

Studies in the Amenability of Kolhapur Bauxite to Bayer's Process—Parts I and II

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PART I—STUDIES IN DIGESTIBILITY OF KOLHAPUR BAUXITE BY BAYER'S PROCESS

DETERMINATION of the digestibility pattern of the bauxite samples is the most important step towards the design of an integrated alumina plant principally based on Bayer's process. Of all the aluminous minerals, the trihydrate gibbsite is the most amenable to caustic digestion, and diaspore the hardest to treat. Altekar and Mathad¹ proceeded to determine the mineralogical set-up of the Kolhapur bauxite. The samples were obtained by the senior author from seventeen different pits dug to an average depth of 17' in a 30-acre plateau on top of a 3,000' high hill near Udgeri. The deposit has been since estimated at 3.5 million tons of bauxite. The findings of the author were that the principal and predominant mineral of aluminium is gibbsite and it was therefore predicted that its response to caustic treatment would be quite favourable. This paper records the results of detailed investigations concerning the digestion of the bauxite.

Over five hundred cwt of the samples were crushed and mixed together and ground to fine powder; it was from this stock that samples were weighed out for digestion. The experiments were carried out on two scales: preliminary investigations using ten-gram samples followed by bench scale experiments involving 500 gms. The following variables were studied: effect of particle size, caustic strength, molar ratio of alumina to caustic, temperature of digestion, duration of digestion and variation in pressures.

Effect of particle size

The following size ranges were investigated: +8 mesh, +40 mesh, +120 mesh and -220 mesh. In testing the effect of the size the other factors were kept constant at the following values: sample weight -25

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gms; concentration of NaOH 200 gpl; molar ratio: 1:4; temperature of digestion 100-105°C; duration -1 hr.; pressure -1 atm. The results obtained are tabulated as below:

TABLE I

Size of bauxite particles	Percentage of extraction of alumina
+8	80
+40	89.4
-100+120	90.7
-120	90.5

The results tabulated above show that particles coarser than 8 mesh give a lower recovery than the particles at 40 mesh; but there is no further substantial increase in recovery by crushing the bauxite any finer. In fact in the finer size range difficulties were experienced in sedimentation of the residue, its washing and filtering, which difficulties would be proportionally magnified in commercial practice. It was observed that digestion resulted in disintegration of 10 mesh particles.

Concentration of caustic soda

This was investigated under the following constants and conditions: Temp. 100, Molar ratio 1:4, Digestion period 5 hours, Pressure 1 atm, Particle size of bauxite = 90% passing through 120 mesh. The evaporation was checked by using a reflux condenser. The final liquor was filtered and filtrate analysed for alumina content. The following results were obtained:

TABLE II

Effect of caustic concentration.

Concentration of caustic	Percentage extraction
100 gms. per litre	80.5
200 do	89.8
300 do	90.0
400 do	90.5

It may be mentioned here that the gibbsite content in the alumina bearing minerals is 93%. As the extraction figures reach 90% most of the gibbsite goes into solution. The refractory monohydrate is unaffected at this pressure and rise in concentration of the caustic alone will be ineffective. Higher concentration involves greater expenses in evaporation of the recycled caustic from the hydrolysers. The optimum figure would be between 250 gms and 300 gms per litre.

The period of digestion

The effect of this variable factor was investigated with a molar ratio of 1 : 4, temperature of digestion of 100°C, and at 1 atm. pressure. Two concentrations were used : 200 gpl and 300 gpl of caustic. The digestion time was progressively increased in steps of 10 minutes from 10 to 60 minutes. The percentage extraction was determined as usual. The results are tabulated in Table III.

TABLE III
Effect of increasing the time of digestion.

Time of digestion minutes	Percentage extraction using 200 gms NaOH/L	Percentage extraction using 300 gms NaOH/L
10	74.5	84.4
20	83.7	86.4
30	89.0	88.7
40	90.5	89.0
50	91.0	90.8
60	91.7	91.8

It is seen from the above results that the rate of digestion of bauxite is high in the beginning for both liquors, the one for the stronger of the two being higher, in the initial stages up to 30 minutes period. By this time percentage extraction has reached a figure of 89% in both the cases. This figure goes up by another 2% only over the next 30 minutes period. Certain minor discrepancies in the figures are mostly within the range of experimental error. Higher concentration liquor is consistently showing lower figures of extraction at 30, 40 and 50 minutes.

Effect of molar ratio of alumina to caustic

In this investigation the rate of extraction was determined at intervals of 10 minutes using the following 3 molar ratios of alumina to caustic : 1 : 2, 1 : 3 and 1 : 4. The following factors were kept constant: Temperature 100°C, Pressure 1 atm., Caustic concentration 300 gms/L. The results obtained are tabulated in Table IV.

It is seen from the table that with a molar ratio of 1 : 2 only 43-44% extraction is obtainable between the periods 10 and 60 minutes. With a molar ratio of 1 : 3 the extraction reaches 77% at the end of an hour's leach. With a molar ratio of 1 : 4, the extraction gradually increases from 84.4% at 10 minutes' leaching to 91.8% at the end of 60 minutes' leaching. The lack of higher recovery than 44% obtained with the use of the

theoretical molar ratio of 1 : 2 is unlikely to be improved by increasing the time.

TABLE IV
Effect of molar ratio on rate of digestion of Udgeri bauxite.

Period of digestion	Percentage extraction		
	Molar ratio 1 : 2	Molar ratio 1 : 3	Molar ratio 1 : 4
10 minutes	43	62.5	84.4
20 "	43.5	69.8	86.4
30 "	44.5	73.2	88.7
40 "	44.0	76.6	89.0
50 "	43.8	79.3	90.8
60 "	44.2	80.5	91.8

Effect of pre-treatment of bauxite

Bauxite often contains organic vegetable matter due to its location in tropical and subtropical regions and its usual nearness to the surface of the earth. The organic matter colours the aluminate solution dark brown; but more adversely it retards the rate of decomposition of the aluminate liquor in the hydrolyser. Several plants therefore practise calcination of the bauxite to burn off the organics.

Such high temperature treatment also results in change of the chemical and physical makeup of the bauxite. It progressively loses water of crystallisation so that trihydrate turns into monohydrate. It also changes in hardness and specific gravity and in addition is reported to change in its response to caustic leaching. It was therefore decided to determine the effect of calcination on the Udgeri bauxite.

Fixed amounts of bauxite samples were heated to various temperatures. The samples were then leached under the following constant conditions : Caustic concentration—200 gms/L., Molar ratio—1 : 4, Period of digestion—1 hour, Temperature of digestion 100°C, Pressure—1 atm., Original gibbsite content of the sample—93% on total alumina basis and 50.5% on bauxite basis.

The results of calcination at various temperatures are tabulated in Table V.

TABLE V
Effect of calcination on alumina extraction.

Temperature of calcination	Percentage extraction of alumina	Per cent conversion of gibbsite to bohemite and to alumina
100°C	92	—
200°C	91	1
300°C	83	9
400°C	72	20
500°C	67	25
600°C	41	51
700°C	26	66
800°C	21.5	70.5
900°C	16.0	76.0

The period of calcination in all these experiments was kept constant at 1 hour.

It is seen that under the conditions of calcination, the gibbsite continuously changes over to bohemite which being insoluble in the caustic at atmospheric pressure is responsible for progressively lower yields. The liquor after filtration was only faintly coloured instead of the usual brown from uncalcined bauxite.

It may therefore be concluded that there is on the whole an adverse effect on the natural digestibility of the bauxite when it is calcined.

Effect of presence of sodium aluminate in caustic leach

In plant practice, the regenerated caustic solution from hydrolysers is recycled by evaporators to the autoclaves. The liquor from hydrolysers is however always associated with a substantial amount of undecomposed sodium aluminate which also gets recycled through the process. The experiments reported here so far have used fresh and pure sodium hydroxide only. It was therefore pertinent to observe the effect of the presence of sodium aluminate in the leach liquors on the efficiency of the extraction.

Since the molar ratio of NaOH : alumina in hydrolysed liquors is about 6 in usual practice, a liquor was synthesised to contain the two ingredients in accordance with this ratio. Another liquor with a ratio of 2 : 1 was also tried for comparison. The digestions were conducted under the following conditions : Temperature—100°C, Time—1 hour, Pressure—1 atm., Concentration of total NaOH in feed liquor—200 gms/L. The results of this investigation are tabulated in Table VI.

TABLE VI

Effect of presence of sodium aluminate in caustic leach liquor.

Initial molar ratio NaOH : alumina	Concn. of free NaOH	Concentration of Al ₂ O ₃ in feed liquor	Per cent extraction of alumina	Final molar ratio NaOH : alumina
4.2	230 g/l	200 gms per l	19.5	3.78
6.46	260 g/l	109 gms per l	90.0	3.566

It is seen from Table VI that an efficiency of 90% extraction can be maintained in the presence of sodium aluminate in the liquor provided the ratio of NaOH to dissolved alumina is around 6 : 1. This is the usual ratio after hydrolysis in usual plant practices.

Verification of optimum results on semi-pilot scale

Duplicability of these bench scale experiments was tested on larger scale using the following optimum conditions of experiments on the basis of results obtained earlier. In this series 1 kg of bauxite was digested per batch under the following conditions : Caustic concentration 200 gpl., Final molar ratio :

NaOH : Alumina 4 : 1, amount of NaOH liquor : 4.24 L., Temperature of digestion : 100-105°C, Pressure of digestion : 1 atm., Period : 1 hour (excluding pre-heating time).

The digestion was carried out in a 10-litre vessel of porcelain fitted with an improvised stirrer which was electrically driven. The heating was done by an immersion electric heater suspended together with a thermometer. The predetermined quantity of caustic liquor was first heated alone in the vessel, and when the temperature reached 100°C, the ground and weighed quantity of bauxite was charged with continued stirring. Temperature was adjusted by a Sunvic energy regulator. At the end of the prescribed period, slurry was taken out and allowed to settle down for 18 hours. A clear concentrated solution was decanted, the residue washed with 5,000 c.c. of water, the washings filtered out and analysed along with the decanted solution and red mud.

The following results were obtained :

TABLE VII
Results of large scale experiments.

Item	Amount	Analysis (% Al ₂ O ₃)	Alumina content	% Distribution
Bauxite	1 kg.	53%	530	100
Strong liquor	4.5 L.	86.2 gpl	388 gms	75
Washings	5.0 L.	12.12 gpl	66 gms	12
Red mud	295 gms	26%	76 gms	13

It was observed during this experiment that there was a strong tendency for the coarser grains of bauxite to settle down at the bottom of the tank due to inefficient operation of the improvised stirrer arrangement. This is the principal reason of obtaining only 87% extraction instead of the 91% obtained in the smaller scale experiments. A specially designed digester to treat 5 kg lots will be used for pilot scale experiments planned for the immediate future.

Redigestion of red mud

In the above experiments about 86 gms of alumina were left behind in the red mud—partly in the form of undigested gibbsite due to poor stirring, partly in the form of insoluble bohemite content, and partly in the form of unrecovered products of digestion. It was felt that if this red mud be subjected to digestion with fresh caustic leach, not only the undigested gibbsite may go into solution, but some of the bohemite may also be dissolved. This assumption was made on the logic that in ordinary digestions tried so far, the more readily soluble gibbsite dissolved into the caustic making it weak and unavailable for the bohemite which due to its refractoriness is very slow to react under the conditions tried, and if the red mud from the first digestion (now predominantly of bohemite) be re-subjected to digestion it will get an opportunity to react with the caustic without competition from the gibbsite.

Accordingly, 20 gms of red mud were redigested with 36 c.c. of 200 gpl liquor (NaOH : alumina ratio of 4 : 1) at 100°C for one hour when the slurry was filtered and residues washed. The filtrate was analysed and the percentage extraction determined.

It was observed that under these conditions, 61% of the entrained alumina in the red mud is extracted. In terms of the original alumina content of the treated bauxite, this figure represents an additional 6.1% recovery, thus giving a final total recovery of 93%. This shows that at atmospheric pressure only gibbsite dissolves and none others.

Conclusion

It is seen that 93% of extraction recovery of alumina is possible at atmospheric pressures, 100°C, 4 : 1 molar ratio, with a 200 gpl of caustic within 1/2 hour's digestion. The layout and cost of the proposed plant will be very favourably influenced by these experimental results. Pilot plant experiments are in progress.

PART II—SEDIMENTATION STUDIES OF RED MUD IN BAYER'S PROCESS

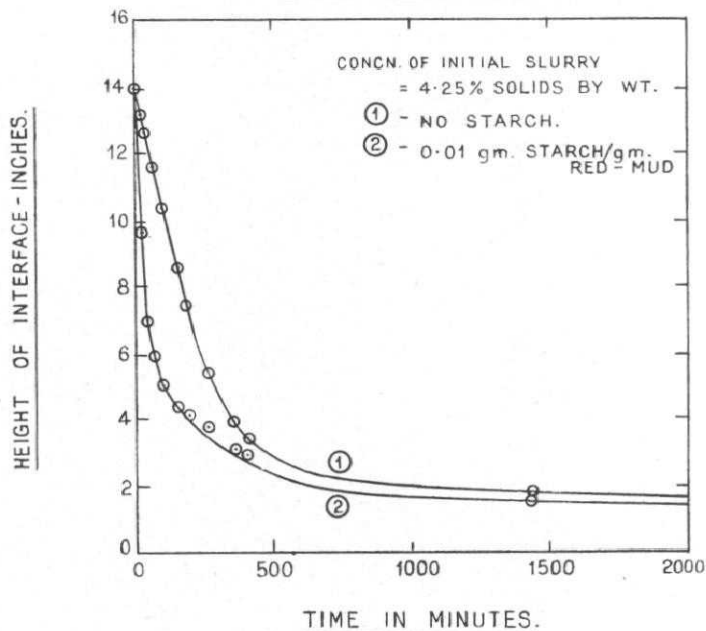
The sedimentation of red mud, so as to separate the aluminate liquor for hydrolysis, follows the digestion step in Bayer's Process. It is a well known fact in the aluminium industry that the major contribution to the cost of final alumina is from the evaporation of dilute liquor from hydrolysers and the soda losses. Soda losses can be classified into (1) chemical soda loss and (2) the free soda loss. The former directly depends upon the silica content of bauxite and is hence constant for a feed of a given composition ; whereas the free soda loss can be minimised to a great extent by washing the red mud thoroughly in thickeners. And this requires a careful design of thickeners and washers and this can be done only with the knowledge of settling characteristics of the solids involved. Further, the settling rate of solids determines the area of a thickener and hence the cost of equipment and so it is important from the economy point of view to control the settling rates. Since the settling rate inversely affects the thickener area, some agency, which will effect an increase in settling rate and thus bring about a corresponding reduction in settling area, should be investigated. From these points of view, study of sedimentation, for an economic and efficient design of thickeners, becomes indispensable.

Experiments : Experiments were carried out with the pulps of dilution, which are usually encountered in industry ; so that the settling rates thus obtained can be directly used for the calculation of thickener area.

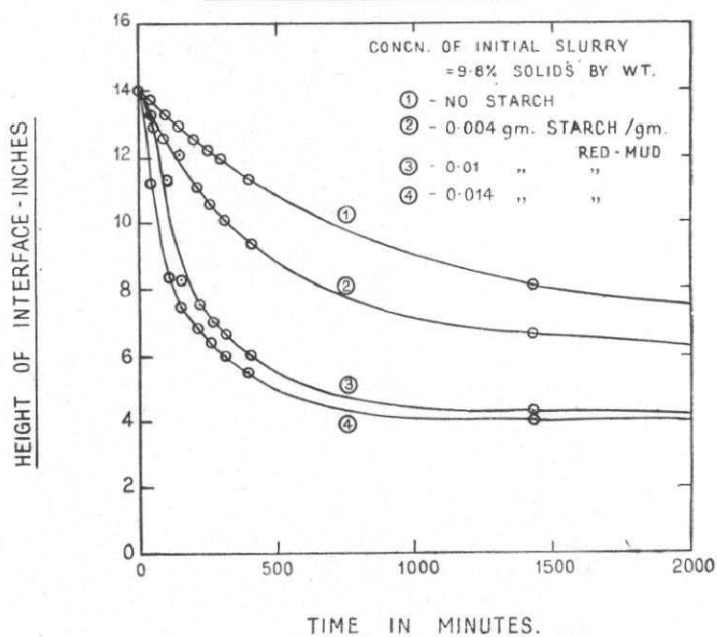
The bauxite was digested and the consistency of the digested slurry was adjusted to a predetermined value and the rate of settling in a cylinder studied over a period of 24 hours. The height of the cylinder used was 14" and its diameter was 2.3".

The effect of addition of different quantities of starch, as coagulant, on the rate of settling was also studied.

GRAPH - 1.
EFFECT OF ADDITION OF STARCH ON
RATE OF SETTLING.



GRAPH - 2.
EFFECT OF ADDITION OF DIFF. AMTS. OF
STARCH ON RATE OF SETTLING.



From the settling curves so obtained, the variation of settling rate with the concentration of solids settled can be calculated from Kynch Theory and used for the design calculations.

Results: Temperature—27°C, Particle size of bauxite used=20% passing.

TABLE VIII

Slurry (I) consistency=4.25% solids or density =1.11 gms/cc.

Slurry (II) ,, =2.8% solids or density =1.275 gms/cc.

Time in minutes.	Height of interface in inches					
	Slurry I			Slurry II		
	No starch	Starch : 0.01 gm/gm of red mud	No starch	Starch : 0.004 gm/gm of red mud	Starch: 0.01 gm/gm of red mud	Starch : 0.014 gm/gm of red mud
0	14.0	14.0	14.0	14.0	14.0	14.0
10	13.72	11.0	13.92	13.9	13.92	13.80
20	13.58	9.62	13.81	13.83	13.81	13.50
40	12.60	6.83	13.75	13.55	12.80	11.22
60	11.54	5.85	13.57	13.25	11.00	9.65
80	11.03	5.21	13.43	13.0	9.85	8.85
100	10.35	4.91	13.27	12.63	9.35	8.46
120	9.65	4.65	13.12	12.22	8.86	8.05
150	8.54	4.33	12.92	12.00	8.34	7.64
180	7.40	4.05	12.74	11.62	7.95	7.29
210	6.60	3.85	12.55	11.15	7.64	6.82
260	5.30	3.64	12.21	10.61	7.15	6.45
310	4.48	3.36	11.93	10.15	6.72	6.00
360	3.96	3.12	11.68	9.73	6.36	5.82
410	3.32	3.01	11.41	9.35	6.04	5.52
24 hrs.	1.85	1.65	8.08	6.62	4.26	4.15

The table reveals that there is certainly an advantage in adding a little quantity of starch. The effect of starch is to coagulate the fine red-mud particles which then can settle fast in the medium. The optimum amount is 0.01 gm/gm red mud which is in good accordance with the one used in practice.^{2, 18}

Applying Kynch Theory¹⁹ to curve 2 of graph 1, the rate of settling of red mud at discharge concentration of 20% solids by weight, is about 0.05 t/hour. Using this rate, the thickener area is calculated for handling different quantities of red mud slurry.

$$\text{Thus, } A = \frac{1.333(F-D)}{R \times 5.9} \text{ and } \gamma = \frac{1.33T(G_S - G_L)}{G_S(G_P - G_L)}$$

where A=area per ton of dry solids per 24 hours sq ft
F=Wt. ratio of liquid to solids in feed pulp

D= " " " " discharge pulp
R=Settling rate of pulp in ft/hour at a given discharge concentration and with initial dilution F

S.g.=sp. gr. of liquid

V=Volume of compression pulp in cft per ton of solids per 24 hours

T=Detention time in hours

G_S =Average sp. gr. of solids

G_L =Average sp. gr. of liquid

G_P =Average sp. gr. of pulp.

For calculating the area, various values starting from feed dilution to discharge dilution are substituted for F, with the corresponding values of R, the max. value of area is taken as the correct area. Obviously, the largest area is when F has dilution of discharge and while calculating the area for this concentration, D is taken as the dilution of compression pulp which is 2.7 lb of liquid/lb of solid.

$$\therefore A = \frac{1.333(4-2.7)}{0.05 \times 1.15} = 30 \text{ ft}^2/\text{tons of solids}/24 \text{ hrs.}$$

$$V = \frac{1.33 \times 5(2.4-1.5)}{2.4(1.41-1.15)} = 13.25 \text{ cft/ton of solids}/24 \text{ hrs.}$$

Thus, to handle 23 tons of solid/days (from 100 tons of bauxite)

$$\text{Total area} = 30 \times 23 = 690 \text{ ft}^2 \text{ or } D = 30 \text{ ft.}$$

$$\text{Ht. required for compression} = \frac{13.25 \times 23}{690} = 0.45 \text{ ft.}$$

Density of solution being 72 lb/cft (i.e. 0.032 tons/cft).

$$\text{Volume required per 24 hours for clarification} = \frac{23}{0.032} = 720 \text{ ft}^3.$$

$$\therefore \text{Ht. required for clarification} = \frac{720}{690} = 1.04 \text{ ft.}$$

\therefore Total ht. of thickener,

Clarification depth 1 1/2 ft

Compression depth 1/3 ft

Ineffective depth due to sloping of rates 1 1/2 ft

Feed well 1 1/2 ft

\therefore Total height=5 ft.

Therefore dimensions of thickener=30' x 5'

Number of thickeners needed will depend upon the degree of washing of red mud and each one will be of the same dimensions.

Following similar calculations, the thickener dimensions for plants of various sizes are calculated and summarised below:

Size of alumina plant tons of alumina/year	Tons of red mud per day	Area of each thickener ft ²	Size of each thickener dia. x ht. cft.
1,000	2.3	69	10' x 4'
10,000	23	690	30' x 5'
50,000	115	3,450	67' x 7'

Studies in hydrolysis of aluminate liquor in Bayer process

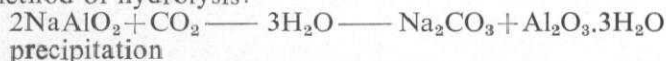
The next important step after digestion, in Bayer's process, is the hydrolysis of sodium aluminate liquor formed during digestion. The influence of various factors, as will be mentioned later, on the hydrolysis has been studied by many workers³⁻¹⁴ and yet the exact mechanism of hydrolysis is not fully understood. Particularly, the correlation and generalisation of the effect of quality of seeds on rate of hydrolysis is very

complicated. Further, the duration of hydrolysis, as encountered in industrial practice, varies from 50 to 200 hours¹⁵⁻¹⁸ and thus the study of optimum conditions to have the shortest practicable hydrolysing time becomes very important. Not only is the hydrolysing time important but the particles size of the product also, because the finer the product the more will be the loss of alumina as dust in the kiln and reduction cells. Again, it has been found from practice that the feed to reduction cells should be of some particular size. The typical size distribution of alumina (Tyler mesh) feed to cells is +48, nil, -48+100, 0.5%; -100+200, 53.5%; -200, 46%; -325 (wet on original samples) 12%. So it is desirable to get the product of the mentioned size distribution. Hence the correlation of various conditions, as will be mentioned later, so as to get the proper product in the least possible time, is one of the most complicated tasks experienced in the aluminium industry.

Hydrolysis or the precipitation of $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ is effected by one of the following methods :

- (1) Bubbling of CO_2 gas through aluminium liquor.
- (2) Hydrolysis in presence of $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ seeds.

(1) Carbon dioxide is not widely used in alumina manufacture because of its inherent disadvantages. Firstly, the Na_2CO_3 that is formed during precipitation by this method has to be converted back to NaOH by treating with lime before it can be reused for digestion, thus involving a step more as compared with the second method of hydrolysis.



Secondly, CO_2 is a costly raw material which will increase the cost of production of alumina, whereas in the second method no other raw material is needed except seeds taken from the previous batches. As the reaction is a precipitation reaction, the only factor in favour of this method is that the time of precipitation will be considerably less.

(2) *Hydrolysis in presence of seeds*: This being the method widely used in industry, it has been studied in detail and the optimum conditions have been evolved.

Sodium aluminate solution has got one peculiar property of remaining in stable form even under conditions of high super saturation. The stability of solution increases with the presence of organic impurities and excess of caustic soda. But this solution can be made to decompose to precipitate $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ by diluting it and in the presence of some fresh finely divided alumina trihydrate seeds with continuous stirring. However, the rate of decomposition is dependent on various other factors as :

- (1) Concentration of NaOH in liquor.
- (2) Molar ratio of total NaOH to alumina.
- (3) Period of hydrolysis.
- (4) Quantity of seeds added i.e. seed ratio (seed ratio is defined as Al_2O_3 in solution to Al_2O_3 added as seeds).
- (5) Stirring mechanism.
- (6) Temperature of hydrolysis.

The above factors were investigated with liquors obtained from Kolhapur bauxite using freshly prepared seeds and the observations are discussed below :

(1) *Effect of concentration on rate of hydrolysis*: As a general rate it can be said that the rate of decomposition of sodium aluminate solution decreases with increase in concentration. The experiments were carried out for four concentrations viz. 100, 120, 150 and 180 gpl of NaOH . The other conditions of hydrolysis were

- (a) Molar ratio $\frac{\text{Na}_2\text{O}}{\text{Al}_2\text{O}_3} = 1.88$
- (b) Seed ratio = 3 : 1 particle size of seeds :
40% - 100+200
60% through 200 mesh
- (c) Period of hydrolysis = 2 days (48 hours)
- (d) Temperature of hydrolysis = room temperature 30°C .

TABLE IX

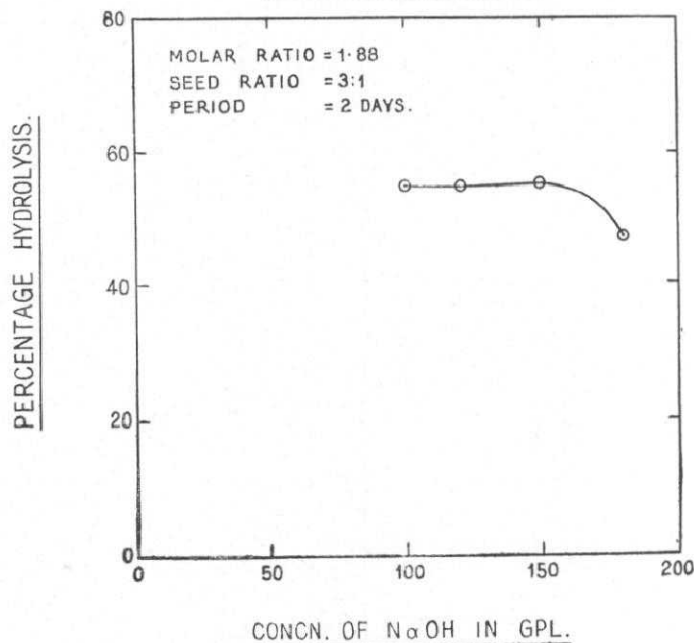
Concentration of NaOH gms/litre ...	100	120	150	180
* % Hydrolysis at the end of 48 hours ...	55	55	55	47

Alumina trihydrate precipitated at the
end of expt.—Amt. of seeds.

$$\text{* \% Hydrolysis} = \frac{\text{Alumina trihydrate precipitated at the end of expt.—Amt. of seeds.}}{\text{Total alumina in the original solution as trihydrate.}}$$

GRAPH - 3.

EFFECT OF CONCENTRATION ON
RATE OF HYDROLYSIS.



The results show that the rate does not vary in the initial ranges of concentration and any one of the values (except 180) can be taken as the optimum concentration. With dilution, the subsequent evaporation costs will increase and so, 120 to 150 g/l of NaOH can be taken as the optimum concentration.

(2) *Effect of time and molar ratio on rate of hydrolysis:* The same conditions as in (1) were kept except that the molar ratios of the solution varied from 1.88 to 2.18.

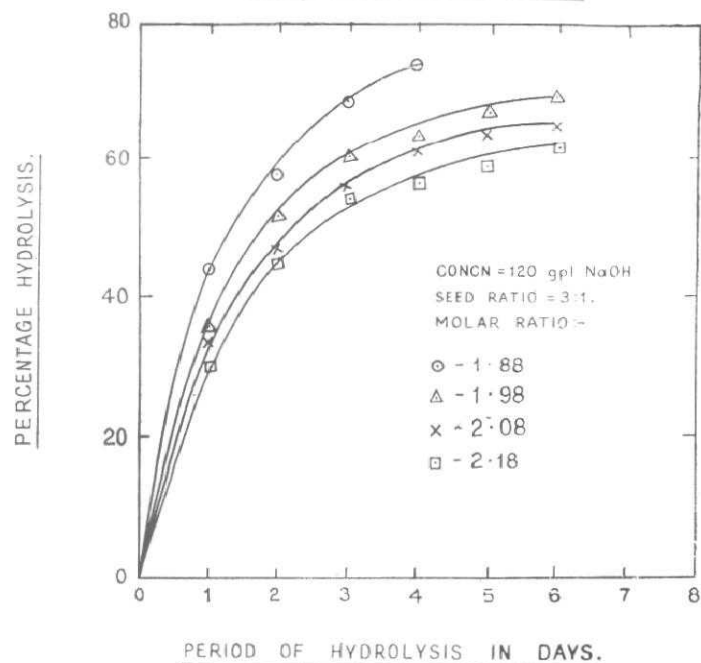
TABLE X
Percentage hydrolysis

Period Molar ratio	1 day	2 days	3 days	4 days	5 days	6 days
1.88	44	58	69	74	—	—
1.98	36	52	60.5	64	67.5	62.5
2.08	33.5	47	56	61.5	64	65
2.18	30	45	55	57	59	62

The table shows that the rate is more in the beginning than at the end. The optimum hydrolysis is almost reached within three days. This can be explained by the fact that the rate of hydrolysis decreases with increase in molar ratio of the solution and is also indicated by the table. Thus, as hydrolysis proceeds precipitating the trihydrate, the dissolved alumina content goes on decreasing or, in other words, the molar ratio of the undecomposed solution goes on increasing and this causes the decrease in the rate of hydrolysis.

GRAPH - 4.

EFFECT OF MOLAR RATIO AND PERIOD
ON RATE OF HYDROLYSIS.



The optimum molar ratio is dependent upon the digestion step, since during digestion a solution of constant molar ratio is formed. As the experiments show, a molar ratio of more than two is not preferable the time taken for hydrolysis being very high. In our previous digestion studies, the molar ratio of the solution obtained is about 3.5 to 4 and this itself can be taken as the optimum ratio.

The optimum period is about fifty hours for a hydrolysis of about 55% or to a final molar ratio of 3.5:1, which is the usual value used in practice. Since the equilibrium is reached by this time, it is not economical to continue hydrolysis beyond this period, obviously the optimum time is dependent upon the molar ratio of liquors.

(3) *Effect of seed ratio on rate of hydrolysis:* Conditions of experiment:

- (1) Concentration of hydrolysis = 120 g/l of NaOH.
- (2) Temperature of hydrolysis = 30°C.
- (3) Seed size = $\frac{-100 + 200}{-200}$ $\frac{40\%}{60\%}$

TABLE XI
Percentage hydrolysis

Molar ratio	Seed ratio Period of hydrolysis	Seed ratio			
		2:1	3:1	4:1	5:1
1.98	1 day	44.5	36	34	26
	2 days	62	52	50	42
	3 days	67	60.5	57	54
	4 days	68.5	64	60	59
1.88	1 day	—	33.5	30	19.5
	2 days	—	47	45	42.5
	3 days	—	56	54	52
	4 days	—	61.5	60	57

The results were plotted on a graph (period of hydrolysis against % hydrolysis) and the following table was prepared from this graph.

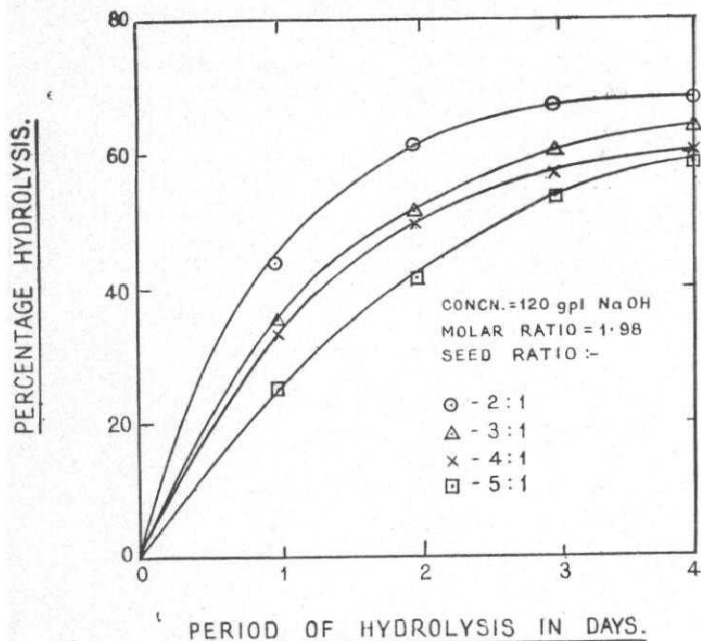
TABLE XII
Period of hydrolysis (hours)

Quantity of seeds as % of Al ₂ O ₃ in solution	Seed ratio	Hours of hydrolysis necessary for following % hydrolysis				
		20%	30%	40%	50%	60%
50%	2:1	7	12	19	30	46 2 days
33%	3:1	12	18	29	45	70
25%	4:1	14	20	32	48	88
20%	5:1	19	30	44	62	120 5 days

The above two tables clearly show that the lower the seed ratio the higher is the rate of decomposition. But addition of many seeds increases the load on thickeners thus decreasing the output. An optimum ratio of 2:1 is recommended.

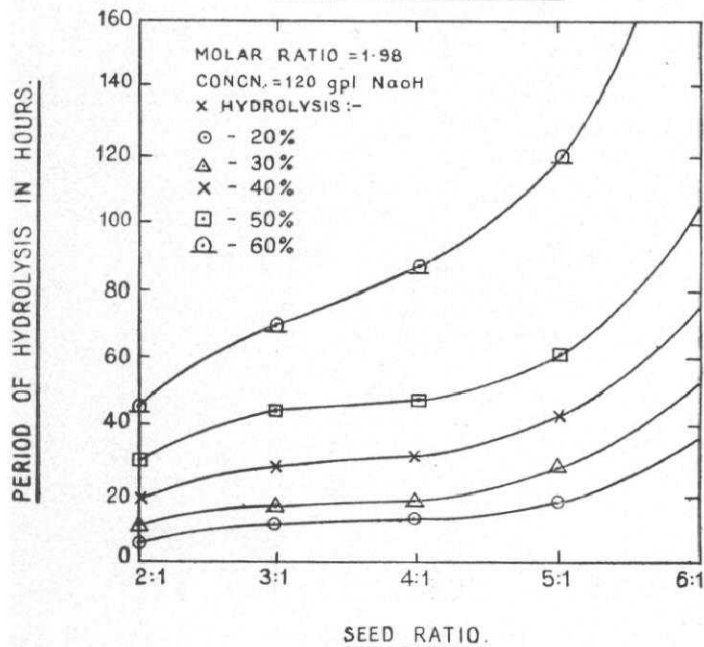
GRAPH - 5

EFFECT OF SEED-RATIO ON
RATE OF HYDROLYSIS.



GRAPH - 6.

EFFECT OF SEED-RATIO ON
RATE OF HYDROLYSIS.



The effect of temperature on rate of hydrolysis and particle size of the final product as well as the effect of quality of seeds on the quality of product is yet to be studied in detail and it is only after the complete knowledge of all these factors that a whole set of optimum conditions can be recommended.

Further work

Work is in progress to cover other factors affecting hydrolysis. Also a pilot plant has been designed to treat 100 kgs of bauxite per day. It is hoped that the data obtained from the operation of this plant will enable to undertake design work of commercial pilot plant, handling, say, about 10 tons of bauxite per day. Experiments are also in progress on continuous extraction in tower type experiments.

Conclusion

It can be concluded from the experimental results (Parts I and II) that Kolhapur bauxites are predominantly gibbsitic in character since about 90% of the total alumina is dissolved in caustic soda at atmospheric pressure in less than an hour. This is a point very much in favour of Kolhapur bauxite since its digestion will be under more mild conditions than those employed for other Indian bauxites processed at present. Further, due to the fact that the digestion is at atmospheric pressure, costly pressure autoclaves are not needed and this considerably reduces the capital investment and steam cost. Also, because the caustic concentrations employed are very low the subsequent evaporation costs will also be less and all these factors together will contribute to the reduction in the cost of production of alumina. Therefore it can be said that the capital outlay and other working costs will be very favourable to the plant processing these bauxites as compared to the existing plants in operation elsewhere in India.

Acknowledgement

Thanks are due to the Bombay State Research Committee for sponsoring and financing the investigation; to the Directorate of Geology and Mines, Bombay, for assisting in obtaining samples on the spot at Udgeri and to the Director, Department of Chemical Technology, University of Bombay, for his keen interest and encouragement.

References

- 1 V. A. Altekar and G. G. Mathad, Determination of Alumina Minerals in Kolhapur Bauxite and its Amenability to Bayer's Process, Science and Culture, 25, 695-697, June 1960.
- 2 S. C. Jain and P. D. Paud, Production of Aluminium from Indian Bauxite, Trans. of Ind. Inst. of Metals, April 1949.
- 3 Elmore, Mason and Hatfield, Precipitation of alumina from sodium aluminate solutions. J. Am. Chem. Soc., 67, 1449-52 (1945)
- 4 Taichi Sato, Hydrolysis of sodium aluminate solutions, J. Chem. Soc., Japan, Ind. Chem. Sect., ... 56, 322-401 (1953)

⁵ Effect of amount of seeds, J. Chem. Soc., Japan, Ind. Chem. Sect., ... 55, 198-200 (1952)

⁶ Effect of particle size distribution of seed charge., J. Chem. Soc., Japan, Ind. Chem. Sect., ... 56, 743-6 (1951)

⁷ Effect of various kinds of seeds, J. Chem. Soc., Japan, Ind. Chem. Sect., ... 56, 840-2 (1953)

⁸ Precipitation by seeds of low bulk density. J. Chem. Soc., Japan, Ind. Chem. Sect., ... 57, 111-13 (1954)

⁹ Effect of conc. of solution, J. Chem. Soc., Japan, Ind. Chem. Sect., ... 57, 540-2 (1954)

¹⁰ Effect of decomposition temp. J. Chem. Soc., Japan, Ind. Chem. Sect., ... 57, 805-8 (1954)

¹¹ Effect of addn. of calcined aluminium J. Chem. Soc., Japan, Ind. Chem. Sect., ... 58, 325-30 (1955)

¹² Maricic and Markovic, The kinetics of formation of aluminium hydroxide by seeding sodium aluminate solution with hydrargillite crystals. Experiments with a seed classified according to particle size, Arhiv Kem, 27, 45-7 (1955).

¹³ Volf and Pudovkina, Process of decomposition of aluminate solutions and methods for improving its efficiency, Khim. Referat. Zhur. No. 8, 89 (1940).

¹⁴ Manoilov and Benglyants, Improving the Bayer method of decomposing aluminate solutions by using supersaturated solutions, Khim. Referat. Zhur., No. 8, 88 (1940).

¹⁵ F.I.A.T. 989

¹⁶ B.I.O.S. 288

¹⁷ B.I.O.S. 764

¹⁸ Kenneth M. Reese, Alumina, Ind. Eng. Chem., 47, 1672 (1955)

¹⁹ Walter L. Badger and Julius T. Banchemo, Introduction to Chemical Engineering, Chapter 14, McGraw-Hill Book Company, Inc. New York.

DISCUSSIONS

Dr. C. G. Rao, Aluminium Corporation of India Ltd., Jaykaynagar: The authors are to be complimented on their good amount of work done on the amenability of Kolhapur bauxite to Bayer's process.

1. I could not find in the paper any reference to the charging molar ratio which matters a lot for recovery, as extraction will be more if the ratio (mols free Na₂O/mols Al₂O₃) is taken as 1.80 or 2, and will be much less if it is 1.40. I would like to know at what molar ratio the charging was done. In plant scale, it generally varies between 1.60 and 1.70. It is of course true that at high molar ratio extraction is more in the beginning, that is up to 10-12 minutes of digestion but afterwards, the extraction is almost the same even if the molar ratio is varied between 1.40 and 1.70 (vide Table I).

2. One should aim in the alumina plant to remove the impurities in the bauxite as quick as possible. Therefore it is important to design the filtration equipment carefully. For this purpose, may I know the analysis of the Kolhapur bauxite?

3. It has been pointed out that the molar ratio of the spent liquor after decomposition is about 6. I would like to state that in an actual plant practice it is around 4 and in some of the European plants it has gone up to 5. Of course, we can have it increased but the amount of decomposition volume and seed should be enormous and the cooling of the solution coming out from the Dorr Thickeners from 90-100°C to a temperature of 50-55°C should be taken care of. This cooling plays an important part in the efficiency of hydrolysis according to the reaction:



The concentration of (OH)⁻ ions will decrease and the reaction proceeds towards forward direction and the

TABLE I
Laboratory tests at different molar ratios,
(Lohardaga bauxite)

1. Bauxite analysis					
L.O.I. %	26.20	26.20	26.20	26.20	26.20
SiO ₂ %	1.10	1.10	1.10	1.10	1.10
Fe ₂ O ₃ %	8.50	8.50	8.50	8.50	8.50
TiO ₂ %	10.20	10.20	10.20	10.20	10.20
CaO %	—	—	—	—	—
Al ₂ O ₃ %	54.00	54.00	54.00	54.00	54.00
2. Digestion liquor					
Total					
Na ₂ O g/l	279.0	279.0	279.0	279.0	279.0
Causticity %	80.0	80.0	80.0	80.0	80.0
Molar ratio	4.0	4.0	4.0	4.0	4.0
3. Digestion conditions					
Molar ratio	2.0	1.9	1.8	1.7	1.6
Pressure					
lb/sq in	110	110	110	110	110
Digestion					
time hr.	2	2	2	2	2
4. Red mud analysis					
L.O.I. %	13.36	13.30	13.40	13.26	14.50
SiO ₂ %	4.2	3.44	4.10	3.80	2.60
Fe ₂ O ₃ %	21.60	21.30	21.10	20.80	19.30
TiO ₂ %	33.40	33.70	32.2	30.94	23.60
CaO %	—	—	—	—	—
Total Na ₂ O %	6.90	7.10	7.10	7.0	7.4
Al ₂ O ₃ %	20.50	21.20	22.40	24.20	32.80
5. % Red mud on bauxite					
	39.3	39.9	40.20	40.86	44.00
6. % Recovery					
alumina	91.94	91.54	91.00	90.10	86.60
7. % NaOH					
loss on bauxite	2.71	2.83	2.85	2.86	3.26

precipitation of $\text{Al}(\text{OH})_3$ will be quicker and the molar ratio improves. But as the aluminium hydrate precipitates, thereby (OH) ion concentration will also be gradually decreasing at the same time. Normally one should be able to get a molar ratio of 4 in about 80 hours with a seed ratio of about 300-350% which, of course, depends also on the method of stirring (conventional stirrer of 8 r.p.m. with two scrapers of 100 kg each or air circulation) and the fineness of the seed.

4. I would like to know whether the percentage of trihydrate in bauxite which the author mentioned as 97%, was determined by X-ray diffraction method. We have developed in our laboratory a simple process of evaluating the percentage of trihydrate by taking the solubility factor in caustic soda. One gram of bauxite is taken and is digested with 100 g/l NaOH with a charging molar ratio of 6.0 at a temperature of 100°C , duration of digestion being an hour. About 20 to 30 samples of Lohardaga (Bihar), Katni (M. Pradesh), Jamnagar and Porbandar (Sourashtra), Sheveroy bauxites were taken and the percentage of trihydrate was determined as 91-98%. These results tally with X-ray diffraction method and this process can be easily followed in plant scale.

5. We are told that consideration is given more for time schedule rather than the recovery schedules in the aluminium plants in India. In this connection, I would mention that this also depends on the digestion tests. For example, take the following digestion tests (on plant scale basis—samples collected from autoclave direct discharge), vide Table II.

TABLE II

Test	Bauxite origin	Pressure (lb/sq in)	Digestion time (min)	Recovery Al_2O_3 (%)
1.	Lohardaga	110	40	84.80
		110	90	86.80
		110	150	86.90
2.	Lohardaga	120	90	93.90
		120	150	94.20
3.	Jamnagar	120	90	90.50
		120	120	92.90
4.	Lohardaga	120	60	85.00
		120	120	89.00

Table III gives the calculated figures for Test 4 of Table II considering 2 autoclaves (22 hrs per day running each).

TABLE III

Pressure lb/sq in	Digestion (min)	Recovery (%)	No of charges per day	Bauxite digested tonnes	Al_2O_3 produced tonnes
120	60	85.0	13	52	25
120	120	89.0	10	40	20

The above figures are arrived at considering 1 hr 30 min for raising the pressure, 15 minutes for filling the autoclave and 30 minutes for blowing. By gaining one hour in every charge, one can produce 5 tonnes Al_2O_3 more. Actually, this difference of 4% in the recovery will come down as the temperature of the Dorr Thickeners will increase more in the first case than in the second case. And this will help in less decomposition taking place in the Dorr Thickeners. The net result will be a recovery of 87% in the first case. Therefore, the motto should be more production and the recovery automatically will go up (vide Table IV). The main consideration will be the amount of red mud removing capacity of the Kelly filters or Dorr Thickeners as the case may be. One can also increase the molar ratio and concentration in the Dorr Thickeners to compensate the recovery, if necessary. Of course, one should also keep in mind relationship between the concentration of liquor and settling in the Thickeners, decomposition and evaporation capacity of the plant. These are inter-connected closely and the operation of the alumina plant requires a balance of all these factors.

TABLE IV
Actual plant data.

Bauxite digested per day (tons)	Pressure (lb/sq in)	Digestion period (min)	Al_2O_3 recovery % (from red mud analysis)	Al_2O_3 produced per day (from monthly inventory)
44	120	78	84.2	20.2
38	120	134	78.8	16.7

6. I do not agree with the remark that by the addition of seed, the load on Thickeners increases, as there is no connection between these two. The amount of Al_2O_3 present in the process will no doubt increase. *Dr. V. A. Altekar (Author)*: The authors thank Dr. Rao for his compliments and comments. Considerable amount of interesting data have been put forward by him in the course of his comments. The molar ratio as expressed by us is on the basis of NaOH and not on the basis NaOH converted to Na_2O or the carbonate. The molar ratio used for digestion of the bauxite with pure sodium hydroxide solution to the alumina content of the bauxite was varied from 2:1 to 4:1. When spent liquor was synthesised, the charging was done on the basis of the free available hydroxide content. In both cases it was observed that the best results were obtained if the molar ratio of the alumina to be digested to the free sodium hydroxide was 1:4.

2. The analysis of the bauxite averaged 54% total alumina, 10-12% Fe_2O_3 , 4-5% TiO_2 , 1-1.5% silica, and loss on ignition 28-30%.

3. The fact that our results are in agreement with the suggested levels of molar ratios, becomes obvious when the ratios are expressed on the basis of Na_2O to Al_2O_3 . Thus we completely agree in that the molar ratio $\text{Na}_2\text{O}:\text{Al}_2\text{O}_3$ in the spent liquor after hydrolysis should be about 4, which when restated in terms of

NaOH is 1:8 to which we had allowed the hydrolysis to continue.

4. Regarding estimation of the gibbsite, we had tried digestion with KOH instead of NaOH as mentioned by Dr. Rao. We had also applied another method suggested by Maslenskii and the two results had tallied with each other. It would have been interesting to have subjected the samples to X-ray diffraction analysis, however with two independent methods giving corroborating results there was no need for this.

5. The settling area requirements of a thickener are directly proportional to the amounts of solids to be settled, for a given speed of settling. If a larger proportion of the solids in the slurry are composed of the seeds, the settling capacity of the thickener in terms of actually finished trihydrate is proportionately lessened.

6. The operational conditions of any step of the Bayer's Process are so intimately interdependent upon the conditions of the adjoining steps that any change in the optimum conditions of working of a step is bound to affect the optimum conditions of working in the preceding or following steps. The task of establishing the most economical set of conditions in the Bayer's Process is complicated by these numerous interdependent factors. There is therefore nothing surprising nor regrettable if time schedules are controlled for greater output by greater throughput rather than by greater extraction recoveries.

Dr. C. G. Rao: As Bayer's Process is a complicated one, I thought a written contribution on the subject will serve to focus the importance of studying in detail every type of bauxite before drawing any conclusion regarding the applicability of the Bayer's Process.

It is known that trihydrate is softest among all the different forms of aluminium oxide as shown in Table "A" below:

TABLE A

Alumina form	Formula	Mineral name	Crystal structure	Density
α Alumina	α Al_2O_3	Corundum	Hexagonal	4.0
β Alumina	β Al_2O_3	—	Cubic	3.4
α Monohydrate	$\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$	Bohemite	Orthorhombic	3.0
β Monohydrate	β $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$	Diaspore	"	3.4
α Trihydrate	α $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$	Gibbsite	Monoclinic	2.42
β Trihydrate	β $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$	Bayerite	—	2.50

The pressure at which a particular type of bauxite has to be digested depends upon the percentage of trihydrate content present in the ore.

In India, Sheveroy and some of the Jamnagar bauxites contain 98% trihydrate, whereas the Lohardaga and Katni bauxites consist of 87 to 93%. We found that the former bauxites containing 98% trihydrate can be digested with caustic solution of 100 g/l Na_2O at

atmospheric pressure, whereas the latter bauxites have to be digested at higher concentrations (250—300 g/l Na_2O) and pressures (110—120 lb/sq in) taking into consideration the bauxite is charged at a molar ratio of 1.70. In addition to that, the Sheveroy and Saurashtra bauxites are easier to grind than the Katni and Lohardaga bauxites.

It is important to charge the bauxites at as low a molar ratio as possible. If the ratio is low, the bauxite value per charge will be more. Therefore, the bauxite digested per day is more and the alumina thus produced compensates more than the high recovery obtained, while using high charging ratio. This is because the cost of bauxite is not more than 20% of the total cost of alumina. Even by sacrificing a little amount of recovery, one will be in a position to produce alumina at a cheaper cost (vide Table "B").

TABLE B

	(1)	(2)	(3)
<i>Digestion liquor:</i>			
Total Na_2O (g/l)	300	300	300
Causticity (%)	83	83	83
Molar ratio	3.48	3.43	3.43
$\text{Al}_2\text{O}_3\%$ in bauxite	54.5	54.5	54.5
Vol. of digestion liquor (m^3)	18.6	18.6	18.6
Charging molar ratio	2.0	1.7	1.6
Bauxite value (tonnes)	2.90	4.17	4.50
Charges per day	10	10	10
Bauxite digested per day (tonnes)	29	41.7	45
Overall alumina recovery %	88	85	82
Bauxite required per tonne of alumina (tonnes)	2.09	2.16	2.24
Approx. cost of bauxite per tonne of alumina (rupees)	73	75	78
Tonnes of alumina produced per day	13.9	19.4	20.0
Approx. cost of one tonne of alumina (rupees)	408	340	338

It is therefore important to charge the bauxite at a lower molar ratio as possible and take other measures to improve the recovery like (1) increasing the molar ratio in the dilution tank; (2) increasing the temperature in the thickeners—this automatically rises if the charges taken per day are more as the retention time will be less; the thickeners should also be lagged well; and (3) increasing the concentration in the Dorr Thickeners; but this effects the decomposition badly, while the fineness of the seed, perhaps by autodecomposition and cooling of the liquor, can be controlled. The settling of the red mud can be improved by the addition of maize starch of 0.88 kg per tonne of red mud.

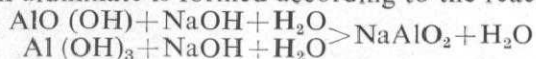
The fineness of the bauxite also plays a role in the extraction of alumina. In the case of most Indian bauxites (excepting Kashmir), as the trihydrate percentage is high, this fineness does not play a big part. But if the fineness is too much, it may give trouble in the settling in the thickeners and if it is too coarse, grid formation will be more and cock valve below the

thickener will be jammed up frequently and it has to be flushed many a time. This unnecessarily disturbs decantation. In Table C the results of the two digestion tests on Lohardaga bauxite, one fine and the other coarse, are given and the settling velocities of the red mud are shown in Fig. 1.

TABLE C
Lohardaga bauxite.
(Laboratory tests)

Bauxite analysis		Fine bauxite	Coarse bauxite
L.O.I. %	...	26.70	26.86
SiO ₂ %	...	2.10	2.12
Fe ₂ O ₃ %	...	6.40	6.72
TiO ₂ %	...	9.12	9.12
CaO %	...	—	—
Al ₂ O ₃ %	...	55.68	55.20
<i>Digestion liquor</i>			
Total Na ₂ O g/l	...	308.45	328.60
Causticity %	...	85.4	85.8
Molar ratio	...	3.24	3.65
<i>Digestion condition</i>			
Charging molar ratio	...	1.70	1.70
Pressure—lb/sq in	...	110	110
Digestion time—hrs	...	2.5	2.5
<i>Red mud analysis</i>			
L.O.I. %	...	8.30	9.58
SiO ₂ %	...	7.68	8.26
Fe ₂ O ₃ %	...	23.68	24.00
TiO ₂ %	...	36.50	34.47
CaO %	...	—	—
Total Na ₂ O %	...	6.20	6.45
Al ₂ O ₃ %	...	17.64	17.24
% Red mud on bauxite	...	27.0	28.0
% Recovery alumina	...	91.40	91.20
% Soda loss on bauxite	...	1.67	1.80
<i>Screen analysis</i>			
+65%	...	13.40	22.18
-100-65%	...	7.98	7.12
+150-100%	...	8.46	8.98
+200-150%	...	7.52	7.92
-200%	...	62.64	53.80

When the bauxite is digested with caustic solution, sodium aluminate is formed according to the reactions



The silica present in the bauxite reacts with NaOH and alumina to form sodium silicate $2\text{Na}_2\text{O} \cdot 2\text{Al}_2\text{O}_3 \cdot 3\text{SiO}_2$.

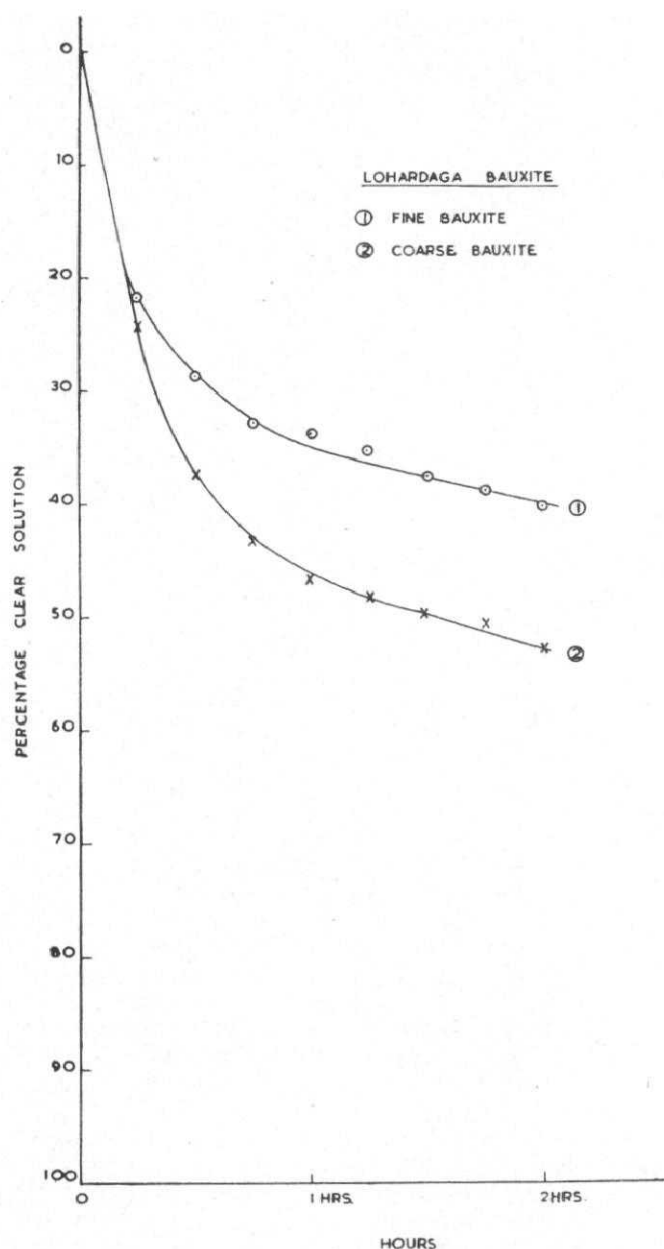


Fig. 1.

$2\text{H}_2\text{O}$. This causes a loss of NaOH and Al_2O_3 in the red mud. That is why, the Bayer's process is economical for the bauxites of low silica content. Over 90% of the Indian bauxites contain less than 3% SiO_2 . The Sheveroy bauxites are an exception to this, but most of the silica present in these bauxites is in the form of quartz.

Titania also combines with NaOH to form sodium titanate. But this hydrolyses into TiO_2 and NaOH according to the amount of washing in the Kelly Filters. TiO_2 content of the Indian bauxites varies between 1.0 to 11.0% (max. in Lohardaga bauxites).

The organic matter present generally in the Indian bauxites does not interfere in the process except it gives foaming troubles in the Dorr Thickeners and a drop in causticity during the digestion in the autoclaves, as the organic matter turns to CO_2 which combines with NaOH to form Na_2CO_3 . This sodium carbonate has to be causticised back to NaOH . We found that the presence of organic matter does not play a very great role in the subsequent process. The organic matter during decomposition is occluded in the hydrate and is burnt off during calcination, as shown in Table D.

TABLE D
Effect of organic matter during decomposition.

Bauxite Origin	Conc. of solution (t. Na_2O g/l)	Organic matter N/10 KMnO_4 consumption for 100 cc	Initial molar ratio	Final molar ratio	Hours
Lohardaga	145	11	1.82	3.66	84
Jamnagar	144	20	1.86	3.64	87
Lohardaga	120	9	2.00	3.80	80
Lohardaga	120	+ 1 % of starch added	2.00	3.85	80

The calcium carbonate present in some of the Jamnagar and Porbandar bauxites up to 7% as CaO does combine with NaOH to form sodium carbonate in the process of digestion. The carbonate separated on the heating coils was so much that the required pressure was attained after 3 to 3.5 hours of applying steam whereas it was previously 1.5 hrs. It became normal again as soon as the autoclaves are washed with water.

The decomposed liquor is sent to the evaporators where it is concentrated and during this process carbonate separates in the tubes, which is washed with water and subsequently causticised. Therefore, the drop in causticity which occurs during the decomposition by the absorption of atmospheric carbon dioxide is made good in the evaporators. The hard sodium aluminium silicate scales deposited slowly in the evaporator tubes are removed by N/2 sulphuric acid wash with 1% Rodin 82 as inhibitor. This inhibition action should be more than 100 times.

Slowly the Dorr Thickeners are also covered with scale inside the walls as well as on the roof. The scales on the roof are very hard as they are hydrate scales. Table E gives an idea of different scales in the alumina plant.

TABLE E

	Evaporator scale	Autoclave scale	Thickener scale (roof)
L.O.I. %	7.20	14.5	32.12
SiO_2 %	28.4	15.3	0.48
Fe_2O_3 %	2.0	9.69	1.12
TiO_2 %	Traces	8.11	1.52
Total Na_2O %	21.60	29.25	2.44
Al_2O_3 %	39.20	23.20	62.20

The bauxite is generally calcined for better settling in the Dorr Thickeners, the reason being that the silica

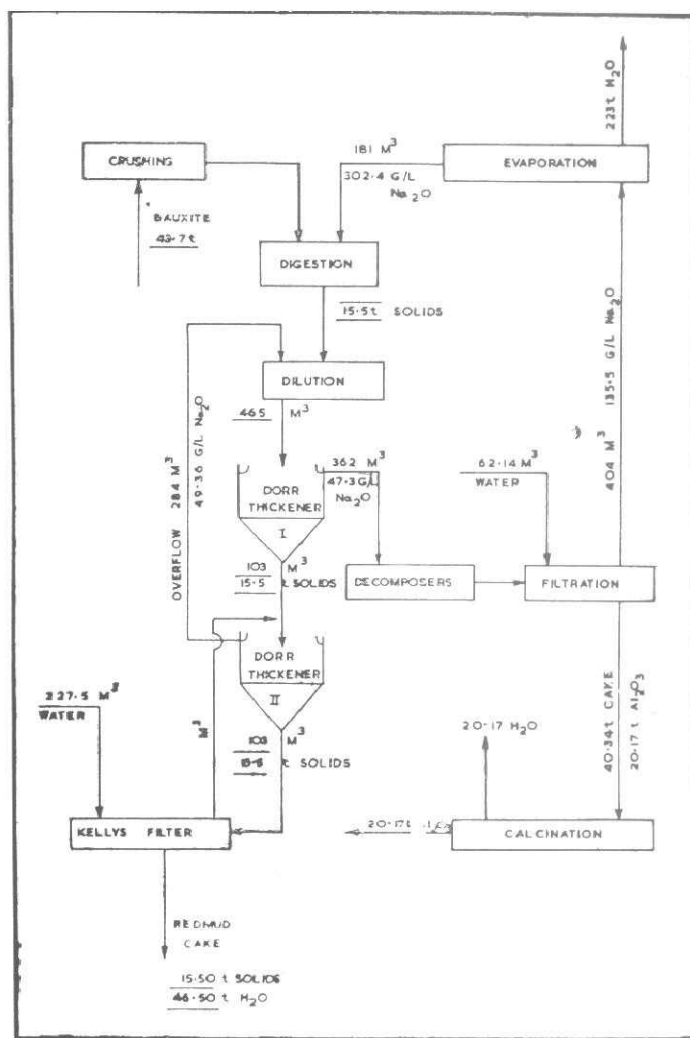


Fig. 2.
Flowsheet for bauxite digestion.

present in the bauxite becomes insoluble in NaOH and consequently goes out with the red mud. The desilication can also be done by having some seed in the dilution tanks. This process can help very well in the case of Sheveroy bauxites. The organic matter also becomes lesser and lesser and the colour of the digested liquor turns from red to white. The titania also becomes less. The alumina extraction remains the same at 91% as there is no transformation from trihydrate to monohydrate at calcination temperatures of 300, 400 and 500°C. The causticity drop between the digestion liquor and the digested liquor also decreases as the bauxite is calcined. At 400 to 500°C, the causticity of both the liquors is the same.

We consider that the calcination step, which is done primarily for improving the settling velocities in the Dorr Thickeners is not required for Indian bauxites as the settling velocities are appreciable.