

THE IMPROVED LOW TEMPERATURE DIGESTION (ILTD) PROCESS: AN ECONOMIC AND ENVIRONMENTALLY SUSTAINABLE WAY OF PROCESSING GIBBSITIC BAUXITES

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Abstract

A short description of the Improved Low Temperature Digestion (ILTD) Process and its experimental background. Presentation of its process flow block diagram and process parameters. In the ILTD Process the bauxite is charged so that the dissolved alumina be fairly close to the equilibrium solubility for gibbsite so that dissolution of gibbsite consume the reactive OH⁻ ions in a short reaction time and a significant part of kaolinite remain un-attacked. The bauxite residue (red mud) is separated just after the digestion. The pregnant liquor is submitted to a pressure post-desilication in order to maintain a low dissolved silica content and to make Bayer sodalite for further use. A Case Study elaborated for processing Trombetas bauxite (Brazil) gives a comparison of the ILTD Process with both the Conventional Low Temperature digestion Bayer process and the so-called Sumitomo New Bayer Process. A profit increase of USD 15-50 per ton of alumina is arrived for the ILTD Process compared with the Conventional Process, the most likely range is USD 30-40. Utilisation potential of the bauxite residue (red mud) and that of the new by-product: Bayer-sodalite (desilication product) is shortly discussed. Bayer sodalite can be converted to zeolite at a low cost.

Introduction

During the last 15-20 years a basic development could be observed in the precipitation step of the Bayer process. The liquor productivity has increased from 50 to 80-90 kg precipitated alumina/m³ pregnant liquor in the sandy type alumina production. The grain size distribution of the product is more uniform, the alumina is almost free of particles less than 20 μm, and the attrition has been reduced significantly. A better understanding of the fundamentals of precipitation, more effective devices for alumina hydrate classification, hydrate washing and calcination, and the use of advanced process control systems made these achievements possible.

There are plenty of papers in the technical literature which deal with the basic reactions of gibbsite and kaolinite in the Bayer liquors [1-9]. However, there was no such a theory which explained the observations in a comprehensive way. A comprehensive theory for the basic reactions has been developed and published in [11].

Basic theory

Stoichiometry

The following reaction equations are proposed to describe the basic reactions in Bayer liquors:

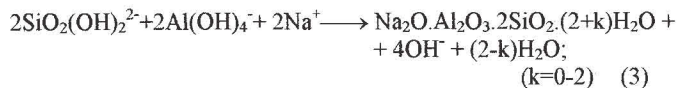
Reaction of gibbsite



Dissolution of kaolinite



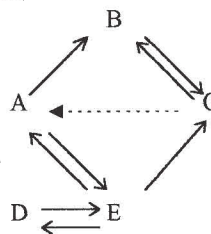
Formation of sodium aluminium hydrosilicate (SAHS)



During the development of a comprehensive kinetic model for these reactions [11], the Na₂O/SiO₂ and Al₂O₃/SiO₂ ratios in the sodium aluminium hydrosilicate (SAHS) were also studied as model parameters. The best fits for the tests results of Sartowski et al. [6] at 100°C were as follows 0.389 (σ 0.092) for Na₂O/SiO₂ and 0.536 (σ 0.033) for Al₂O₃/SiO₂ molar ratios respectively. These ratios are fairly close to the theoretical values of the above formula. At higher temperatures, e.g. 140-150°C, the Na₂O/SiO₂ ratios of SAHS are probably higher as indicated in [1,3] corresponding to the formula 3(Na₂O·Al₂O₃·2SiO₂·2H₂O)·Na₂X, where X: 2OH⁻, CO₃²⁻, SO₄²⁻, 2Cl⁻, 2AlO₂⁻, etc. [1].

Reaction mechanism and kinetic model

The following pattern is proposed to describe the reaction mechanism:



- where
- A: kaolinite
 - B: dissolved silica
 - C: sodium aluminium hydrosilicate (SAHS)
 - D: gibbsite
 - E: dissolved alumina

The equilibrium solubility of alumina for gibbsite is the limit for the dissolution of gibbsite and kaolinite, and the equilibrium solubility of silica is the constraint until the dissolved silica precipitates from the liquor in the form of sodium aluminium hydrosilicate(s). The laboratory kinetic tests showed that the reaction of kaolinite may stop after a certain reaction time [6], probably in connection with the newly formed sodium aluminium hydrosilicate [8,9].

The details of the kinetic model developed by the assessment of the laboratory tests carried out by Sartowski [6] were published in [11]. A basic feature of the kinetic model is the introduction of the reactive OH⁻ concentration (AH) as a common driving force for the dissolution of gibbsite and kaolinite, with the following definition [9-11]:

$$\text{AH} = \text{reactive OH}^-(\text{g/l}) = 2 \times 17 [(c_E^{\text{eq}} - c_E)/102 - c_B/60] \quad (4)$$

The reactive OH⁻ ions attack both the gibbsite and the kaolinite. The dissolution of gibbsite and kaolinite is explained as a competition for the reactive OH⁻ ions being available in the liquid phase. The kinetic model suggests that as long as the dissolution of the reactive components, first of all gibbsite, proceeds and the alumina concentration approaches the equilibrium solubility of alumina for gibbsite, the concentration of reactive OH⁻ ions decreases. The dissolution rate of kaolinite at low reactive OH⁻ concentrations is much slower due to the running out of the reactive OH⁻ ions in the liquid phase (Figs 2 and 3).

Digestion at low reactive OH⁻ concentration

A bauxite sample from the Trombetas deposit, Brazil, with the composition shown in Table I. was extensively studied.

Kinetic tests were carried out in which the dissolution of gibbsite and the reaction of the kaolinite were studied at a conventional digestion and compared with a digestion at a low reactive OH⁻ concentration. The tests were carried out in test bombs with a volume of 200 ml which rotated in an oil bath at 17 rpm. The same digestion yield was obtained, and the Na₂O/SiO₂ ratio in the red mud at a low reactive OH⁻ concentration (<3 g/l) was lower by 25% than the values obtained when conventional digestion was modelled

in 40 or 60 minutes digestion at a high reactive OH⁻ concentration [10,12]. No pre-desilication was applied during the laboratory modelling of the conventional digestion, while the digestion at a low reactive OH⁻ concentration was carried out after pre-desilication.

Table I. Composition of the Trombetas bauxite used for laboratory tests, in w%

Chemical composition		Mineralogical composition
Al ₂ O ₃	54.65	Al ₂ O ₃ in gibbsite 51.8
SiO ₂	3.13	boehmite 0.6
Fe ₂ O ₃	11.51	kaolinite 2.2
TiO ₂	0.82	total 54.6
CaO	<0.3	SiO ₂ in kaolinite 2.6
Na ₂ O	<0.1	as quartz 0.5
K ₂ O	<0.1	total 3.1
Corg	0.04	Fe ₂ O ₃ in goethite 4.1
L.O.I.	29.1	as hematite 7.4
		total 11.5
		TiO ₂ as anatase 0.8
		rutile tr.
		total 0.8

Unreacted kaolinite was clearly detected by XRD after 10 minutes of digestion at 150 °C, when the liquor had a caustic Na₂O concentration of 134 g/l and a caustic molar ratio of 1.19 (reactive OH⁻ 3.7 g/l) [10]. No pre-desilication was applied in the test. Based on the previous technical literature [1], unreacted kaolinite could not have been expected in these circumstances.

The two-stream digestion was modelled in kinetic tests with the same Trombetas bauxite. Two laboratory autoclaves with a volume of 4.5 l each were connected with a tube and appropriate valves (Fig. 1). An anchor type agitator at 200 rpm and in certain tests 400 rpm provided a fairly intensive agitation. The tests were carried out at 130 and 150°C in duplicates [10,12]. The test results are summarised in Figs. 2 and 3. The results show that the dissolution rate of kaolinite highly depends on the temperature, the reactive OH⁻ concentration and also on the intensity of agitation. A duplicate test at 150 °C digestion temperature is shown in Table II. Due to the dissolution of most of the kaolinite, the maximum value of dissolved silica can be nearly 5 g/l. When all the gibbsite and most of the reactive silica dissolves, the digestion yield may exceed the theoretical value which is traditionally calculated only for the dissolution of gibbsite. At this point, the Fe₂O₃ content of the digestion residue (red mud) may reach (or even exceed) 70%.

Improved low temperature digestion process

In typical gibbsitic bauxites, the number of moles of gibbsite is 10-25 times higher than that for kaolinite, and the dissolution reaction rate of gibbsite is higher, possibly by an order of magnitude than that for kaolinite [10-14]. As a consequence, when bauxite is charged so that the molar ratio be close to the equilibrium solubility

of aluminate, gibbsite dissolves in a much greater rate, and it consumes nearly all the reactive OH⁻ ions within a few minutes. During this period of reaction time, at 140°C only about 50% of kaolinite reacts. After the dissolution of gibbsite, a considerable amount of silica (3-5 g/l) may be in the liquid phase. If the slurry were kept further in these circumstances, the dissolved silica concentration would decrease to below 1 g/l due to the precipitation of sodium-aluminium-hydrosilicate(s), meanwhile the chemically combined Na₂O would increase in the red mud. To avoid this, the red mud is separated after the dissolution of gibbsite and the pregnant liquor is desilicated in a subsequent process step.

The Improved Low Temperature Digestion (ILTD) Process is assigned for production of aluminium hydroxide and subsequently alumina from gibbsitic type bauxites. The basic features of the ILTD Process are the following:

- The digestion step is carried out in such a way that the bauxite is charged into the digestion liquor so that the readily soluble gibbsite consumes most of the reactive OH⁻ in the liquid phase. In contrast to the Conventional Low Temperature Digestion Process, practically the total dissolving capacity of the digestion liquor is utilised in the reactor with the maximum digestion yield of the gibbsite. A low reactive hydroxide ion concentration is maintained in the digestion reactor, below 6 g/l, preferably less than 2-3 g/l.
- After the digestion, the digestion residue (red mud) is separated from the slurry as soon as possible, preferably at or near to the digestion temperature.
- The liquid phase (pregnant liquor) obtained from the removal of the red mud is submitted to a seeded pressure post-desilication in a unit specifically designed for this purpose. The precipitated sodium aluminium hydrosilicate crystals are separated from the liquid phase, and they are partly used in the further liquor post-desilication cycles as seed. The other part is a new sodalite by-product of the Bayer process.
- The sodium aluminium hydrosilicate (sodalite) by-product is utilised as it is, or is preferably processed further to value added products such as zeolites.

The process block diagram for the ILTD Process is shown in Fig 4.

Development of the ILTD process

The invention of the Improved Low Temperature Digestion (ILTD) was filed on October 20, 1988 in Hungary on behalf of Aluterv-FKI and later in the most important alumina producing countries.

At first, the aim of the development was to set such process parameters for the digestion which would provide a pregnant liquor with an acceptably low silica concentration. Using a digestion temperature of about 140-145°C and low caustic molar ratios of about 1.2-1.25, it was difficult to attain a pregnant liquor silica concentration of less than 1 g/l even if a pre-desilication process step was applied.

The basic process parameters of the pressure post-desilication were studied in the laboratory tests at different circumstances such as seed charges. Parallely, the experiences of a pregnant liquor desilication under pressure that had traditionally been used in the sintering process were gathered and carefully evaluated. Using a seeded pressure post-desilication process step at elevated

Table II.: Simulation of the two-stream digestion in a stirred autoclave at 150°C

Dosage			Digestion		Liquid phase						Solid phase composition						Digestion yield			
bauxite	liquor	water	temp.	time	c.Na ₂ O	Al ₂ O ₃	SiO ₂	SiO ₂	eqAl ₂ O ₃	react.OH ⁻	L.O.I.	Al ₂ O ₃	SiO ₂	Fe ₂ O ₃	TiO ₂	Na ₂ O	Na ₂ O/SiO ₂	overall	for gibbsite	
g	ml	ml	°C	min	g/l	g/l	-	g/l	g/l	g/l	%	%	%	%	%	%	%/°%	%	%	
Starting materials																				
Trombetas bauxite																				
f=200/min, Run 20																				
221.8	738.0	180									29.53	54.65	3.13	11.51	0.82	0.05				
			150	0	190.9	106.2	2.957	0.70		48.59	16.4	29	6.0	44.6	3	0.8	0.133	86.31	91.05	
			150	3	153.5	85.4	2.957	0.56	232.1	2.61	7.6	10.1	6.0	68.7	3.9	0.6	0.100	96.90	102.24	
			150	6	142.3	196.5	1.191	4.47	211.9	1.92	5.9	7.4	6.0	71.5	4.1	1.7	0.283	97.82	103.20	
			150	12	140.3	198.4	1.163	2.48	208.4	0.19	7.3	15.2	12.0	53.1	4	6.8	0.567	93.97	99.14	
			150	30	142.3	203.0	1.153	4.91	211.9	3.22	6.6	14.8	13.0	52.1	3.8	7.8	0.600	94.02	99.19	
			150	60	142.5	199.4	1.176	1.89	212.3	3.41										
			150	60	140.6	197.1	1.173	0.94	208.9											
f=200/min, Run 21																				
221.8	738.8	180									14.7	25	7.1	48.6	3.2	0.7	0.099	89.17	94.07	
			150	0	193.7	107.7	2.959	0.74		49.52	6.6	8.3	5.5	72.1	4.2	0.6	0.109	97.58	102.94	
			150	3	155.7	86.6	2.958	0.60	236.2	1.34	6.6	8.3	5.5	72.1	4.2	0.6	0.109	97.58	102.94	
			150	6	141.2	198.1	1.173	4.62	210.0	0.27	5.9	7.6	5.5	71.6	4.8	1.5	0.273	97.76	103.14	
			150	12	141.0	201.0	1.154	4.59	209.6	-0.92	6.3	12.8	11.8	57.7	3.8	6.2	0.525	95.33	100.57	
			150	30	138.1	199.1	1.141	4.81	204.5	1.40	6.4	14.2	13.4	52.7	3.6	7.6	0.567	94.33	99.51	
			150	60	138.3	197.4	1.153	1.92	204.9	3.24										
			150	60	140.9	198.0	1.171	1.01	209.4											

temperature was found to be viable, however, the pregnant liquor of a settler had to be re-heated from about 105°C to about 150°C. Introduction of the pressure decanter of Alcan [14-15] raised the possibility of separating of the red mud at or near the digestion temperature, therefore, most of the preheating of the pregnant liquor before its pressure post-desilication could be avoided.

It is widely known that boehmitic bauxites are processed in Hungary with a high temperature digestion process. During the recent years the declining economic situation of the aluminium industry in Hungary was not favourable for the implementation of ILTD. Nevertheless, it is reasonably expected that the process engineers who carried out the design and implementation of several high temperature digestion systems, including tube digesters, are capable of designing the pilot and the plant scale implementation of an ILTD Process. In 1996, the inventors acquired the patent rights of the relevant patent family. Since that time the process development has been carried out in the frame of Siklósi & Co. Ltd.. The current patent status is shown in [16].

A process for the conversion of sodium-aluminium-hydrosilicate to zeolites at a low cost has recently been verified [17]. Understanding the importance of sodium-aluminium-hydrosilicate as source of other valuable products based on Bayer sodalite, made possible to shift the process parameters towards the maximum extraction of sodium aluminium hydrosilicate.

A case study

A Case Study was worked out which comprised a comparison of the Improved Low Temperature Digestion (ILTD) process with the Conventional Low Temperature Digestion (CLTD) process and the so-called Sumitomo's New Bayer Process (SNBP). The overall material and heat balances for the Bayer circuit were calculated for the three processes. For the process simulations the computer model of the Bayer process of Siklósi [18] was used. A typical Trombetas bauxite (Brazil) of export quality was the common basis with the following composition in w%:

Al ₂ O ₃	in gibbsite	50.0	Fe ₂ O ₃ , total	13.0
	in kaolinite	3.0	TiO ₂ , total	1.2
	in boehmite	1.0	Org. C	0.06
	total	54.0	L.O.I.	28.0
SiO ₂	in kaolinite	3.5	Moisture	4.0
	as quartz	0.5		
	total	4.0		

The main process parameters, the basic material and energy consumptions, and the most probable compositions of alumina, Bayer-sodalite and red mud are shown in Tables III-VIII.

Recent achievements of Sumitomo [13] are similar to the ILTD concept. In the plant implementation, Sumitomo seem to focus on a very short digestion time in a tube digester at a relatively low digestion temperature of 135°C in order to allow as little dissolution reaction of kaolinite as possible. Therefore the liquor productivity, the throughput of the digestion and the process steam consumption seem to correspond to the conventional process, and the pregnant liquor desilication has been reported to be avoided.

A higher digestion temperature is used in the ILTD process and this allows to significantly decrease the digestion target molar ratio. A higher amount of kaolinite reacts, however, giving a SAHS by-product is an important feature of the ILTD process. There is some steam need for the pressure desilication of the pregnant liquor, nevertheless, as a balance, energy saving can be attained with the ILTD process. Among other benefits, the red mud which leaves the process, has a very low chemically combined soda content.

Based on the supporting laboratory results, 30% silica obtained as sodalite desilication product and 20% as SAHS in the red mud out of the 50% reacted kaolinite are reasonably expected. The costs and savings were calculated from the corresponding material and energy consumptions. For the bauxite 23.6 USD/t unit price, for NaOH 200 USD/t unit price and 25 USD/t delivery and other costs, for primary energy 3.04 USD/GJ unit price were used. The process steam consumptions were converted to primary energy using a heat utilisation factor of 2386MJ/t (570 Mcal/t) steam and a boiler heat efficiency of 88%.

In the given Case Study, Table IV. a saving of 13% in the process steam consumption was obtained for the ILTD Process. However, the benefits come rather from the 43% savings in the NaOH consumption and from the higher digestion production throughput, the utilisation of the Bayer-sodalite by-product and/or the red mud with new, favourable characteristics. As Table V shows, a total of the profit is expected to increase by 15-50 USD/t alumina, when the ILTD Process is used and all the important factors are considered. The most likely range is 30-40 USD/t.

Table III.: Basic process data. CLTD: Conventional Low Temperature Digestion Process; SNBP: Sumitomo New Bayer Process; ILTD: Improved Low Temperature Digestion Process

	CLTD	SNBP	ILTD
<u>Pre-desilication</u>	in several plants	not used	not used
<u>Digestion</u>			
Digestion liquor Na ₂ O _c , g/l	160	160	160
Caustic molar ratio, -	2.59	2.55	2.67
Digestion liquor, m ³ /t alumina	12.35	12.36	9.11
Temperature, °C	145	135	140-145
Holding time, min	30-90	<5	<5
Target caustic molar ratio, -	1.37	1.37	1.21
Reactive OH ⁻ conc., g/l	11.5	6.8	2.1
Digestion yield for gibbsite, %	98	97	98
Reacted kaolinite, %	100	45	50
SiO ₂ in the effluent, g/l	≅0.8	≅0.8	≅3.5
<u>Red mud separation</u>			
Temperature, °C	100	135	≅135
<u>Pressure post-desilication</u>			
Temperature, °C	-	-	≅150
Holding time, min	-	-	≅30
SiO ₂ conc. after desilication, g/l	-	-	0.5-0.6
<u>Pregnant liquor</u>			
Pregnant liquor Na ₂ O _c , g/l	128	128	128
Caustic molar ratio, -	1.40	1.40	1.30
SiO ₂ concentration, g/l	≅0.6	≅0.6	≅0.6
Liquor productivity, kg/m ³	65.7	65.7	80.0

Table IV. Specific material and energy consumptions and sodalite production

	CLTD	SNBP	% of CLTD	ILTD	% of CLTD
Bauxite, t/t	2.246	2.237	99.6	2.221	98.9
NaOH, t/t	0.0792	0.0414	52.3	0.0448	56.6
Process steam, t/t for digestion	1.11	1.00	90.1	0.85	76.6
for other purposes	0.85	0.88	103.5	0.85	100.0
Total proc. steam, t/t	1.96	1.88	95.9	1.70	86.7
Sodalite produced, t/t	-	-	-	0.07-(0.12)	-

Table V. Costs and profits for the smelter grade alumina production, USD/t. (For the costs of the Conventional Bayer process, King is referred [19].)

	CLTD	SNBP	ILTD
Selling price (long term forecast),	200	200	200
Main operating cost factors			
Bauxite	53	52.8	52.4
NaOH	17.8	9.3	10.1
Energy	36	35.3	33.9
Other materials	2.2	2.2	2.2
(material and energy cost)	109	99.5	98.6
Workforce	43	43	43
Capital	32	32	34
(other direct costs)	75	75	77
Production costs	184	174.5	176
Profit	16	25.5	24
Extra profit			
from a higher production rate	0	0	0-15
from the utilisation of sodalite	0	0	7-12
from savings in the red mud disposal	0	0	0-6
from the utilisation of red mud	0	0-5	0-15
Total profit	16	26-31	31-66
Profit increase	0	10-15	15-50

Table VI. Composition of alumina, w%, (for the CLTD Process, world average quality [20] is used)

	CLTD	SNBP	ILTD
Al ₂ O ₃	98.78	?	≥98.90
Na ₂ O	0.407	?	≤0.35
Fe ₂ O ₃	0.013	?	≅0.007
SiO ₂	0.012	?	≅0.007
CaO	0.026	?	≤0.015
L.O.I.	0.75	?	0.75

Table VII. Composition of Bayer sodalite, Approximate formula: 3(Na₂O.Al₂O₃.2SiO₂.2H₂O).Na₂CO₃

	CLTD	SNBP	ILTD
Na ₂ O	-	-	23.2
Al ₂ O ₃	-	-	28.7
SiO ₂	-	-	33.7
Fe ₂ O ₃	-	-	0.1-0.2
CO ₂	-	-	4.1
LOI (H ₂ O+CO ₂)	-	-	14.3

Table VIII. Compositions of bauxite residue (red mud), w%

	CLTD	SNBP	ILTD
Na ₂ O	8.7	4.0	1-(2.1)
Al ₂ O ₃	16.3	20.4	17.5
SiO ₂	14.5	14.8	12.6
Fe ₂ O ₃	47.5	48.3	55.7
TiO ₂	4.4	4.5	5.1
L.O.I.	9.0	8.0	7.0

Future implications

There are new achievements in Australia and Hungary where red mud amended with gypsum (RMG) have been used for soil amelioration, composting domestic waste and for treatment of domestic sewage or effluents of animal farms [21-25]. The N and P contents of the treated sewage can be reduced by over 90% using RMG and improved water and phosphorus retention properties are reported in sandy soils [21]. (The red mud of the alumina plants in Western Australia contain combined Na₂O of between 1 and 2% due to the very low reactive silica content of the Darling Range bauxites.)

Adjusting the process parameters of ILTD so that maximum SAHS be extracted, the approximate composition of bauxite residue could be Al₂O₃ 11%, SiO₂ 7%, Fe₂O₃ 66%, TiO₂ 6%, Na₂O 1.5-2.5%, LOI 7%. This material is welcome e.g. in the cement industry as additive. The bauxite residue of the ILTD process seems to be suitable for these and several other purposes that were rejected before due to the high combined soda content of the red mud [26]. At least partial utilisation of the red mud instead of the costly and environmentally hazardous disposal seems to be viable, therefore in

the light of the new results, the former studies have to be re-evaluated.

Probably in the near future silica in bauxites will not be considered as a constituent that is simply responsible for costs and many troubles but rather as one that can also be used to increase the economy of the Bayer process!

Summary

An Improved Low Temperature Digestion (ILTD) has been proposed with the following advantages (compared to a Conventional Process)

- 40-60% savings in chemical NaOH losses
- 0.5-3% savings in bauxite consumption
- 5-20% savings in process heat consumption
- 10-40% higher digestion capacity
- 10-25% higher pregnant liquor productivity
- less silica, iron and certain other contaminants in the product (estimated reduction of 10-40%)
- less scalings in the evaporation and in the digestion liquor preheaters (estimated to be 40-60%)
- 60-90% less chemically bound NaOH content in the red mud to be disposed
- option of selling the desilication product (Bayer-sodalite) as a new by-product, and/or converting it to value-added products such as zeolites at low cost
- option of at least partial utilisation of the red mud instead of the costly and environmentally hazardous disposal.

Denominations

- A: kaolinite
 AH: reactive OH⁻ concentration, g/l
 B: dissolved silica
 C: sodium aluminium hydrosilicate (SAHS)
 D: gibbsite
 E: dissolved alumina
 F: caustic soda as Na₂O
 c_B: silica concentration, g/l
 c_E: alumina concentration, g/l
 Na₂O_c: caustic Na₂O concentration, g/l
 σ: variance of the model parameters
 eq as superscript: equilibrium solubility for the given constituent

Acknowledgements

The authors are grateful for the kind support of dr János Zámbo, Eleonóra Molnár, dr Katalin Györgyi and Antal Klemm in the preparation of this paper.

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Figure 1. Sketch of the experimental device

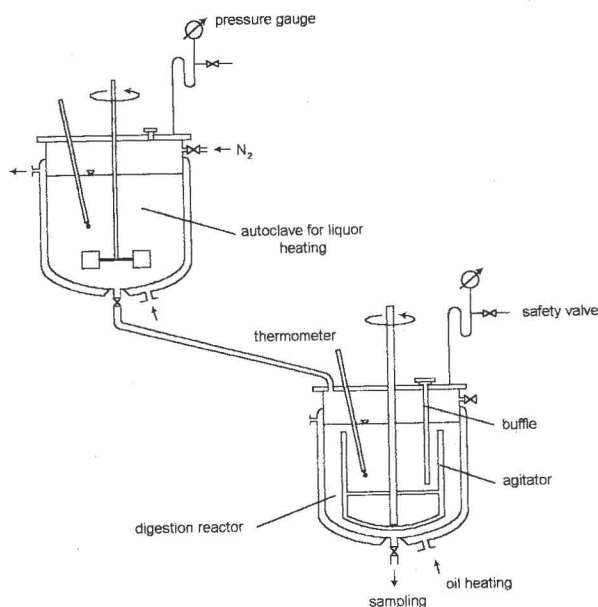
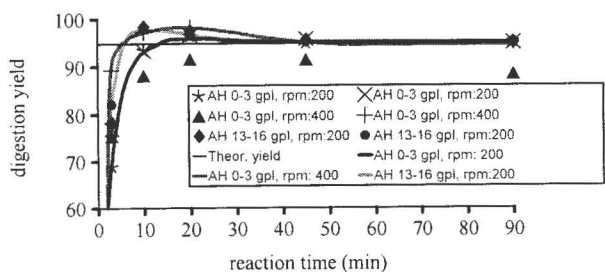
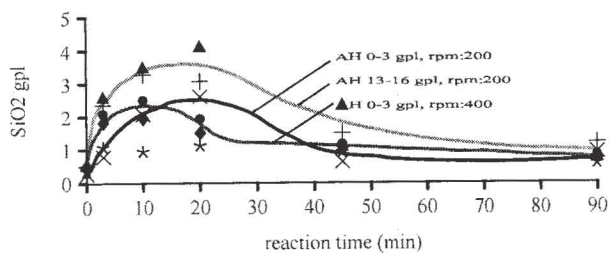


Figure 2: Two-stream digestion tests at 130°C in a stirred autoclave with Trombetas bauxite
Digestion yield vs. reaction time



SiO2 concentration vs. reaction time



Na2O/SiO2 mass ratio in the red mud vs. reaction time

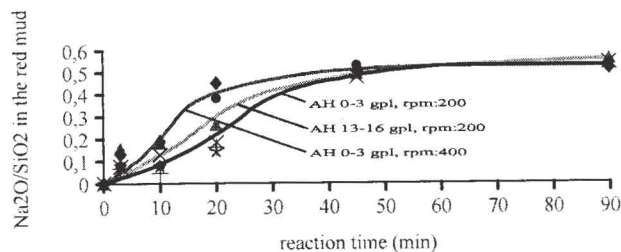
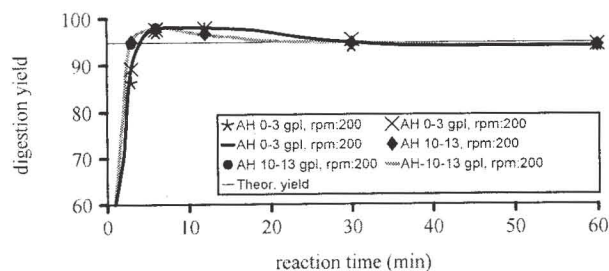
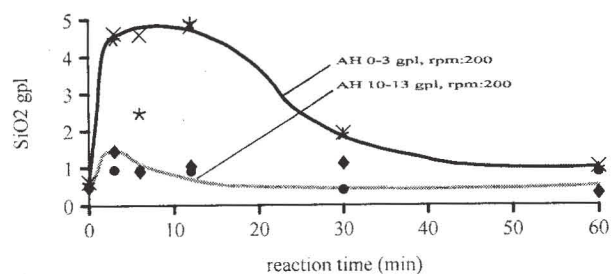


Figure 3: Two-stream digestion tests at 150°C in a stirred autoclave with Trombetas bauxite
Digestion yield vs. reaction time



SiO2 concentration vs. reaction time



Na2O/SiO2 mass ratio in the red mud vs. reaction time

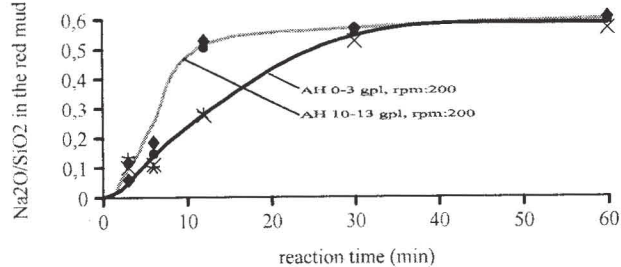
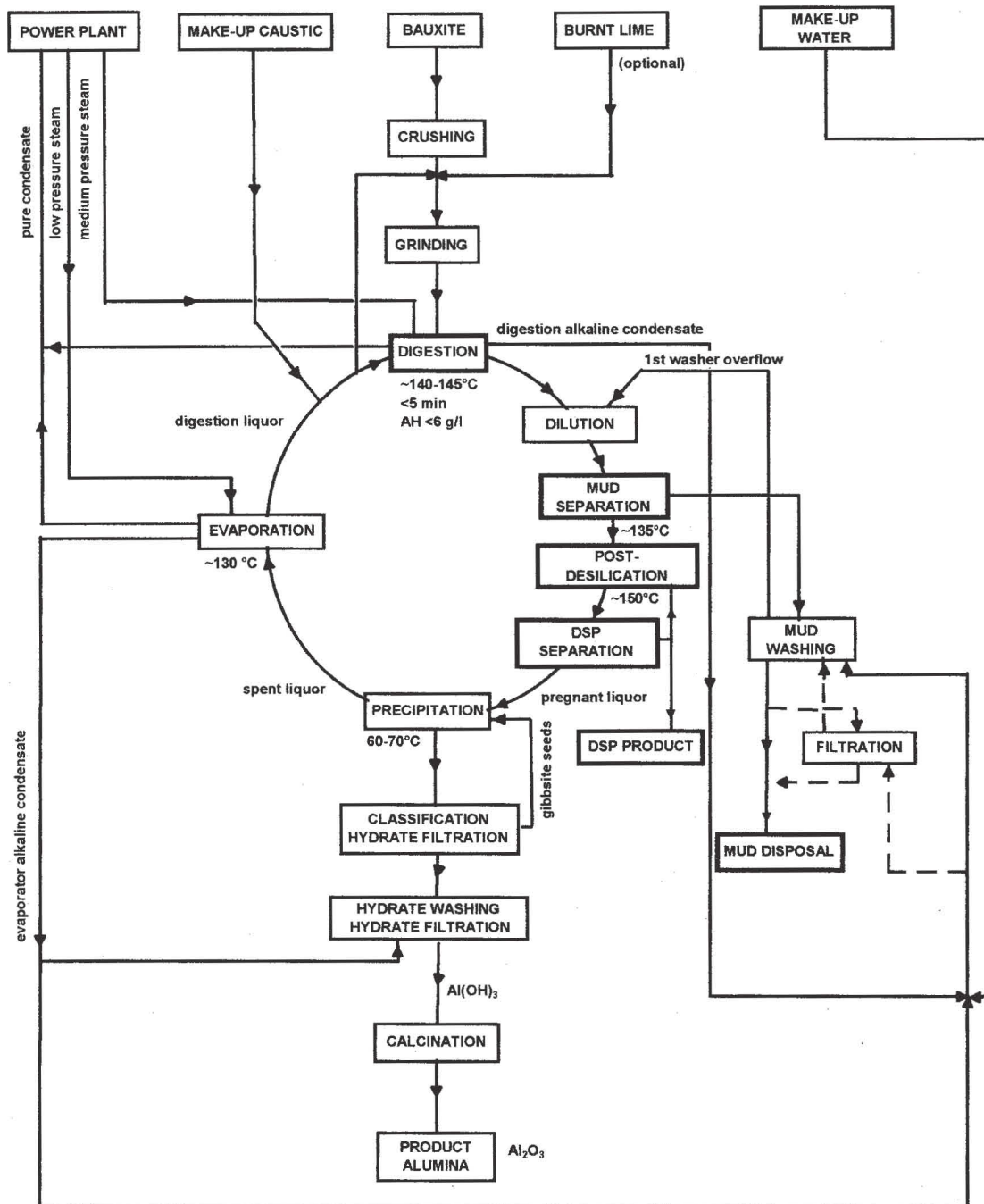


Figure 4. Process block diagram for the Improved Low Temperature Digestion (ILTD) Process



Remarks: new/modified units/products
 DSP desilication product (sodalite)
 AH reactive OH concentration