AA07 - Analysis of the Break-Even Point of Guinea Bauxite Digestion at High and Low Temperature

Zhenyong Luo[1], Yang Ni [2], Hui Yang[3] and He Huang [4]
1. Director, Alumina Engineering Institute
2. Director, Alumina Engineering Institute
3. Engineer
4. Engineer
Guiyang Aluminum and Magnesium Design and Research Institute Co. Ltd., Guiyang, China
Corresponding author: 13985109527@163.com

Abstract

By analyzing the effect caused by a change of the total alumina and the available alumina contents in the Guinea bauxite on the operating expense excluding overheads, a break-even point of the high and low temperature digestion process is predicted, to assist Chinese refineries that have the possibility to switch between low and high temperature digestion. The model is based on the price of bauxite at 350 Chinese yuan per tonne and of caustic soda at nearly 2,000 Chinese yuan per tonne when the content differential between the total alumina and the available alumina (TA-AA) at low temperature is between 6.7 and 7.8%. The break-even point decreases as the rise of the bauxite price and rises as the rise of the caustic soda price.

Key words: Guinea Bauxite, Break-even Point, Digestion, Alumina.

1. Introduction

With the continuous mining and utilization of bauxite resources in China, the bauxite grade is decreasing year on year, and the domestic bauxite resources are increasingly scarce. In recent years, the consumption of import bauxite is increasing in China, the amount of the import bauxite is approximately 111 million tonnes in 2020. A proportion of about 60% of China's bauxite consumption is from overseas. The following figure shows the distribution of import bauxite sources in 2020 [1].

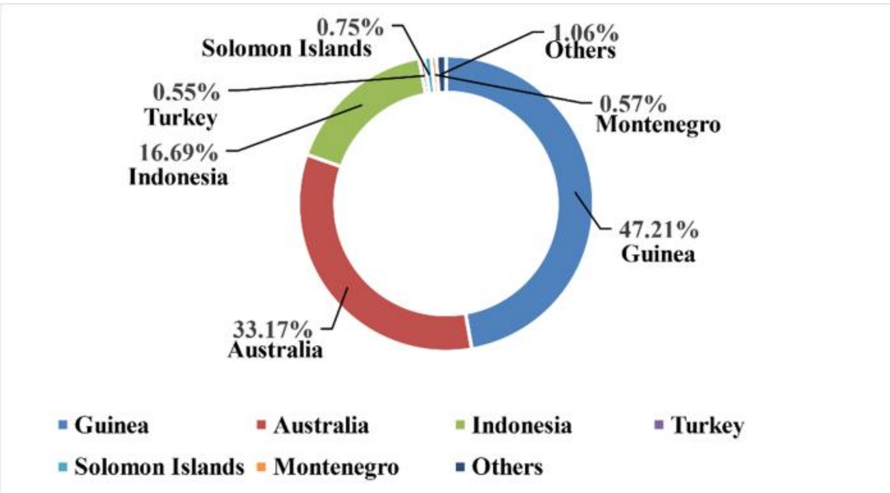

Figure 1. Distribution of import bauxite in China, 2020.

Figure 1 shows that the bauxite imported to China are mainly from Guinea (nearly 50%), Australia, and Indonesia. Processing Guinea bauxite using high or low temperature digestion is always a debate. Currently, most of the alumina refineries processing Guinea's bauxite use a low temperature digestion process, while a few use high temperature, and some have the possibility to switch between low and high temperature digestion. This paper analyzes the advantages and disadvantages of high and low temperature with bauxite from Guinea in the perspective of operating expense. A break-even point is determined and provides a reference basis for operating strategy for alumina refining.

2. Quality of Guinea Bauxite

2.1 Reserves and Distribution

Guinea bauxite is a typical laterite ore, which is mainly gibbsite with some boehmite. Guinea's bauxite reserves are about 24 billion tonnes, of which 7.4 billion tonnes is proven, accounting for 1/3 of the world's reserves, and the total alumina content is in the 38 to 62 % range. The minerals are mainly distributed in Fria, Kindia, Boke and Telimele regions. Bauxite in the Central Guinea natural area is mainly distributed in Labe, Gaoual and Tougue areas. The minerals distributed in Kindia and Boke districts of Lower Guinea are about 5 billion tonnes. Among them, the average grade of bauxite in Kindia is 46 % Al_2O_3 and 2.8% SiO_2; the average grade of Boke is 44.6 to 60 % Al_2O_3 and 1.8 % SiO_2; in Central Guinea, bauxite in Labe Region is about 500 million tonnes, with Al_2O_3 of 46.7 % and SiO_2 of 2.3 %. There are about 500 million tonnes of high grade bauxite in the Gaoual area, with a resource of about 460 million tonnes, with an average grade of 48.7 % Al_2O_3 and 2.1% SiO_2; there are about 1.9 billion tonnes of bauxite resources in the Tugai and Dabola Provinces of Upper Guinea, with an average grade of 44.1 % Al_2O_3 and 2.6 % SiO_2.

The Boke mining area, including the Boffa Province, is currently the area where Chinese companies are concentrated: WCS, SPIC, CHINALCO, CHICO, and TBEA are all mining bauxite in this area. Most of the bauxite exported to China is from the Boke region.

2.2 Mineral Composition

Guinea bauxite is typically gibbsitic and a series of typical mineral compositions are given in Table 1, for samples from different mine areas. By combination of XRD measurement, chemical analysis and necessary calculation, this set of data shows that the boehmite in the bauxite is highly variable among the analysed samples, and that the percentages of the alumo-goethite and hematite are generally high. In these samples, approximately 20% molar Fe is substituted by Al in goethite.

Table 1. Typical mineral compositions of a suite of Guinea bauxite samples.

Compositions	Gibbsite	Boehmite	Alumo-goethite	Hematite	Kaolinite	Others
Sample 1	60.00%	1.00%	17.00%	15.00%	3.50%	3.50%
Sample 2	62.00%	-	15.00%	10.00%	3.00%	10.00%
Sample 3	61.62%	2.67%	18.46%	8.00%	1.07%	8.18%
Sample 4	54.60%	0.30%	18.80%	16.70%	3.30%	6.30%
Sample 5	50.80%	0.70%	20.80%	18.39%	1.50%	7.81%
Sample 6	76.30%	1.49%	12.84%	4.35%	0.30%	4.72%
Sample 7	58.00%	6.80%	19.24%	11.70%	0.28%	3.98%
Sample 8	60.70%	3.79%	18.86%	9.99%	0.59%	16.07%

2.3 Chemical Composition

By chemical analysis for the liquor composition, X-ray fluorescence spectroscopy for Al_2O_3 and SiO_2 in DSP and atomic absorption spectroscopy for Na_2O in DSP, the chemical compositions of the same samples are given in Table 2.

Table 2. Typical chemical compositions of a suite of Guinea bauxite samples.

Compositions	T.Al_2O_3	A.Al_2O_3	T.SiO_2	R.SiO_2
Sample 1	43.60%	40.69%	2.52%	1.58%
Sample 2	46.54%	39.74%	2.63%	1.47%
Sample 3	45.68%	40.04%	2.02%	0.46%
Sample 4	40.22%	35.61%	2.54%	0.72%
Sample 5	38.80%	-	2.49%	-
Sample 6	53.60%	49.87%	1.09%	0.60%
Sample 7	47.15%	37.92%	1.17%	0.50%
Sample 8	46.40%	39.67%	2.16%	0.90%

NOTE for all tables:
T.Al_2O_3 total Al_2O_3.
A.Al_2O_3 available Al_2O_3, at 145 °C ;
T.SiO_2total SiO_2 ;
R.SiO_2reactive SiO_2, at 145 °C

It is shown in Table 2 that the available alumina at 145 °C is low when the content of boehmite and alumo-goethite is high and the differential between T.Al_2O_3 and A.Al_2O_3 is large. For Guinea ores, this alumina content differential is alumina in boehmite and alumo-goethite that cannot be digested at 145°C but can be digested at 260°C, defined as T.A-A.A. in this paper, this determines that digestion should be carried out at high temperature or at low temperature .

3. Selection of Process Conditions

3.1 Digestion Temperature

In the Bayer process, it is common to choose the appropriate digestion process system to achieve the best result based on the type of bauxite. The comparison of the digestion temperature for different mineral compositions is shown in Table 3.

Table 3. Typical digestion temperatures for different mineral compositions.

Compositions	Gibbsite	Boehmite	Alumo-goethite	Diaspore
Digestion Temperature, °C	105–150	210–260	220–260	260–280

Table 3 shows that gibbsite is digested at low temperature (i.e., 105 to 150 °C), boehmite is generally digested above 245 °C, and alumo-goethite is digested completely at least at 260 °C [2] and generally above 270 °C. At 270 °C, Al_2O_3 in both boehmite and alumo-goethite can be digested. Therefore, for Guinea bauxite, 270 °C is a sensible temperature for high temperature digestion process, and 145 °C for low temperature digestion process.

3.2 Differences in Process Targets

The digestion rate is a significant target in an alumina refinery. It is strongly related to the digestion temperature, digestion residence time, caustic soda concentration, ore particle size and stirring intensity. For the treatment of the same type of bauxite, the comparison of conventional process targets between low and high temperature digestion is shown in Table 4.

Table 4. Comparison of low temperature and high temperature process targets.

Items	Low temperature	High temperature
Caustic soda concentration, grams Na_2O /L	180	180–220
Digestion temperature, °C	145	270
Digestion Residence time, minutes	60–90	30
Digestion A/C_Na_2O	1.2	1.25
Thickener capacity, $t/m^2 \cdot h$	0.2	0.3

NOTE: A/C_Na_2O is the mass ratio of Al_2O_3 to caustic Na_2O, both expressed in g/L.

From the comparison in Table 4, for Guinean bauxite, when the high temperature digestion process is selected, the digestion time can be shortened, and the digestion A/C_Na_2O value can be increased. Since the percentage of alumo-goethite in the ore is as high as 17 %, when it is digested at low temperature, there is a great impact on the thickening process. This is based on the operation experience from a Chinese refinery where it was noticed that a high percentage of alumo-goethite worsens the slurry thickening and compaction, and cause a high solids concentration of 0.15–0.2 g/L in the overflow. When it is digested at high temperature, the alumo-goethite originally in the ore changes into hematite [2, 3, 4], which improves the thickening process, the underflow compaction is improved, and the washing times can be appropriately reduced.

3.3 Differences in Technical and Economic Targets

Compared with the low temperature digestion process, a high temperature digestion leads to a lower bauxite consumption because of the recovery of the alumina contained in boehmite (or diaspore) and alumo-goethite [2, 5]. High temperature digestion however leads to high caustic soda, steam, power and water consumption. There is nevertheless little difference in fuel consumption at calcination, cooling water consumption and compressed air consumption.

4. Changes of Differential Between Total Alumina and Available Alumina

It was presented in Table 1 and Table 2 that the chemical and mineralogical compositions, and the percentage of low-temperature insoluble alumina (which equals to the total alumina minus the available alumina (T.A-A.A)) of Guinea bauxite varies significantly. The chemical composition of Guinea bauxite used actually in a Chinese refinery is listed as Table 5.

Table 5. Chemical composition of the bauxite

Compositions	T.Al_2O_3	A.Al_2O_3	T.SiO_2	R.SiO_2
Percentage, %	43.60	40.69	2.52	1.58

The composition percentage of total Al_2O_3, available Al_2O_3, total SiO_2 and reactive SiO_2 in Table 5 can be considered as the basic data used to calculate the operation expense caused by Guinea bauxite refining in this article. Based on the figures shown in Table 5, two kinds of changes of the bauxite T.A-A.A are considered:

- Group 1, total alumina percentage unchanged and available alumina percentage changed.
- Group 2, total alumina percentage changed and available alumina percentage unchanged.

For both Group 1 and Group 2, the differentials are presumed to change regularly to show the trends. All the presumed composition and percentage value is close to the actual Guinea bauxite imported in China.

4.1 Group 1, Total Alumina Percentage Unchanged

In Group 1, the differential between total alumina and available alumina (T.A-A.A) is between 2 and 11 %. It is presumed that total alumina percentage remains unchanged at 43.6 %, and available alumina percentage decreases from 41.6 to 32.6 %. Also, total SiO_2 increases as available alumina decreases, but reactive silica ($R.SiO_2$) remains unchanged at 1.58 %. Group 1 bauxite data is presented in Table 6.

Table 6. Presumed chemical composition of bauxite in Group 1.

Samples	T.A.-A.A.	A.A.	T.SiO₂	R.SiO₂
Sample 1	2 %	41.60 %	2.32 %	1.58 %
Sample 2	3 %	40.60 %	2.52 %	1.58 %
Sample 3	4 %	39.60 %	2.72 %	1.58 %
Sample 4	5 %	38.60 %	2.92 %	1.58 %
Sample 5	6 %	37.60 %	3.12 %	1.58 %
Sample 6	7 %	36.60 %	3.32 %	1.58 %
Sample 7	8 %	35.60 %	3.52 %	1.58 %
Sample 8	9 %	34.60 %	3.72 %	1.58 %
Sample 9	10 %	33.60 %	3.92 %	1.58 %
Sample 10	11 %	32.60 %	4.12 %	1.58 %

4.2 Group 2, Available Alumina Percentage Unchanged

In Group 2, the differential between total alumina and available alumina (T.A-A.A) is also between 2 and 11 %, the available alumina remains unchanged at 40.6 %, while the total alumina increases from 42.6 to 51.6 %. Table 7 data also show that total SiO_2 increases as total alumina increases, but like in Group 1, $R.SiO_2$ remains unchanged at 1.58 %.

Table 7. Presumed chemical composition of bauxite in Group 2.

Samples	T.A.- A.A	T.A.	T.SiO₂	R.SiO₂
Sample 1	2 %	42.60 %	2.32 %	1.58 %
Sample 2	3 %	43.60 %	2.52 %	1.58 %
Sample 3	4 %	44.60 %	2.72 %	1.58 %
Sample 4	5 %	45.60 %	2.92 %	1.58 %
Sample 5	6 %	46.60 %	3.12 %	1.58 %
Sample 6	7 %	47.60 %	3.32 %	1.58 %
Sample 7	8 %	48.60 %	3.52 %	1.58 %
Sample 8	9 %	49.60 %	3.72 %	1.58 %
Sample 9	10 %	50.60 %	3.92 %	1.58 %
Sample 10	11 %	51.60 %	4.12 %	1.58 %

5. Operation Expense Prediction

5.1 Caustic Soda and Bauxite Consumption

Caustic soda consumption and bauxite consumption are calculated in Table 8 and Table 9. Table 8 shows that with a high temperature digestion (HTD) process of fixed T.A. and a decreasing A.A. (Group 1), caustic soda consumption and bauxite consumption rise up with the T.SiO2 content increasing; and that with a low temperature digestion (LTD) process, caustic soda consumption remains stable and bauxite consumption rises with A.A. decreasing.
Table 9 shows that with a high temperature digestion (HTD) process of fixed A.A. and an increasing T.A. (Group 2) , caustic soda consumption rises up with the T.SiO2 content increasing and bauxite consumption goes down because of the increasing T.A.; and that with a low temperature digestion (LTD) process, caustic soda consumption and bauxite consumption remains stable.

Table 8. Caustic soda consumption and bauxite consumption from samples in Group 1

Group 1	High temperature digestion		Low temperature digestion	
Samples	Caustic soda consumption, kg NaOH / tonne Al_2O_3	Bauxite consumption, t dry bauxite / tonne Al_2O_3	Caustic soda consumption, kg NaOH / tonne Al_2O_3	Bauxite consumption, t dry bauxite / tonne Al_2O_3
Sample 1	64	2.74	53	2.77
Sample 2	66	2.75	53	2.82
Sample 3	69	2.76	53	2.86
Sample 4	71	2.77	53	2.91
Sample 5	74	2.78	53	2.96
Sample 6	78	2.79	53	3.01
Sample 7	80	2.80	54	3.06
Sample 8	82	2.81	54	3.12
Sample 9	85	2.82	54	3.18
Sample 10	88	2.83	54	3.25

Table 9. Caustic soda consumption and bauxite consumption from samples in Group 2

Group 2	High temperature digestion		Low temperature digestion	
Samples	Caustic soda consumption, kg NaOH/ tonne Al_2O_3	Bauxite consumption, t dry bauxite / tonne Al_2O_3	Caustic soda consumption, kg NaOH/ tonne Al_2O_3	Bauxite consumption, t dry bauxite / tonne Al_2O_3
Sample 1	62	2.81	53	2.82
Sample 2	66	2.75	53	2.82
Sample 3	68	2.70	53	2.82
Sample 4	71	2.65	53	2.82
Sample 5	74	2.60	53	2.82
Sample 6	77	2.55	53	2.82
Sample 7	79	2.51	54	2.82
Sample 8	82	2.46	54	2.82
Sample 9	84	2.42	54	2.82
Sample 10	87	2.37	54	2.82

To simplify calculations and to highlight the main factors, operating expense mainly consists of material, fuel and power expense, wages, welfare, and overheads, as described in Table 10.

Table 10. Composition of alumina operation expense.

Operation expense	Material expense	Main factor: bauxite, lime and caustic soda.
	Fuel and power expense	Main factor: steam, natural gas, fresh water and electricity.
	Wages and welfare expense	
	Overheads	Depreciation costs, repairing costs, low value consumables, machine and material consumption, office expenses, travel expenses, labor insurance expenses, etc.

Since the overheads depend on the management level in each individual alumina refinery in China, it is more objective that overheads are excluded from operation expense. The composition and value of operation expense, excluding overheads, are listed in Table 11, based on refineries in Guangxi Province, China.

Table 11. Composition and value of operation expense.

Items	Unit	Unit price (Chinese Yuan)	Remarks
Bauxite	t	350	Excluding tax
Lime	t	460.18	Excluding tax
Solid caustic soda	t	1998.64	Excluding tax
High pressure steam	t	105	Excluding tax
Low pressure steam	t	90	Excluding tax
Natural gas	m^3	1.81	Excluding tax
Fresh water	m^3	1	Excluding tax
Electricity	kWh	0.25	Self-generating
Wages and welfare	t	49.9	

The price of lime and solid caustic soda is the average in the past year. The price of high pressure steam and low pressure steam is the converted price (when high pressure steam is used, electricity self-generating capacity decreases, and the refinery needs to purchase electricity. Therefore, these changes are converted to the price variance of high pressure steam and low pressure steam).

5.2 Break-even Point for Bauxite Samples of Group 1

For the samples in Group 1, with a high temperature digestion (HTD) process, as the differential between total Al_2O_3 and available Al_2O_3 increases from 2 to 11 %, all the consumption factors remain the same due to the unchanged total Al_2O_3 that is mostly extracted at high temperature. With a low temperature digestion (LTD) process, however, as the T.A-A.A differential increases from 2 to 11 %, the decrease in available alumina at low temperature cause an increase in bauxite consumption. The resulting operation expense trends are shown in Figure 2, where an almost flat trend can be observed for the HTD process (red squares) and a strongly increasing trend for the LTD process (green triangles). The two curves cross at a break-even point when T.A-A.A is at 6.7 %. When T.A-A.A is higher than 6.7 %, the operation expense of a high temperature digestion process is lower; otherwise, the operation expense of a low temperature digestion process is lower.

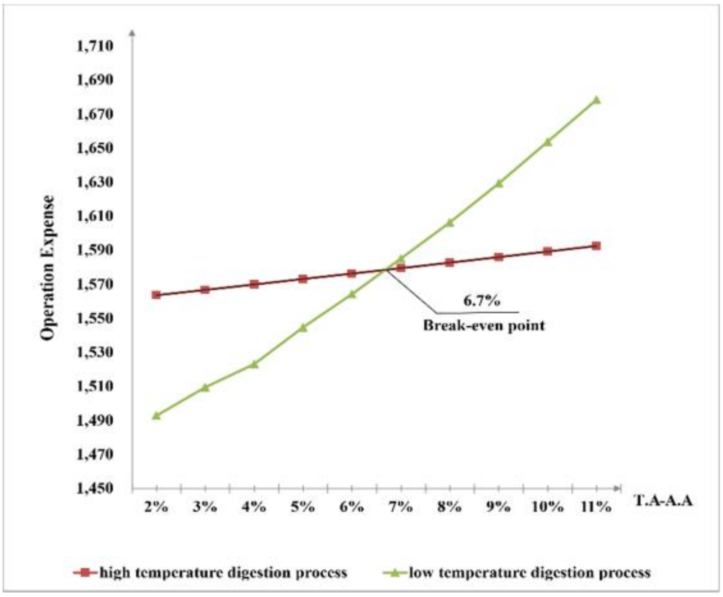

Figure 2. Operation expense trends of samples in Group1 for LTD and HTD.

5.3 Break-even Point for Bauxite Samples of Group 2

For the samples in Group 2, with a high temperature digestion process, as the differential between total Al_2O_3 and available Al_2O_3 increases from 2 to 11 %, the increasing total Al_2O_3 content cause a decrease in bauxite consumption and the increasing total SiO_2 cause an increase in caustic soda consumption. With a low temperature digestion process, however, when the differential between total Al_2O_3 and available Al_2O_3 increases from 2 to 11 %, all of the consumptions remain the same due to the unchanged available Al_2O_3 at low temperature. The operation expense trends are shown in Figure 3, where an almost flat trend can be observed for the LTD process (green triangles), and a significantly decreasing trend for the HTD process (red squares). The two curves cross at a break-even point when T.A-A.A is at a value of 7.8 %. When T.A-A.A is higher than 7.8 %, the operation expense with a high temperature digestion process is lower; otherwise, the operation expense with low temperature digestion process is lower.

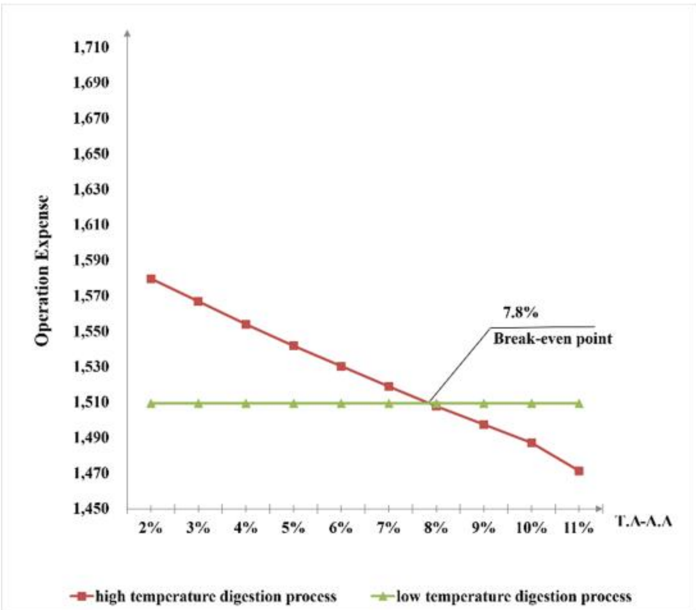

Figure 3. Operation expense trends of samples in Group2 for LTD and HTD.

5.4 Effect of Bauxite Price Changes on the Break-even Points

When estimating the operation expense, excluding overheads (as explained in Table 10), the bauxite price is a significant factor. The market price of bauxite imported from Guinea is highly variable and is closely related to mining costs, sea freight, land transportation cost, etc. The changes in high and low temperature digestion process break-even point were calculated for Guinea bauxite with CIF price between 300 and 600 Chinese yuan per tonne, and the results are shown in Figure 4. The T.A-A.A break-even point goes down as the bauxite price increases, but this decreasing trend is more pronounced for Group 2 (fixed A.A) than Group 1 (fixed T.A). However, for both Groups 1 and 2, operating a high temperature digestion process becomes increasingly favorable with increasing bauxite prices.

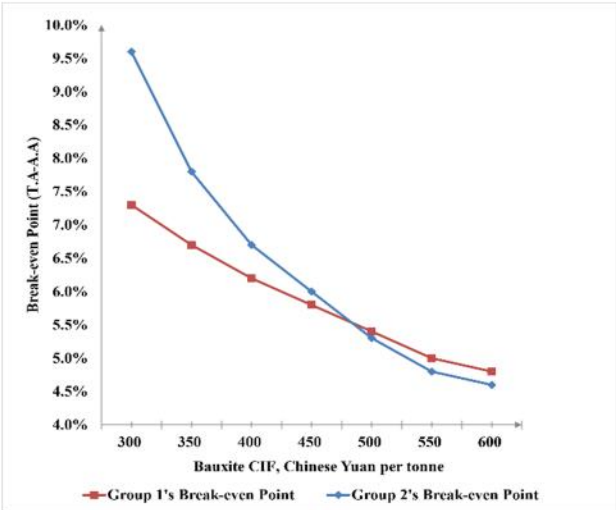

Figure 4. Break-even points variation due to bauxite price changes

5.5 Effect of Caustic Soda Price Changes on Break-even Points

The changes of high and low temperature digestion process break-even point were calculated with a fixed bauxite price of 350 Chinese yuan per tonne, for solid caustic soda prices between 500 and 3000 Chinese yuan per tonne. The resulting trends are shown in Figure 5, where it can be observed that the T.A-A.A break-even point increases as the caustic soda price increases. This means that at higher caustic soda prices, a low temperature digestion process becomes more advantageous.

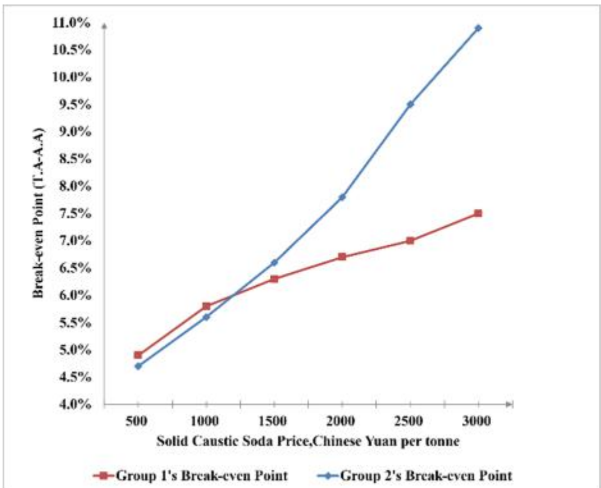

Figure 5. Break-even points variations due to caustic soda price

6. Conclusions

By accounting for the alumina operation expense, excluding manufacturing costs, based on a bauxite price of 350 Chinese yuan per tonne and a caustic soda price of 1999 Chinese yuan per tonne, for Guinea bauxite, the LTD vs HTD break-even points of the T.A-A.A are 6.7 % or 7.8 % for Group 1 (fixed T.A) and Group 2 (fixed A.A) scenarios, respectively. This means that for a fixed T.A, HTD is more advantageous for bauxite having a T.A-A.A above 6.7 %. On the opposite, for a fixed A.A, LTD is preferred for T.A-A.A above 7.8 %. These break-even point are however variable as well and go down with increasing bauxite price and go up with increasing caustic soda price. Therefore, when processing Guinea bauxite, the financial advantage of operating a high or a low temperature digestion process will vary depending on bauxite, caustic soda and coal price.

7. Reference

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