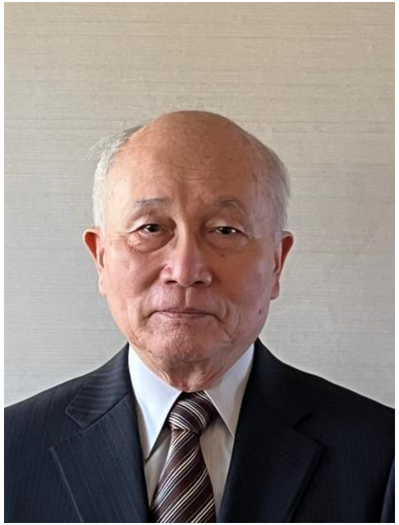
IBAAS 2023
TECHNICAL LECTURE SERIES

DEVELOPMENT OF SUMITOMO's DIFFERENTIAL EXTRACTION PROCESS

A CASE STUDY FOR EASTERN GHATS (ODISHA) BAUXITE OF INDIA AND ADVANTAGES AND CHALLENGES

Takuo HARATO

My Experience of Developing Alumina Technology



Takuo HARATO

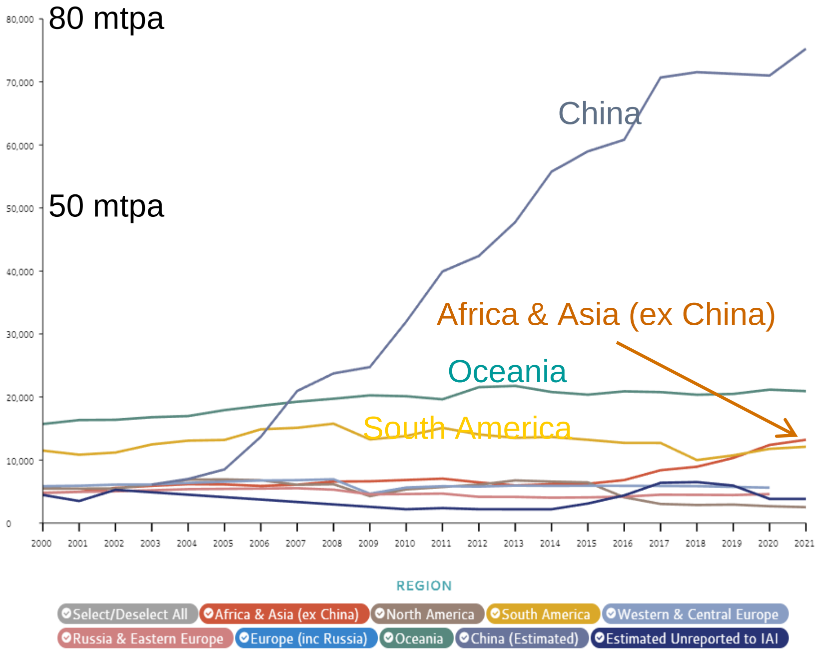
- Sumitomo Chemical
  - Evaluation of some bauxites (Gove, Boke, Rennell Island, etc.)
  - SO_2 removal in flue gas using red mud
    - Ehime Works — Boiler (power plant)
    - EurAllumina (Italy) — Boiler & Alumina calciner
  - Sumitomo's differential extraction process
  - Fluidized bed alumina calciner (SGA…sandy alumina)
  - Various grades of specialty alumina and hydrates
  - Feedstock change
  - Visited NALCO in around 2005? (When NALCO was planning the fourth digestion line)
- CSIRO (Australia)
  - Neutralization of red mud with sulfuric acid and recovery of NaOH by electrochemical processing (WO 2012_145797 A1)
- Norsk Hydro, Brazil (Alunorte)
- Waseda University

Agenda

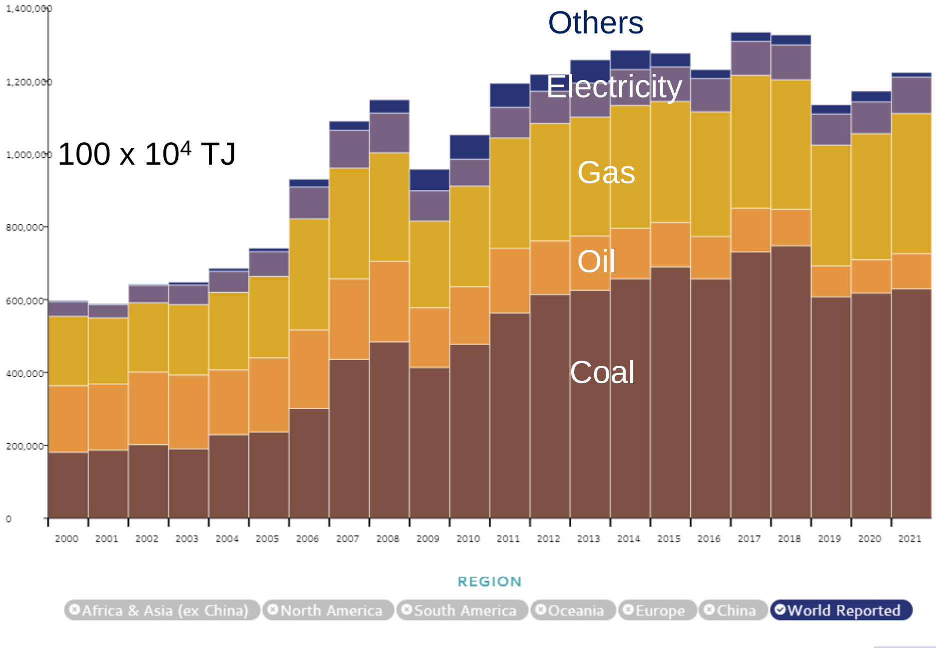
- Issues Towards Sustainable Alumina Refineries
- Differential Extraction of Bauxite
- Sumitomo's Differential Extraction Process
- Eastern Ghats Bauxite (Odisha) of India
- A Case Study for EG Bauxite with Sumitomo Process
- Challenges to Achieve Practical Use of Sumitomo Process

Alumina Production & Energy Consumption

Global Alumina Production



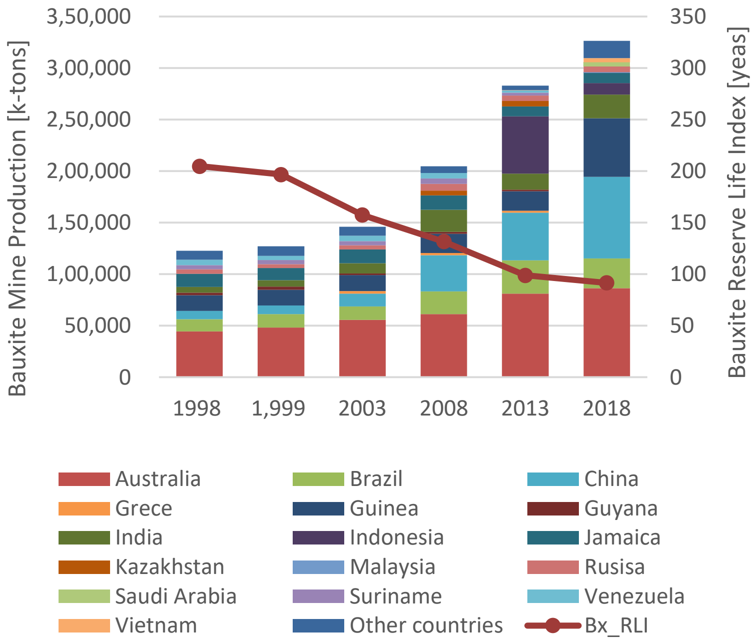
Energy Consumption & Sources



Source: IAI, https://international-aluminium.org/statistics/alumina-production/

Bauxite Resource & Environment

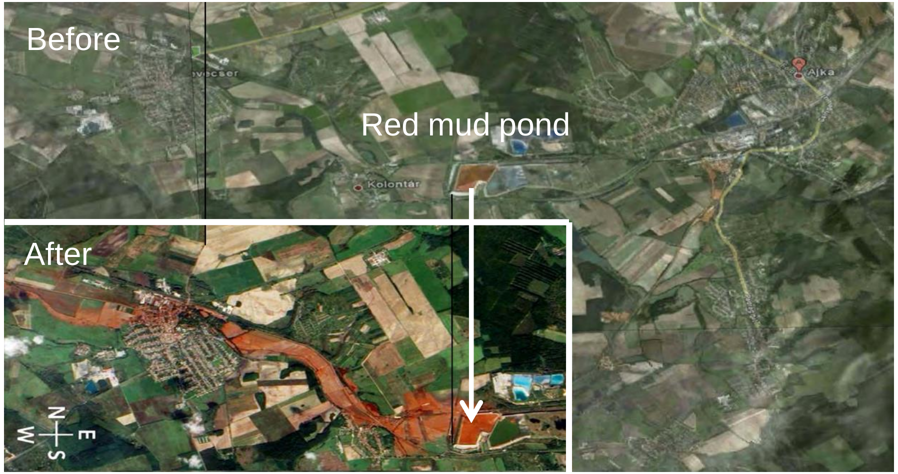
Bauxite Mine Production & RLI



Data source: U.S. Geology Survey, RLI = Reserves/mine production

Red Mud Storage & Use

Ajka Alumina Refinery (Hungary), 2010



- Storage: Pond, Lagoon → Dry stack (Press filter)
- Use of red mud, circular economy: Barriers
  - Volume
  - Na_2O content of red mud

Issues towards Sustainable Alumina Refinery

- Energy…Renewable energy, efficiency
  - Solar thermal
  - Hydrogen
  - MVRC (mechanical vapor re-compression)
- Bauxite resource
  - New bauxite mines
  - Low-grade (high-silica) bauxite

Increase

- Amount of red mud
- Na_2O in red mud
- Caustic soda consumption

- Environment
  - Emission of CO_2, etc.
  - Red mud disposal area
- Circular economy
  - Red mud reuse

How to solve these issues fundamentally?

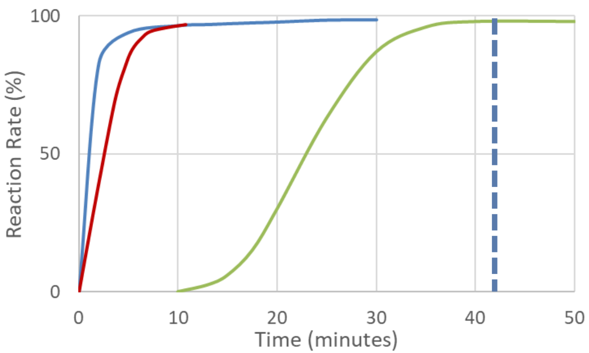
One solution will be "**differential extraction** of bauxite." It will reduce the consumption of caustic soda, which results low soda content in red mud. Then, …

Differential Extraction…Kinetics

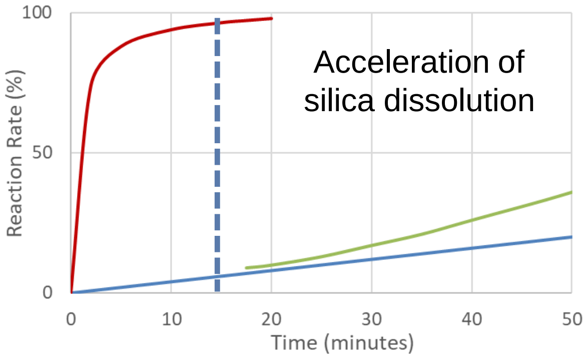
These Figures below are redrawn from Takenaka (2003) and Harato et al. (1996)

- Dissolution of alumina
- Dissolution of reactive silica
- Precipitation of DSP
- Residue separation

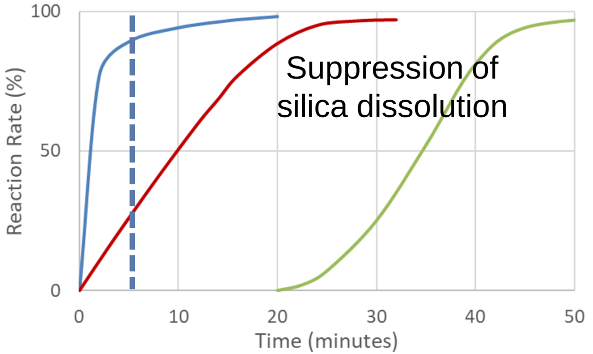
Conventional Bayer process



1. Alumina and silica are fully dissolved.
2. Desilication is carried out after the dissolution.
3. Red mud with DSP is separated after the desilication completed.
4. Then, low-silica pregnant liquor and digestion residue with DSP are recovered.



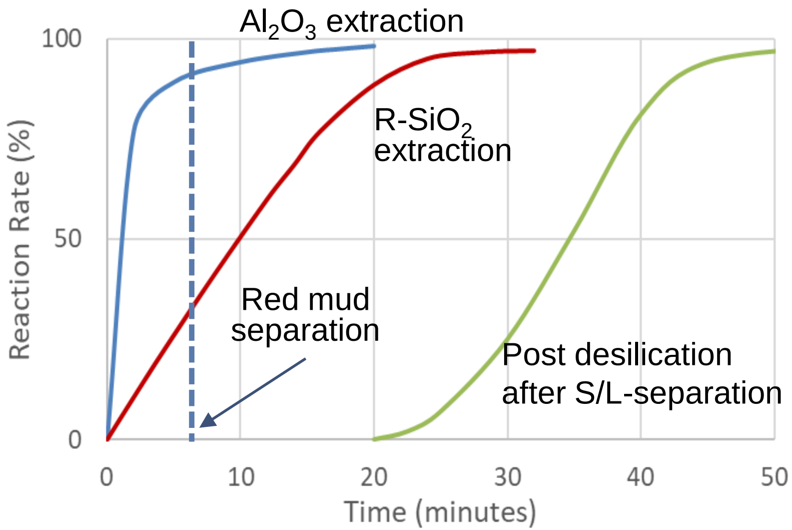
1. Dissolve silica suppressing precipitation of DSP.
2. Separate DSP from the bauxite-residue.
3. Then, digest the residue to recover alumina as in the conventional process.
   - Kanehara (1981, 1983)
   - Kokoi (1993)
   - Hollitt (2001)
   - Takenaka (2003)



1. Extract alumina suppressing dissolution of silica.
2. Separate residue before silica is fully dissolved into the liquor. The liquor is treated with post-seeded desilication.
   - Takahashi (1962)
   - Oku (1972), Harato (1996)…Sumitomo
   - Grubbs (1986, 1987)
   - Iwase (1987, 1988), Fulford (1991)
   - Banvolgyi (1992)…ILTD

Sumitomo Process…Principle & Key Technologies

Principle of Sumitomo Process



- Extraction of alumina suppressing the dissolution of $R\text{-}SiO_2$ as much as possible
  - Digestion temperature: 130°C
  - Digestion time: 3 minutes
  - Desilication: post-seeded desilication

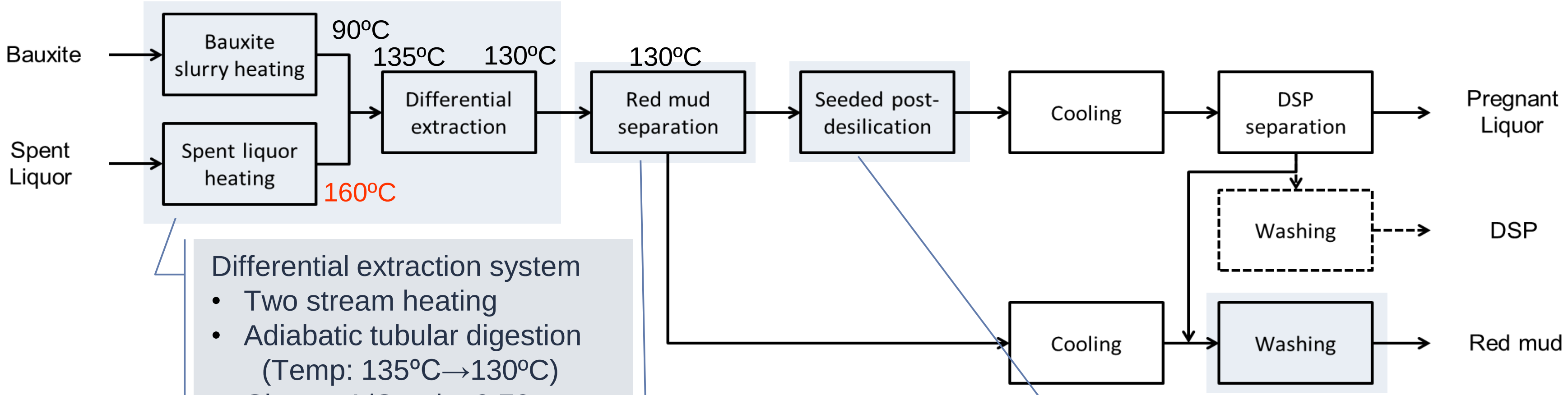
Key Unit Operations

- Digestion system:
  Two-stream heating and a tubular digestion
- A high rate settler
- Desilication by seeded post-desilication
- High-rate washers (counter current decantation)

Development

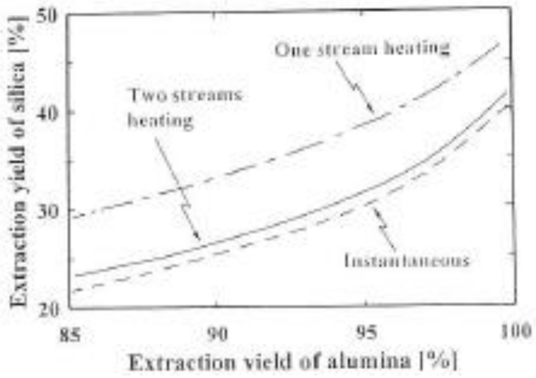
- Laboratory tests (1990)
- Bench & pilot scale tests
- Commissioned on November 1993
  - Retrofitted a low-temperature digestion process
  - Production rate: 600t/d
  - Bauxite: Bintan (50%) & Gove (50%)
- Stopped operation in 2001 (feedstock change to observe London Dumping Treaty)

Block Diagram of Original Sumitomo Process



Differential extraction system
- Two stream heating
- Adiabatic tubular digestion (Temp: 135ºC→130ºC)
- Charge A/C ratio: 0.70

Extraction yield vs. heating system



Fast S/L-separation
- Pressure decanter designed for short residence time of BR
- High-efficiency flocculant
- (Low DSP content in residue)

Seeded post-desilication
- Preparation of seed
- Activation of seed
- Separation of fine seed

Operation Results of Original Sumitomo Process

Harato, et al. (1996) 4th AQW (Darwin)

	Unit	Sumitomo original DEx	Conventional (before retrofit)
Production rate, Al_2O_3 (A)	t/D	600	600
Digestion conditions			
• Digestion temperature	°C	135 (130)	150
• Pregnant liquor			
• $C-Na_2CO_3$	g/L	219	219
• A/C ratio	-	0.69	0.69
• SiO_2	g/L	0.6	0.5
Unit consumption			
• NaOH	kg/tA	37	81
• Bauxite	kg/tA	2,350	2,330
Chemical compositions of red mud			
• Na_2O	%	3.7 (<1.0*)	8.0
• $R-SiO_2$	%	6.6	0
• Generated amount of red mud	kg/tA	770	790
Extraction ratio from bauxite			
• $T-Al_2O_3$	%	88	89
• $R-SiO_2$	%	45	100

✓ Consumption of NaOH was reduced by 55%

✓ Extraction of Al_2O_3 reduced 1%.

✓ Na_2O content in red mud reduced from 8.0 to 3.7%.
  * When the red mud was analyzed before DSP was mixed, the Na_2O content was <1%.

- **40~60% reduction in caustic soda** was achieved.
- **Soda in red mud* <1%** was achieved if DSP is recovered separately.
- Regular maintenance was required every three months.

New Challenges of the Process & Improvement

Defects in the original Sumitomo process

1. Low liquor productivity because of low A/C ratio of pregnant liquor
2. Seeded post-desilication was a troublesome operation
3. Scaling of DSP on the fast settler (descaling was required every three months)

How to raise the A/C ratio of the pregnant liquor?

- Increase charge of bauxite keeping digestion temperature
  - ➡ Decreased extraction of Al_2O_3 in bauxite, and equilibrium limit of solubility
- Increase digestion temperature
  - ➡ More sophisticated fast S/L-separator is required to suppress dissolution of silica.

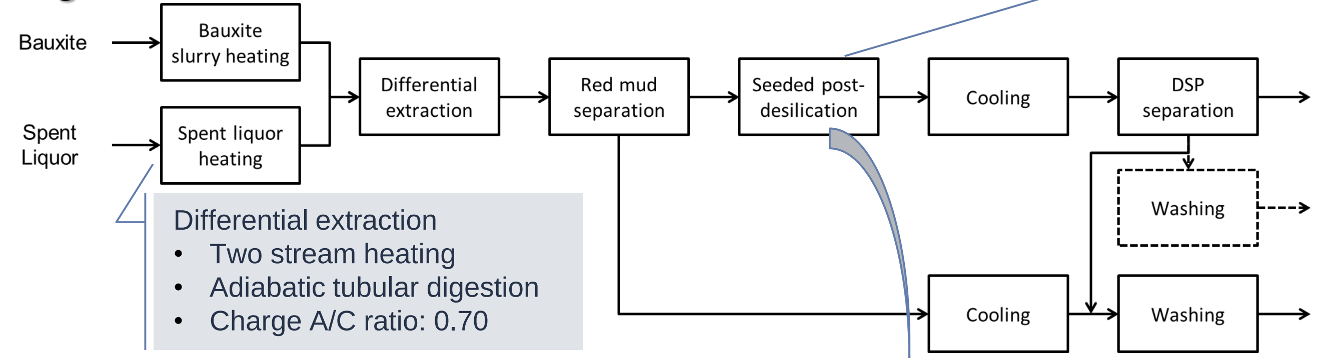
Sumitomo's solution:

➡ Differential extraction (130ºC) + "Sweetening digestion" with second bauxite (145-150ºC)
This sweetening digestion simultaneously solved the problem in seeded post-desilication!

… US Patent 6,299,846 B1 (2001)

Block Diagram of Sumitomo's Process with Sweetening

Original Sumitomo's Differential Extraction Process



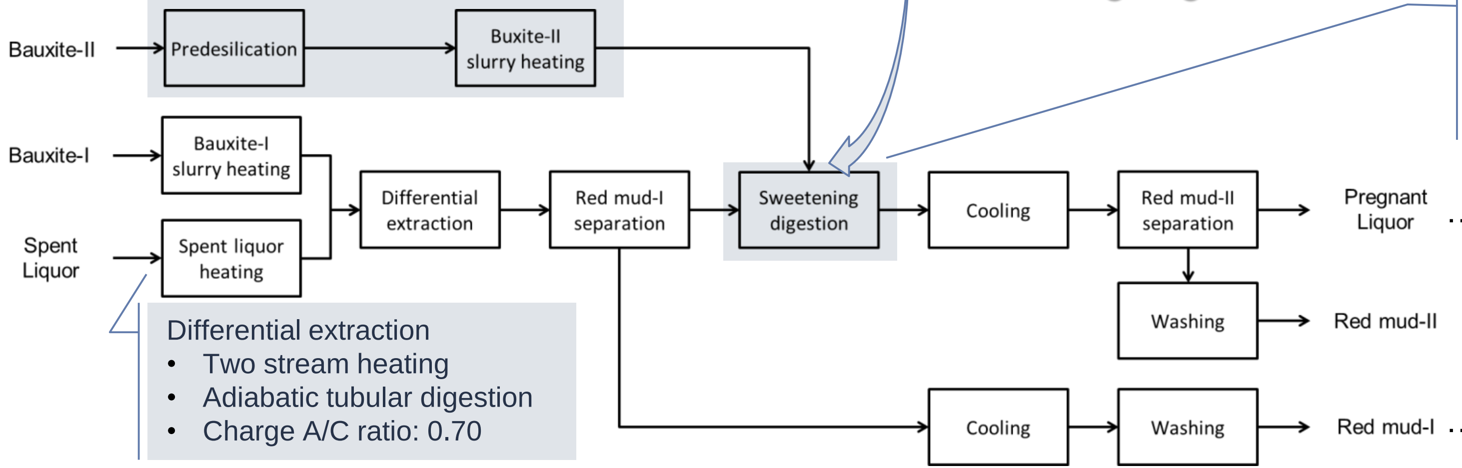
Desilication
- Temp.: 130ºC
- Time: >50 min.
- Charge A/C: 0.70

Pregnant Liquor ….. A/C 0.70

Red mud ….. Na_2O <1% (when DSP is separated)

Differential extraction
- Two stream heating
- Adiabatic tubular digestion
- Charge A/C ratio: 0.70

Sumitomo's Differential Extraction Process with Sweetening Digestion



Sweetening digestion
- Temp.: 145~150ºC
- Time: 30~40 min.
- Charge A/C: >0.75

Pregnant Liquor ….. A/C 0.75

Red mud-I …..Na_2O <1%

Differential extraction
- Two stream heating
- Adiabatic tubular digestion
- Charge A/C ratio: 0.70

Eastern Ghats Bauxite (EG-Bx)

		Eastern Ghats Bauxite (EG-Bx)					Sumitomo 1999	Trombetas 1998	South32		Imported bauxite
		EG-1	EG-2	EG-3	EG-4	EG-5			Worsley	MRN	
Chemical composiion	Al2O3 , %	45.80	46.39	49.42	44.50	39.74	51.28	54.65			
	Fe2O3 ,%	24.68	24.57	20.34	23.99	18.29	13.89	11.51			
	SiO2 , %	1.67	1.15	0.73	4.51	21.14	5.12	3.13			
	LOI ,%	25.13	25.41	27.12	24.20	18.25	27.29	29.10			
	TiO2 ,%	2.00	2.08	1.90	2.13	2.01	2.07	0.82			
	P2O5, %	0.122	0.106	0.266	0.450	0.144	Others				
	SO3 ,%	0.082	0.170	0.089	0.088	0.110	0.35				
	Σ, %	99.48	99.88	99.87	99.87	99.68	100.00	99.21			
Mineral cmposition, %	Alumina as										
	Gibbsite (AA)	42.16	42.48	47.38	37.91	19.93	45.98	51.8	27.7	48.1	44.1
	Boehmite	0.42	0.42	-	0.85	0.42	1.37	0.6			
	Diaspore	0.42	0.85	-	0.85	0.85	0.00	0.0			
	Alumogoethite	1.36	1.36	1.13	1.67	1.13	0.35	0.0			
	Kaolinite	1.38	0.99	0.59	3.16	16.98	3.58	2.2			
	Total	45.74	46.1	49.1	44.44	39.31	51.28	54.6			
	Silica as										
	Kaolinite (RS)	1.63	1.16	0.7	3.72	20.02	4.22	2.6	1.7	5.8	1.3
	Quartz	-	-	-	0.5	1	0.90	0.5			
	Total	1.63	1.16	0.7	4.22	21.02	5.12	3.1			
	Titania as										
	Anatase	1.5	2	1	1.5	2	2.07	0.8			
	Rutile	0.5	-	0.5	0.5	0	0.00	tr			
	Total	2	2	1.5	2	2	2.07	0.8			
	Iron as										
	Hematite	12.5	12.5	10	9	7	8.48	7.4			
	Alumogoethite	12.0	12.0	10.0	14.9	10.0	5.4	4.1			
	Total	24.5	24.5	20.0	23.9	17.0	13.9	11.5			
RS/AA ratio		0.039	0.027	0.015	0.098	1.005	0.092	0.050	0.061	0.121	0.029

Data source of bauxite compositions

- EG-Bx: Ashok Nandhi (private mail on April 19, 2022)
- Trombetas: G. Banvolgyi, P. Siklosi, Light Metals 1998, p.45-53.
- Sumitomo (Bintan 50%, Gove 50%): Harato, et al. 4th AQW (1996)
- South32: Annual Report 2021. p.155. “Total Ore Reserves (%)”
- Imported bauxite: A. Nandi, Minerals & Metal Reviews – August 2021 p.35-37. “Imported” means “imported to India” from where (Guinea? The author guesses)

Eastern Ghats Bauxite (EG-Bx)

Comparison of Bauxites

	EG-1~3	EG-4	Sumitomo	Worsley	Trombetas (MRN)		Imported by India
					1998	2021	
Gibbsite (AA)	42.2~47.4	37.9	46.0	27.7	51.8	48.1	44.1
Other alumina*	1.1~2.6	3.4	1.7	n/a	0.60	n/a	n/a
Kaolinite (RS)	0.7~1.63	3.72	4.22	1.7	2.6	5.8	1.3
RS/AA ratio	0.015~0.039	0.098	0.092	0.061	0.050	0.121	0.029

*Other alumina:
- gibbsite
- boehmite
- alumogoehthite

- EG-1~3 & 4 are good bauxites for low temperature digestion in Bayer process (except EG-5).
- EG-1~3 are as well or better than the imported bauxite (from Guinea?)
- RS/AA ration of EG-4 is lower than currently available MRN bauxite.
- Quality of MRN (Trombetas) bauxite seems to have deteriorated in the past two decades.
- EG-4 will become a standard quality in the near future when compared to the qualities of bauxites for Sumitomo, Worsley and MRN.

➡ What are the advantages of employing *Sumitomo process* for Ghats bauxite?

Case Study of Sumitomo Process for EG Bauxite

Process Conditions for the Case Study

- Process: Sumitomo process with sweetening digestion (cf. conventional process*3)
- Digestion liquor conditions (g/L)

C-Na_2CO_3	Carbonate	Al_2O_3	A/C ratio	SiO_2
275	25	110	0.400	0.60

- Digestion/extraction conditions

	Differential extraction	Sweetening digestion
Digestion Temperature, °C Time, minutes Charge A/C ratio	 130 <7* 0.700	 145 45 0.750
Extraction extent (%) Available alumina (AA) R-SiO_2 (RS) Desilication (%)	 98 40 0	 100 100 100

- Bauxites for study
  - EG-1, 2, 3, 4; Sumitomo (Bintan/Gove); Trombetas (1998)
  - EG-1 with gangue EG-5 to adjust RS content up to RS 10%.

Bench Marks of Study

- Unit consumption of bauxite
- Unit consumption of NaOH**
- Unit generation of red mud-I & II
- Na_2O content in red mud-I & II

*The digestion time includes residence time in S/L-separator.

**Just NaOH consumption by DSP formation was evaluated. Liquor carried with residue at the 1st S/L-separation is neglected. And DSP formation at differential extraction is also neglected. Process loss is not included.

*3 Extraction extent at conventional digestion is the same as the sweetening digestion.

Increase Resources in Existing Mines / Deposit

Adopt Natural Cut-off Grade - Bauxite resources of India can be increased by adopting natural cut-off grade of alumina and silica.

A. Nandi (2022). Technical lecture series, slide 44 & 45

Pariculars	Cut-offs Al2O3 ≥35%, SiO2≤10%, ≥1m	Cut-offs Al2O3 ≥40%, SiO2≤9%, ≥1m	Cut-offs Al2O3 ≥42%, SiO2≤6%, ≥1m
No. of Bore Holes	234	234	234
No. of Positive Holes	134	92	56
Av. Bauxite Thickness	5.74m	4.44m	3.63m
Ore Tonnage in MT	9.26	5.43	2.67
Av. % Al2O3	41.2	43.23	44.36
Av % SiO2	6.07	5.47	4.13

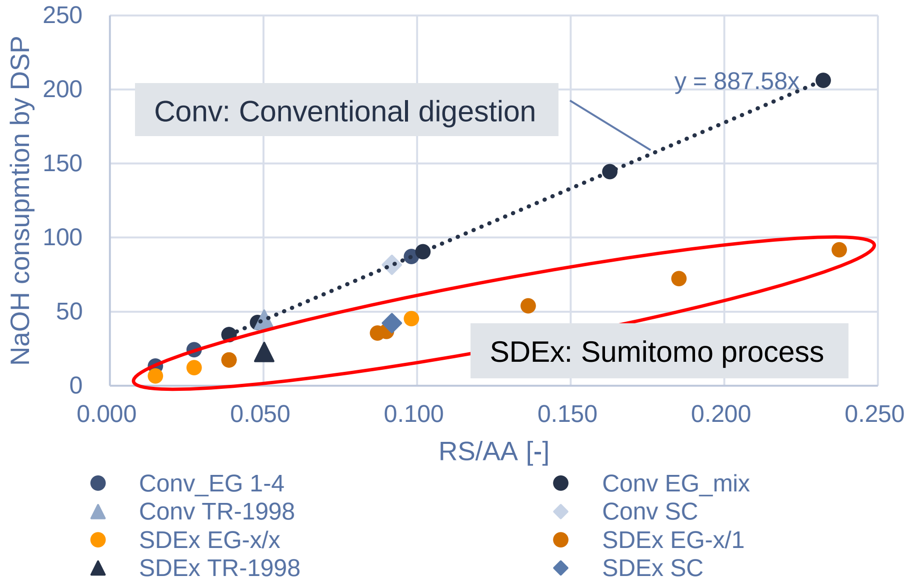
Orebody disposition at 35/10 cut off | Orebody disposition at 40/9 cut off | Orebody disposition at 42/6 cut off

Cut-offs	Av-Al_2O_3 (%)	R-SiO_2 (%)	RS/AA (-)
35/10	41.2	6.07	0.147
40/9	43.23	5.47	0.126
42/6	44.36	4.13	0.093

Making high-RS/AA ratio bauxite available is an important for sustainable alumina industry in India!
Then, high silica bauxite (R-SiO_2 (RS) 6%, AA 36.9%; RS/AA 0.163) was assumingly synthesized from data of EG-1 & EG-5 for the following study (EG-mix).

Result of Case Study: NaOH Consumption

NaOH consumption vs. RA/AA ratio of bauxite



Remarks to bauxite:

- EG-mix…EG-1 (base) with gangue EG-5 contaminated
- EG-x/y…x = Bauxite-I, y = Bauxite-II
- TR-1998; Trombetas bauxite (1998), SC; Bintan/Gove bauxite

Bauxite		Process	RS/AA* [-]	NaOH [Kg/tA]
I	II			
EG-I	---	Conv	0.039	34
EG-2	---	Conv	0.027	24
EG-4	---	Conv	0.098	87
EG-4	EG-4	SDEx	0.098	45
EG-4	EG-I	SDEx	0.087	36
EG_RS 6% (Al_2O_3 36.9%)	---	Conv	0.163	144
EG_RS 6%	EG-1	SDEx	0.137	54
Import	---	Conv	0.029	26
Tr-1998	---	Conv	0.050	45
Tr-1998	Tr-1998	SDEx	0.050	23

*weighted mean of Bx-I & Bx-II was calculated for SDEx process

Result of Case Study: Red mud

		Case 1	Case 2	Case 3	Case 4	Case 5
Conventional	Bauxite I	EG-1	EG-4	EG-4	EG-RS 6%	TR-1998
	AA [%]	42.2	37.9	37.9	36.9	51.8
	RS/AA [-]	0.039	0.098	0.098	0.163	0.050
	Red mud Amount [kg/tA]	873	1,187	1,187	1,313	441
	Na_2O [%]	3.0	5.7	5.7	8.5	7.8
	Al_2O_3 [%]	10	15	15	15	13
	Fe_2O_3 [%]	67	53	53	47	50
SDEx	Bauxite-II	EG-1	EG-4	EG-1	EG-1	TR-1998
	RS/AA (weight av. of I&II)	0.039	0.098	0.087	0.136	0.050
	Bauxite-I [wt%]	84	82	83	81	84
	Red mud RM-I Amount [kg/tA, %]	722 (80%)	882 (73%)	876 (77%)	860 (71%)	332 (72%)
	Na_2O [%]	0	0	0	0	0
	Al_2O_3 [%]	11	15	15	15	15
	Fe_2O_3 [%]	69	60	60	58	57
	RM-II Amount [kg/tA]	184 (20%)	321 (27%)	266 (23%)	352 (29%)	129 (28%)
	Na_2O [%]	7.3	10.9	10.3	11.8	13.6
	Al_2O_3 [%]	15	20	18	19	21
	Fe_2O_3 [%]	51	36	41	36	29

Conv-Red mud is separated into two muds by SDEx:

Red mud-I

- Low Na_2O (<1%)
- High Iron (Fe_2O_3)
- Most mud (70~80%) is in low/free-soda

Red mud-II

- High Na_2O
- Low Iron
- Most mud-II (20~30%) needs strict management as is conventionally done

Advantages & Disadvantages of Sumitomo Process

Advantage

- Caustic soda consumption is reduced by 50%.
- High-silica bauxite can be processed economically.
- Auto-precipitation is inhibited.
- Red mud can be separated into two muds, red mud-I & mud-II
  - Red mud-I is characterized by contents of free-Na_2O (<1%) and high-iron, and large portion of residue (70-80%) is red mud-I.
  - Red mud-II is characterized by high-soda (Na_2O) and its portion is limited to 20-30%.
- Red mud-I will find applications easily because of free-Na_2O which is the largest barrier of red mud use. And management of red mud on disposal will get much easier. Disposal of red mud-II needs strict management as before, but recovery of soda will be much easier because of smaller volume than before.

Disadvantage

- Application is limited to gibbsitic bauxite.
- Process complexity?
- Scaling?
- Energy consumption?
- CAPEX?

Why Differential Extraction Is Not Employed?

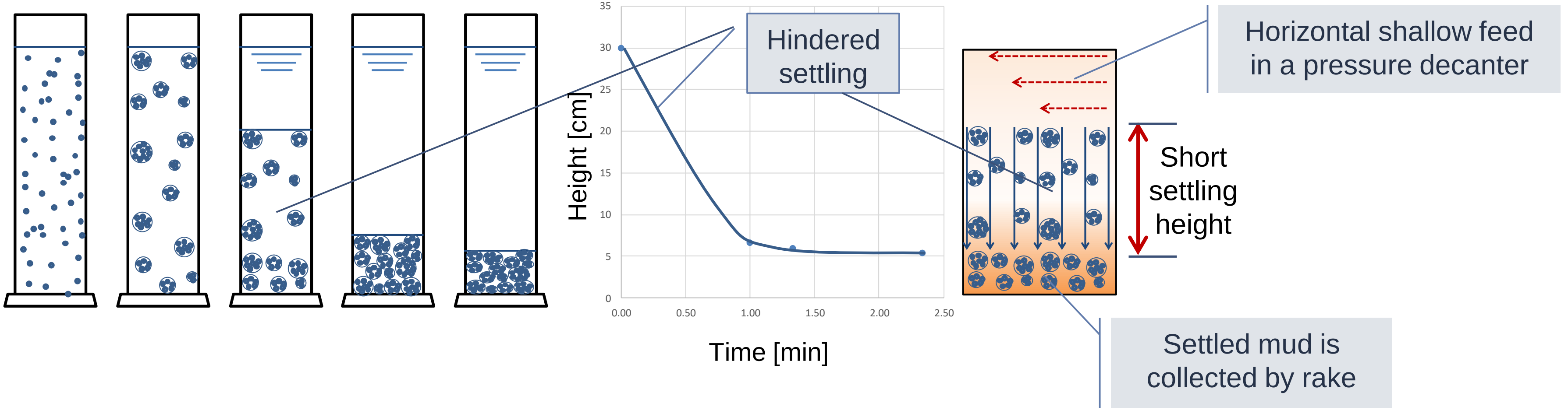
Advantages of differential extraction are widely recognized, but not employed. Why? Skeptical?

	Skeptical issues	Answer/Solution/Future work
I	**Red mud separation** and washing • Can red mud separated within a few minutes? • How about washing?	Yes, Sumitomo developed a new pressure decanter and it worked well. We've started **CFD modeling** study to prove its efficiency for scaling-up. Skilled operator was required because of short residence time.
II	Desilication by seeded post-desilication	Yes, it was a troublesome operation. But introduction of sweetening by second bauxite solved the problem.
III	Scaling	No problem in tubular digestion because of adiabatic reactor. Fast red mud separator operated for three months and maintenance work was carried out. How to heat the pseudo-pregnant liquor (liquor to sweetening digestion) will be a new challenge.
IV	**Energy consumption**	Slightly disadvantage compared to single-stream digestion system. Mechanical vapor-recompression (MVRC) is necessary to solve the problem.
V	Complexity of differential extraction with sweetening	Compared to single-tube digestion, the process is complicated. But very similar complexity to double-digestion system
VI	Economy; CAPEX, OPEX	Pros: High silica bauxite is available, and NaOH can be recovered. Cons: CAPEX?

Challenges: Fast Red Mud Separation (Pressure Decanter)

Concept of fast S/L-separator with horizontal shallow feed

Batch-wise settling test | Pressure decanter

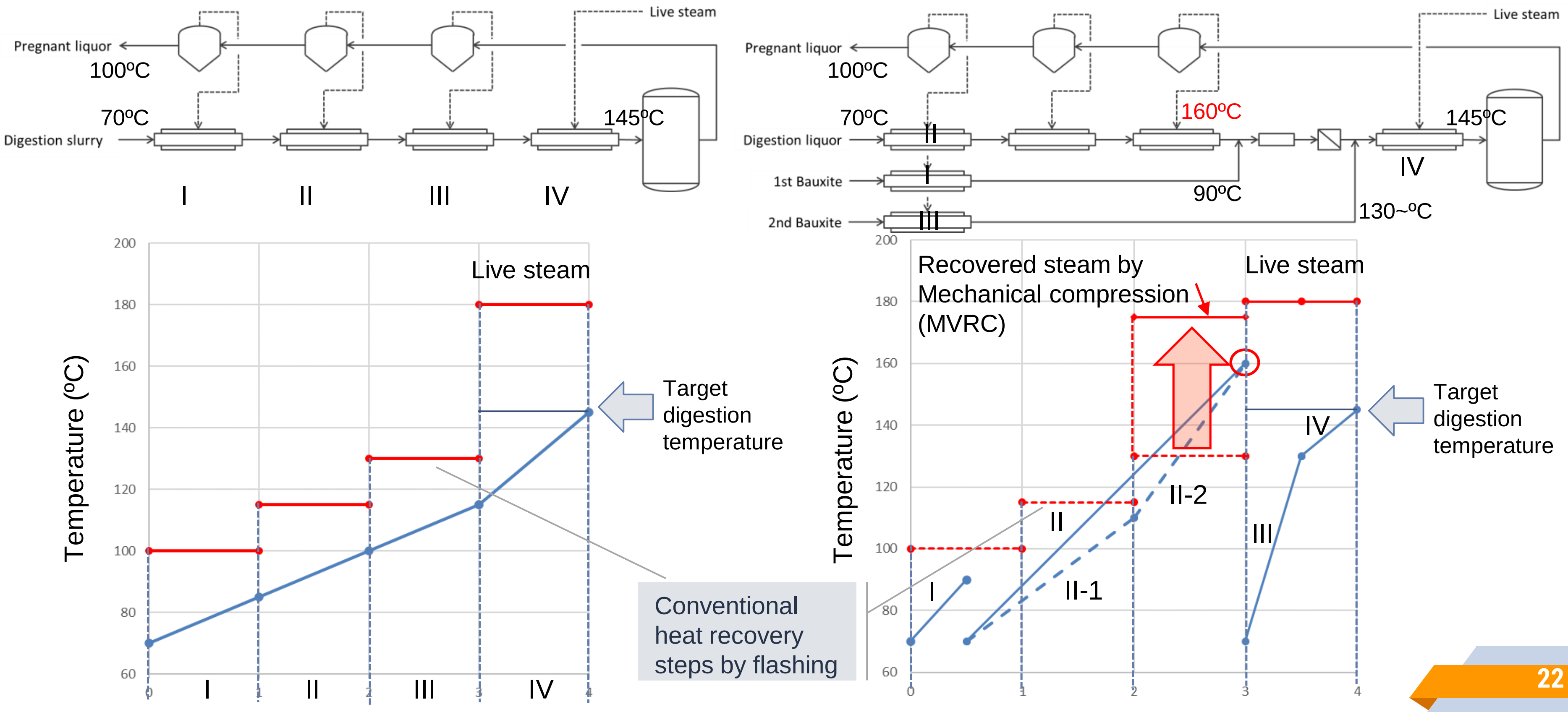


Scaling-up to high throughput for a bigger refineries → CFD Modeling/Simulation

Challenges: Energy

Conventional process

Differential process with sweetening



Challenges

Challenges to introduce Sumitomo’s differential extraction (SDEx) process in India

- Laboratory digestion test of differential extraction and sweetening processing to find optimum digestion conditions
- Laboratory settling test to find a good flocculant
- Evaluation of the two resultant residues red mud-I & red mud-II
- Conceptual design of SDEx process for Ghats bauxite (and other bauxites)
- Estimation of CAPEX, OPEX (Cost/benefit analysis)

Conclusion

- Answer to the question by Ashok:

  "Yes, India can provide enough bauxite to the growing alumina industry"
- Sumitomo's differential extraction process with sweetening digestion (SDEx process) is useful to process Eastern Ghats bauxite. Even high-silica portion will be economically processed.
- The resulted red mud can be separated into two residues of virtually free-soda and high-soda and it will help to solve red mud issues fundamentally.
- The process will be applied to the existing low temperature digestion plants by retrofitting.

Thank you!

Contact

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