment cost summary, caustic regeneration section (continued)

Total equipment cost x factor indicated:	
Foundations, x .159	9174500.
Buildings, x .025	1464100.
Structures, x .050	2892600.
Insulation, x .045	2580900.
Instrumentation, x .150	8677900.
Electrical, x .025	1443900.
Piping, x .750	43389700.
Painting, x .050	2892600.
Miscellaneous, x .100	5785300.
Total	78301500.
Total direct cost	147104500.
Field indirect, 10.0 pct of total direct cost	14710500.
Total construction cost	161815000.
Engineering, 10.0 pct of total construction cost	16181500.
Administration and overhead, 5.0 pct of total construction cost	8090800.
Subtotal	186087300.
Contingency, 15.0 pct of above subtotal	27913100.
Subtotal	214000400.
Contractor's fee, 5.0 pct of above subtotal	10700000.
Section cost	224700400.

(1) Equipment costs are based on the M and S index of 749.3.
(2) Installed cost.

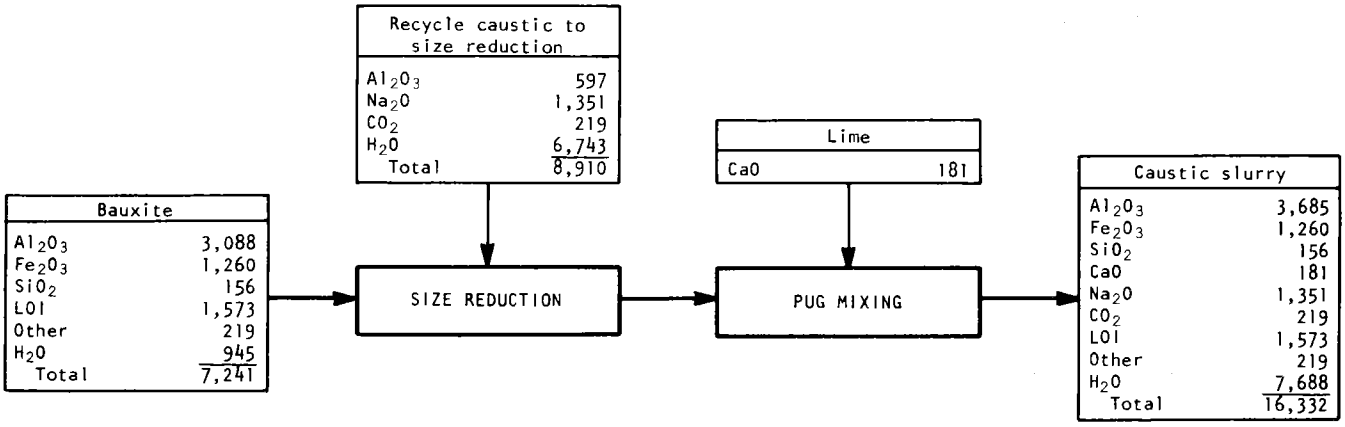

FIGURE A-1. - Material balance, bauxite handling and slurry preparation section (tons per day).

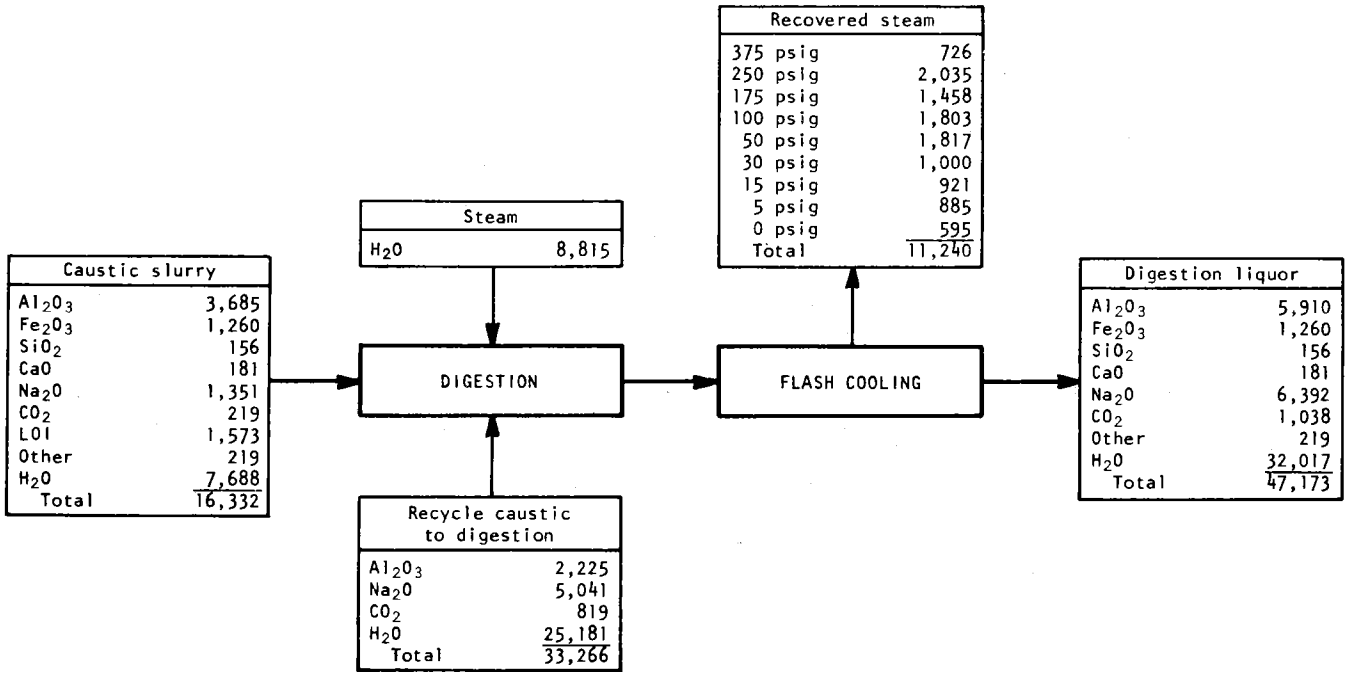

FIGURE A-2. - Material balance, digestion section (tons per day).

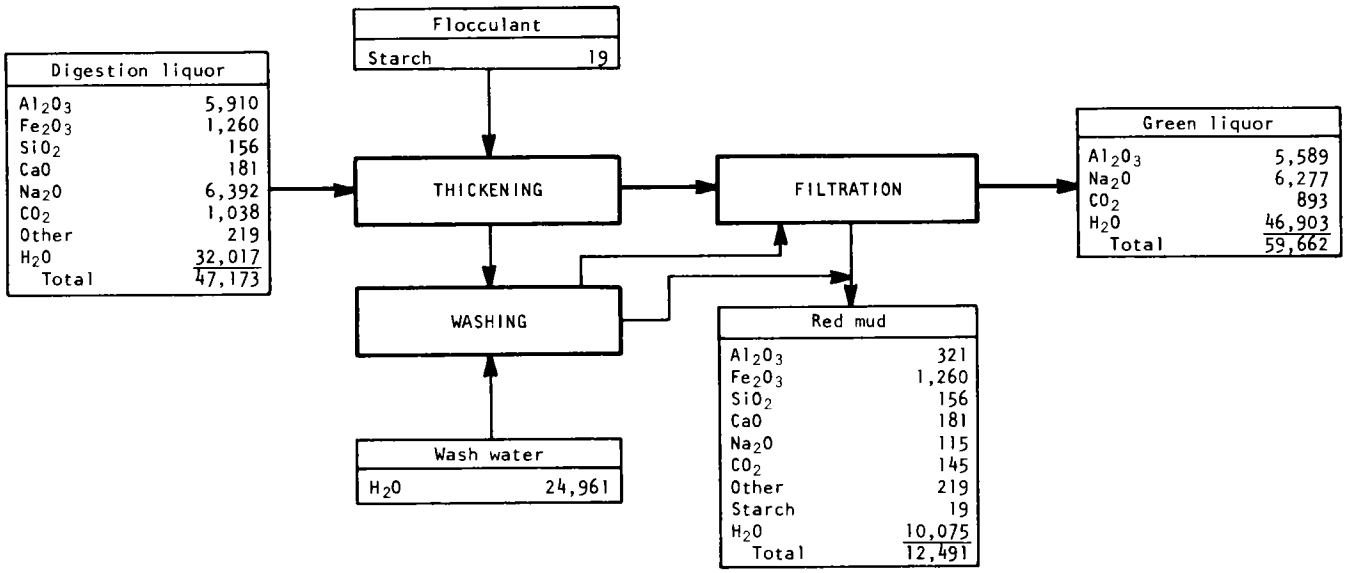

FIGURE A-3. - Material balance, clarification section (tons per day).

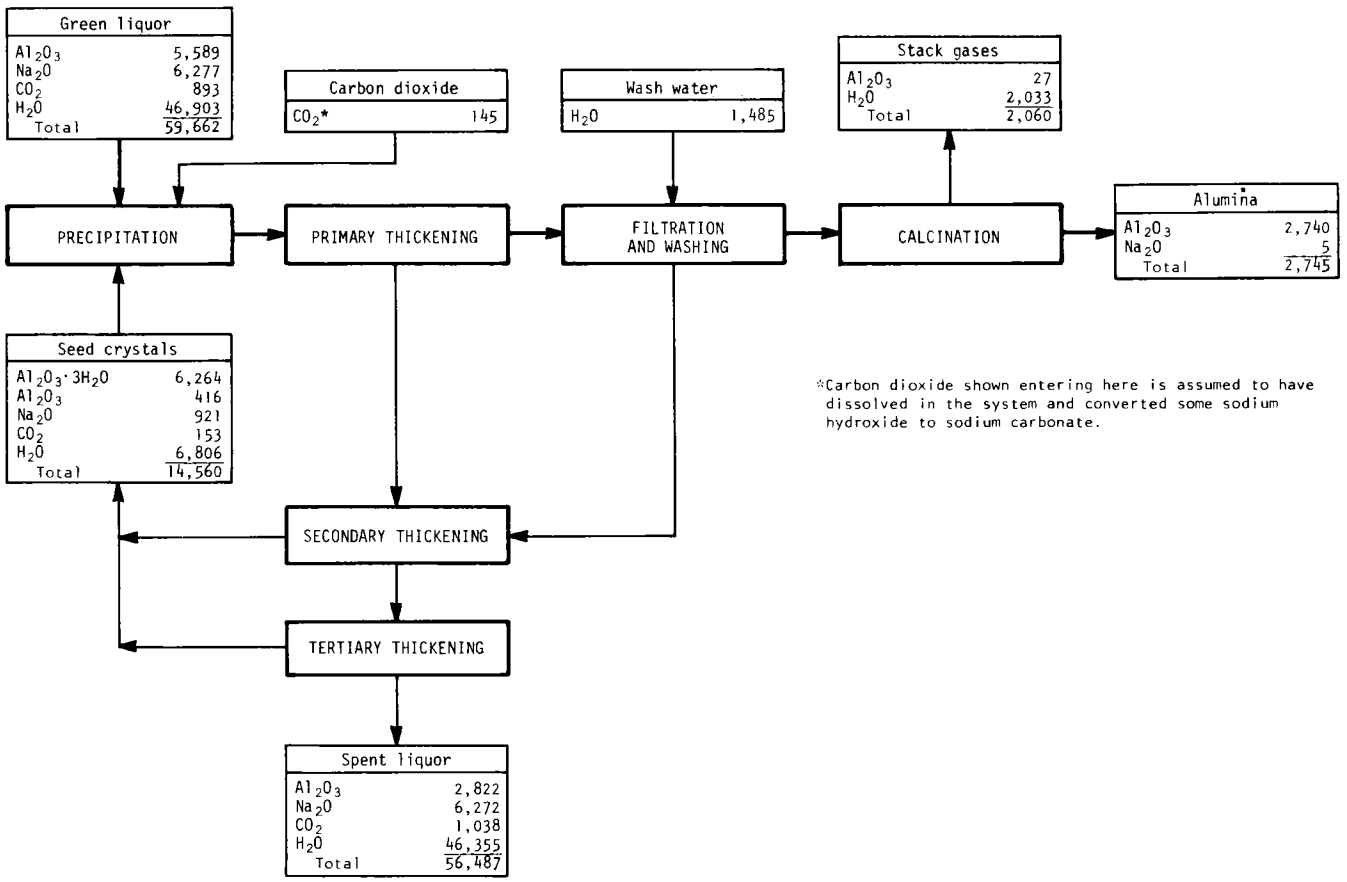

FIGURE A-4. - Material balance, precipitation and decomposition section (tons per day).

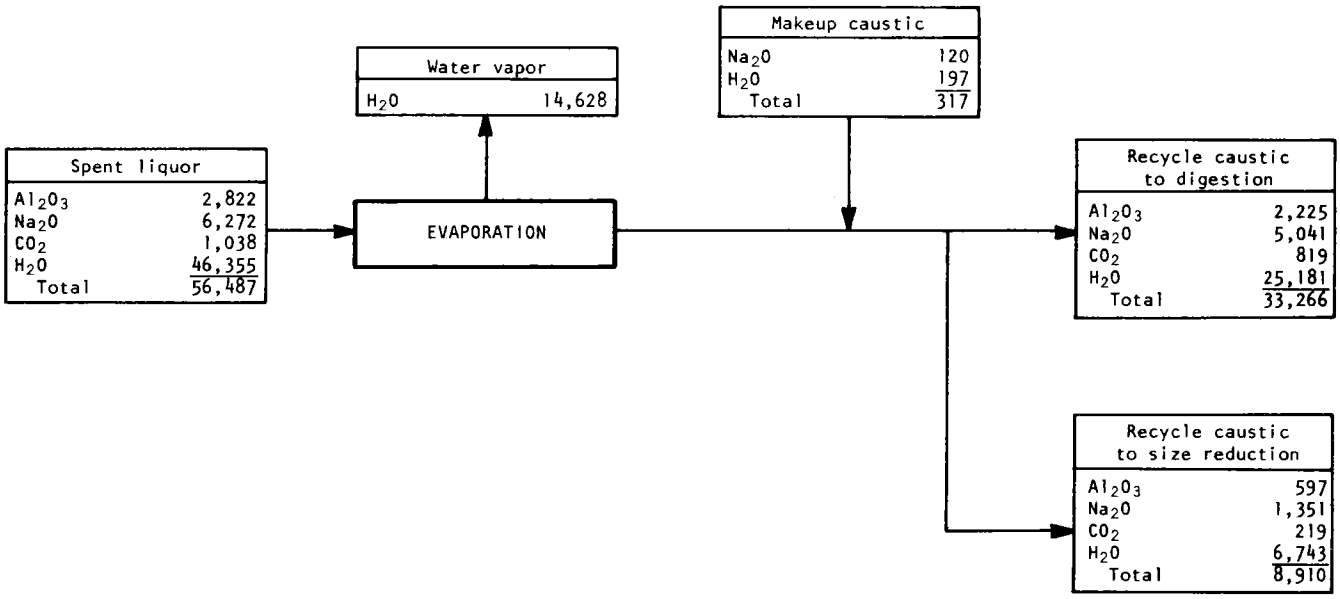

FIGURE A-5. - Material balance, caustic regeneration section (tons per day).