AA06 - Study of Guinean Bauxite Processing under Low and High Digestion Temperatures

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Abstract

This article studies the digestion performance of one Guinea bauxite. The chemical and mineralogical composition of the bauxite were analyzed, the digestion performance was studied in detail under different digestion conditions such as temperature and holding time. Empirical formulas were used to verify the experimental results. Based on the experimental results and the industrial practice of China alumina refineries, mass balance and heat balance calculations were conducted. The production costs in different digestion conditions were compared, as well as the impact on the bauxite residue properties in the context of its utilization. The research results of this article have important guiding significance for the selection of production conditions for the treatment of Guinea bauxite.

Keywords: Guinea bauxite, Digestion, Temperature, Holding time, Production cost

1. Introduction

China is the world's largest alumina producer, with a total alumina production of 81.86 million tonnes in 2022, about 57.6 % of the world's total alumina production. However, with the decline of domestic bauxite resources, the greenfield and brownfield alumina projects mostly use imported bauxite. Bauxite imports to China mainly come from Guinea, Australia, Indonesia and other regions with rich bauxite resources, of which Guinea is the largest with about 56 % of the total bauxite imports in 2022. Guinea bauxite is typically gibbsitic bauxite. In addition to gibbsite, it also contains a certain amount of boehmite and alumogoethite [1-3]. In Chinese alumina refineries treating Guinea bauxite, either low or high temperature digestion process is used according to the bauxite composition. This article compares the digestion performance and production costs of one Guinea bauxite under high and low temperature conditions.

2. Experimental Materials and Methods

2.1 Experimental Materials

The bauxite sample is from one bauxite mining area in Guinea. The test liquor used for digestion is prepared with distilled water, aluminium hydroxide (industrial grade), sodium hydroxide (analytical pure), and sodium silicate (analytical pure).

2.2 Digestion Test Method

The digestion test is carried out in a molten salt/oil bath heating device (oil bath at 150 °C, molten salt heating above 200 °C), with a temperature control accuracy of ± 1 °C, equipped with digestion steel bombs. The materials in the steel bomb achieve uniform reaction due to a continuous flipping mechanism. After reaching the target test temperature, the temperature is maintained during the appropriate holding time, then the reactor is removed and cooled down quickly. After cooling, the digested slurry solids-liquids are rapidly separated. Bauxite residue is washed with hot water above 98 °C combined with vacuum filtration, the liquid and solid phase components are analyzed.

The extraction efficiency is expressed as a relative number using the calculation formula:

$$\eta_A = \frac{Al_2O_3(D)}{Al_2O_3(A)} \times 100\% \tag{1}$$

where:

η_A	Relative digestion rate, %
$Al_2O_3(D)$	Fraction of alumina digested, %
$Al_2O_3(A)$	Fraction of available alumina in bauxite, %

2.3 XRD, XRF and LOI

The chemical composition was determined by an ARL PERFORM'X 4200 X-ray fluorescence analyzer (XRF), the loss of ignition (LOI) was determined by a muffle furnace calcination, and the mineralogical composition was determined by an XRD-7000 X-ray diffraction (XRD) instrument.

3. Experimental Results and Discussion

3.1 Chemical and Mineralogical Composition

The dried bauxite was first crushed by a jaw crusher. After crushing, the bauxite was ground using a disc milling equipment and sieved to the proper size distribution. The product bauxite samples were used for chemical and mineralogical analyses, and subsequent experiments. The results of chemical composition analysis is shown in Table 1, and the XRD spectrum is shown in Figure 1. The mineralogical composition calculated based on the XRF and XRD results is shown in Table 2.

Table 1. Chemical composition of bauxite samples.

Al_2O_3	Na_2O	K_2O	SiO_2	CaO	Fe_2O_3	TiO_2	LOI
46.87	0.01	0.01	2.15	0.02	23.1	2.12	24.12

Table 2. Mineralogical composition of bauxite samples.

Gibbsite	Boehmite	Kaolinite	Quartz	Goethite	Hematite	Anatase
61.3	3.95	3.15	0.68	18.3	8.86	2.12

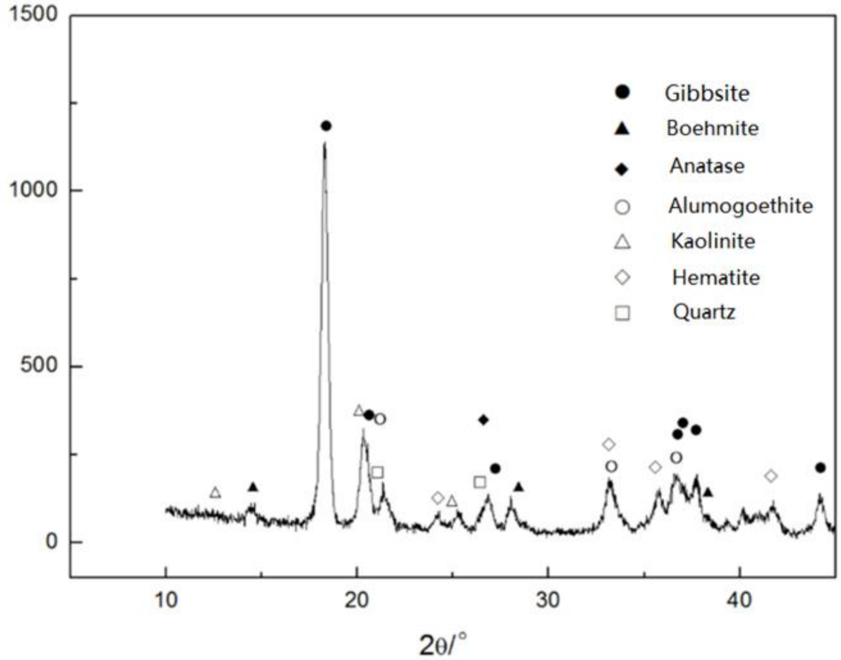

Figure 1. XRD spectrum of bauxite sample.

It can be seen from Figure 1 that obvious characteristic peaks of gibbsite and boehmite are observed in the XRD spectrum, indicating that the bauxite sample contains both alumina species in the following approximate proportions 61.3 % gibbsite and 3.95 % boehmite. The XRD analysis also suggests 18.3 % goethite in which the iron should partly be substituted by alumina to form alumo-goethite.

At digestion temperatures of 150 °C and 250 °C, the available alumina and reactive silica contents of the bauxite were tested experimentally and the results are shown in Table 3.

Table 3. Experimental results of available alumina and reactive silica.

Item	**Units**	**150 ℃**	**250 ℃**
Available alumina	%	40.03	42.86
Reactive silica	%	1.47	2.15

It can be seen from Table 2 and Table 3 that this sample is a typical low-quartz gibbsitic bauxite, which also contains a certain amount of boehmite, so the digestion performance of high temperature and low temperature digestion should be tested to determine the more appropriate process.

3.2 Effect of Digestion Temperature on Digestion Performance

The digestion temperature and composition of test liquor are shown in Table 4, where Na_2Ok represents the caustic concentration, and ak the molar ratio (moles Na_2O per mole Al_2O_3). The experimental results are shown in Figure 2.

Table 4. Digestion test conditions.

No.	Temperature (°C)	Composition of test liquor g/L		
		Al_2O_3	Na_2Ok	ak
Case 01	145	114.0	194.8	2.81
Case 02	270	100.1	170.4	2.8

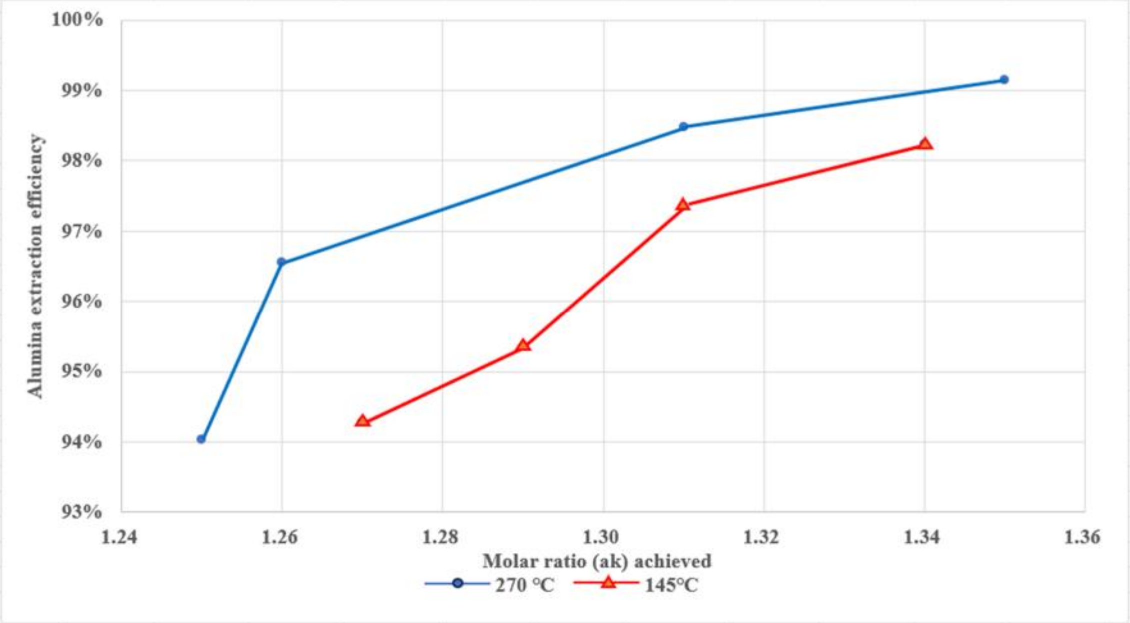

Figure 2. Digestion performance at different temperatures.

It can be seen from Figure 2 that the extraction rate of alumina is usually higher and much lower liquor ak values can be obtained at higher temperature [4-7]. The trend in Figure 2 well illustrates that due to kinetic effects, the extraction rate of alumina increases with the increase of ak in the liquor. In the alumina production process, at a given target ak value of the digested liquor, the extraction efficiency will increase when digestion temperature increases. For example, at an ak target of 1.31, the extraction rate of alumina increases from about 97.35 % at 145 °C to over 98.5 % at 270 °C. And it also can be seen that with the ak value increases, the digestion efficiency difference between high and low temperature is narrowing. Furthermore, a lower bauxite consumption can be achieved under high temperature digestion for the same ak target value compared with low temperature conditions. This is because the boehmite and alumina in alumogoethite can be dissolved under high temperature conditions [8-9].

3.3 Effect of Digestion Temperature and Dilution on Alumina Hydrate Precipitation

After digestion, the slurry is mixed with bauxite residue washing liquor (first washer overflow) and enters the settling system to undergo solid-liquid separation and bauxite residue washing. This leads to dilution and cooling of the slurry where the supersaturation of alumina in the solution increases and auto-precipitation can occur.

A test was carried out where the high and low temperature digested bauxite slurry were diluted, cooled and held at 98 °C for 5 hours. A sample was taken every hour for composition analysis. The ak values are shown in Figure 3.

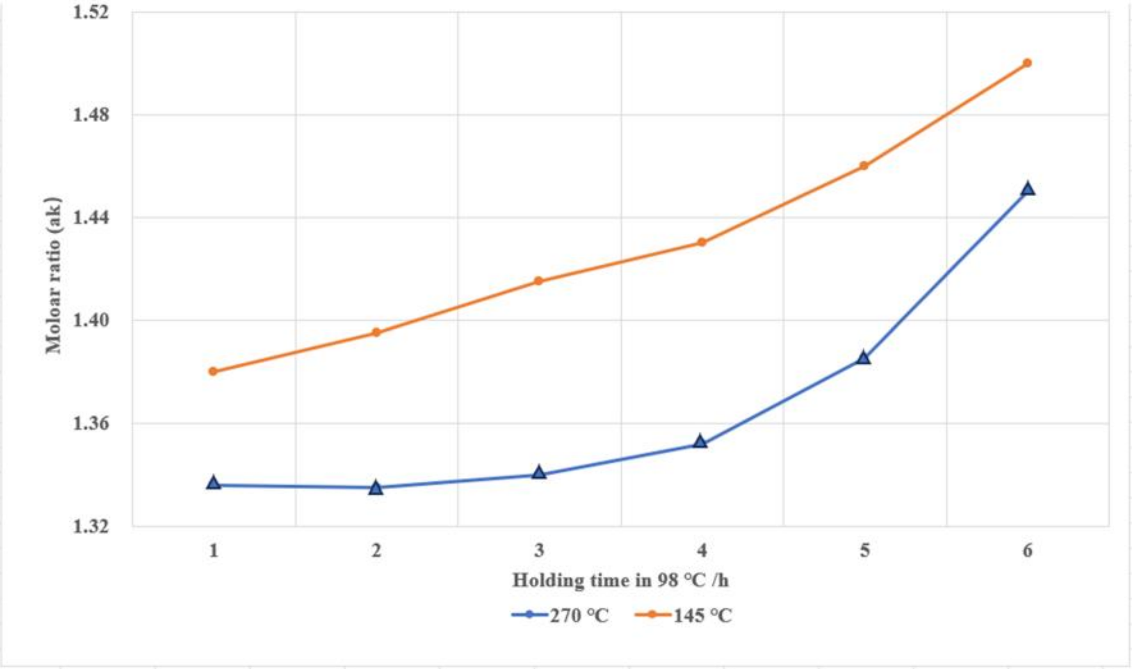

Figure 3. Solution ak value change with holding time.

It can be seen from Figure 3 that during the holding process following the 145 °C digestion, the ak value almost linearly increases with time, from 1.38 to 1.5 after 5 hours. However, the solution obtained by a 270 °C digestion exhibits initial stability, with an ak value that does not change much within the first 2 hours, and it is only after 3 hours that the ak change rate increases (albeit very rapidly), reaching 1.45 after 5 hours.

The reason is likely that gibbsite in the bauxite has not been 100 % extracted during the low temperature digestion, and native gibbsite in the solid phase acts as the seed for precipitation. Under high temperature digestion conditions, gibbsite has basically dissolved out, and only after a long induction period (> 2 hours) does auto-precipitation start [10-11]. However, it can also be seen from Figure 3 that after enough induction period, enough alumina hydrate has been produced from the high-temperature digested slurry which has a high surface area, and the precipitation rate rapidly increased [12]. This suggests that high-efficiency separation equipment during the bauxite residue separation and washing process should be used to decrease the residence time to minimize alumina losses due to precipitation.

3.4 Effect of Digestion Temperature on the Precipitation Process

It is well known that the composition of liquor to precipitation and the precipitation process conditions are both driving the precipitation performance. The precipitation process is divided into two stages: agglomeration and growth. The agglomeration process is the key process to determine the quality index of alumina products, especially impurities in the product and product strength. The most favorable condition for agglomeration is high temperature and high supersaturation. In order to obtain high supersaturation under high temperature, the solution should have a low ak value. When other conditions are the same, the supersaturation of different ak sodium aluminate solutions, calculated by the Rosenberg-Healy formula [13], are shown in Figure 4.

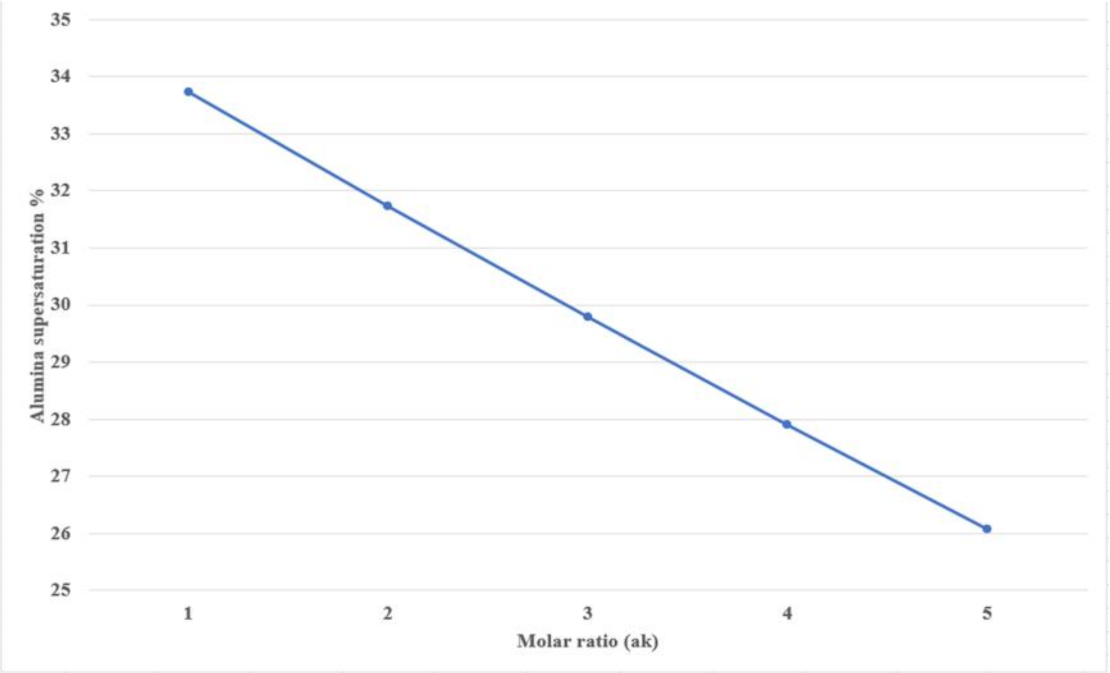

Figure 4. Supersaturation of sodium aluminate solutions at various ak values (Na_2O = 140 g/L, T = 103 °C).

It can be seen from Figure 4 that with the increase of ak value, the solution supersaturation basically decreases in a linear relationship. Furthermore, from Figure 2, higher digestion temperature is needed to achieve higher digestion rate based on the same target ak value of the digested solution. Therefore, a higher digestion temperature leads to a lower digestion ak value, and a high alumina supersaturation, which will provide better conditions to produce a proper sandy alumina.

3.5 Impacts on Bauxite Residue Utilization Potential

Stockpiling and utilization of bauxite residue is a problem faced by most alumina refineries, and recovering iron is one of the main ways of utilizing bauxite residue which can not only reduce the mud volume, but also recover valuable metal iron from bauxite residue. Since Guinea bauxite typically has a high iron content, with Fe_2O_3 proportions of about 23–25 %, it usually has a better potential for iron recovery than bauxite from other countries. However, most iron in Guinea bauxite is goethite which will not react in low temperature digestion, and directly enters the bauxite residue. The iron in bauxite residue is mainly limonite or goethite, which has poor magnetism and cannot be extracted through conventional magnetic separation method, resulting in poor recovery rate. In addition, in low temperature digestion, the alumina extraction rate is also lower, so more alumina will enter the concentrate along with the iron separation process, resulting in poor quality of the concentrate. On the other hand, in high temperature digestion, goethite will react to form hematite. The magnetism is therefore enhanced, which makes iron recovery easier. In addition, less alumina enters the iron concentrate, thereby improving its quality. According to magnetic separation experiments, the iron fraction in concentrate from high temperature bauxite residue is around 54–55 %, and the recovery rate of iron can reach 40 % [14].

To improve iron recovery from bauxite residue produced during low-temperature digestion, iron recovery using magnetization roasting was studied in academia [15] where weakly magnetic limonite or goethite can be converted into magnetite. This improves the magnetic separation and iron in bauxite residue can be efficiently recovered leading to concentrate with 56 % iron at a 46 % yield.

Both high temperature digestion and high temperature magnetization roasting of bauxite residue make crystal transformation of iron oxide in bauxite residue, increasing magnetism to improve the iron recovery rate and the iron concentrate grade.

4. Economic Comparison of Different Digestion Temperatures

According to the experimental results and refinery production experience, the mass balance and energy balance of production process are calculated to obtain the raw material and energy consumption. The production cost under different temperature digestion conditions is calculated according to the recent market price.

4.1 Calculation Conditions

The calculation conditions are shown in Table 5. The caustic concentration of test liquor in low temperature is higher than high temperature digestion. In high temperature digestion, 2 % lime is added to promote the digestion performance of boehmite and the transformation of alumogoethite to hematite.

Table 5. Calculation conditions of the mass and energy balance.

Item	Unit	Case 01	Case 02
Digestion temperature	℃	145	270
Test liquor concentration (Na_2Ok)	g/L	195	170
Lime added	%	0	2
Bauxite residue A/S (Mass Al_2O_3/SiO_2)	-	3.6	1.7
Bauxite residue N/S (Mass Na_2O/SiO_2)	-	0.47	0.52
Digested liquor ak	-	1.31	1.31
Green liquor ak	-	1.36	1.36
Green liquor concentration (Na_2Ok)	g/L	140	140

4.2 Raw Material Consumption

The raw material consumption under different digestion temperatures is shown in Table 6.

Table 6. Raw material consumption under different digestion conditions.

Item	Unit	Case 01	Case 02
Bauxite (Dry)	t/t Al_2O_3	2.64	2.38
Caustic (NaOH 100%)	kg/t Al_2O_3	53	50.2
Lime (as CaO 100%)	kg/t Al_2O_3	10.5	34.3

The bauxite consumption in low temperature digestion is higher than that of high temperature digestion. This is because in high temperature digestion, the digestion rate of gibbsite increases from 97.35 % to 98.5 %, and the alumina in boehmite and alumogoethite will also be partly dissolved. Although the quartz in bauxite also reacts in high temperature and produce sodium silica slag and calcium silica slag, both leading to the loss of alumina and caustic, the quartz fraction in the bauxite is very low at 0.68 %. Therefore, this loss of alumina is lower than the production gain due to dissolved alumina from boehmite and alumogoethite, so the bauxite consumption is still better.

The caustic consumption is also lower in high temperature digestion compared to low temperature digestion. On the one hand, the reaction of quartz can lead to loss of caustic and alumina. However, following a high temperature digestion, the amount of water evaporated in the flash train is higher, so the amount of bauxite residue wash water intake is also higher (about 4.3 t/t dry mud, compared with 2.8 t/t dry mud when using a low temperature digestion process). More wash water will give better washing efficiency, and the soluble caustic loss with the discharged bauxite residue is reduced accordingly. Our calculation for the bauxite consumption show that the caustic consumption for high temperature digestion is slightly lower than for low temperature digestion.

On the other hand, in high temperature digestion, lime is added in the mills to promote the alumina extraction from boehmite and alumogoethite. The lime consumption in high temperature digestion is consequently higher than in a low temperature digestion.

4.3 Energy Consumption

The energy consumption under high and low temperature digestion conditions is shown in Table 7. For total steam consumption, the high temperature digestion is 1.46 t/t Al_2O_3, which is lower than the low temperature digestion of 1.53 t/t Al_2O_3.

Table 7. Energy consumption under different digestion conditions.

Item	Unit	Case 01	Case 02
Steam	t/t Al_2O_3	1.53	1.46
Electricity	kWh/t Al_2O_3	170	175
Calcination	GJ/t Al_2O_3	2.85	2.85

There is sometimes a misunderstanding about steam consumption of high and low temperature digestion. It is often believed that high temperature digestion always consumes more steam than low temperature digestion. Since digestion is a process involving heating and cooling, where the steam flashed in the cooling process will heat the digestion feed slurry (or liquor), and the digestion temperature does not affect the recovery of heat. In short, the digestion steam consumption is related to the temperature of the discharge slurry which is related to the boiling point elevation (BPE) of the solution. The BPE is related to the concentration of the solution. In high temperature digestion process, a lower liquor concentration will be used compared to low temperature digestion where a higher liquor concentration is required to achieve the same performance. Because of the large amount of water flashed following a high temperature digestion, the concentration of the discharged slurry will be higher than that of low temperature digestion, and the temperature of high temperature digestion discharge slurry is also higher but methods can be employed to recover this heat (for example heat some cold process streams). Furthermore, the caustic concentration required for high temperature digestion being lower, less water needs to be evaporated in the evaporation process leading a lower steam consumption. Considering the above, we can state that high temperature digestion can achieve steam consumption close to that of low temperature digestion, and even lower.

However, high temperature digestion requires high pressure steam which requires more energy to produce, while low temperature digestion only requires lower pressure steam. During the steam conversion from high to low pressure, electricity can be generated to meet the production demand. This represents an advantage of a low temperature digestion process.

The production cost under different digestion temperature were calculated based on the current raw material market prices, and the results are shown in Table 8.

Table 8. Raw fuel consumption and production costs for high and low temperature digestions.

Item	Unit /t-Al_2O_3	Δ-value (H-L)	Cost difference (RMB)
Bauxite (Dry)	t	-0.16	-92.8
Caustic (NaOH 100%)	kg	-2.8	-8.68
Lime	kg	47.6	21.42
Steam	t	-0.07	-12.6
Electricity	kWh	5	30.55*
Calcination	GJ	0	0
In total			-62.11

*Note that electricity of own generated has less cost compared to the power purchased from the grid, and the cost difference of electricity is concerned in Table 8.

5. Conclusion

Guinea bauxite is usually gibbsitic, but also contains boehmite and alumogoethite. The mineralogical composition has a great impact on the selection of the digestion temperature. For the bauxite sample tested in this paper, our conclusions are as follows:

i. Digestion temperature has a significant impact on the digested liquor molar ratio (ak) value: to achieve a target digestion extraction efficiency greater than 98 %, ak decreases from 1.34 at 145 °C to 1.30 at 270 °C. In high temperature digestion, a lower digestion ak can be obtained, and the green liquor supersaturation is large, which will better meet the precipitation and crystallization requirement and produce high quality alumina product.

ii. Use of high temperature digestion to treat the same bauxite allows to achieve the same target ak value which results in lower bauxite and caustic consumption, compared to low temperature digestion. This is closely related to the mineralogical alumina and silica phases in the bauxite.

iii. Use of high temperature digestion and optimization of the related process flow, a lower steam consumption can be achieved compared to low temperature digestion.

iv. Goethite will convert to hematite after high temperature digestion treatment, and the iron recovery performance from bauxite residue is therefore better. Iron recovery not only reduces mud stockpiling volume but also recover useful iron for steelmaking. On the other hand, bauxite residue from low temperature digestion can be treated by magnetization roasting, which can also improve iron recovery rate and iron concentrate grade, at a cost.

v. Overall, based on current raw material price, the use of high temperature digestion to treat can lead to lower production cost compared to low temperature.

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