Effect of Bauxite Mineralogy on Bayer Digestion Process Selection

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Abstract

The gibbsite, boehmite, diaspore, kaolin, quartz, goethite and hematite are the main mineralogical composition in bauxite, and the kaolin is the most common form of reactive silica in bauxite at low digestion temperature, while the reactive silica increases due to the quartz attack at middle and high digestion temperature. Three different imported bauxite samples are as an example in the paper. The mineralogical composition of bauxite is analyzed, the available alumina and reactive silica at different temperatures are determined, and the consumption model of raw materials for the three kinds of bauxite at different temperatures are established. According to the bauxite alumina ratio, total soda consumption, mud factor, the cost of bauxite, caustic and lime price, the consumption of raw materials for different bauxite is calculated, and the optimized digestion process is suggested considering suppressed the quartz attack and boehmite reversion.

Keywords: Bauxite mineralogy, reactive silica, raw materials consumption model, digestion process.

1. Introduction

At present, imported bauxites are widely used by alumina refineries in China, mainly from Guinea, Australia, Indonesia, Ghana, Vietnam and Brazil. The mineralogy composition of bauxites is different, and the silica is the most importance of impurities which directly affects the soda consumption, bauxite to alumina consumption (BAR), quality of alumina products, scaling, etc. [1-3]. In this paper, the chemical composition, mineralogical composition, available alumina, reactive silica and quartz attack rate of three kinds of bauxite are studied experimentally. A calculation model of raw material consumption cost was developed by SAMI in order to Bayer digestion process selection. The model was with the chemical and mineralogy composition of bauxites as input conditions, and the quartz attack rate, BAR, total soda loss, mud factor and materials cost were calculated under different temperature.

Supporting the Bayer digestion process selection objective, the concept of whole engineering design process is introduced to provide a new approach for the application of the model. The model introduces a systematic and comprehensive approach to evaluating an optimized process technology through test work, model calculation and economic estimation.

2. Methodology

2.1. Materials

The bauxite samples studied in this paper were provided by different mining supplier. All of them were a mixture of gibbsite and boehmite bauxite. When the three types of ore sample were delivered to the lab, the representative sample was prepared for laboratory digestion sample through homogenization, quartering, splitting, crushing, grinding and screening process.

The synthetic spent liquor used in the digestion test was a mixture of aluminum hydroxide (industrial grade), NaOH (AR), Na_2CO_3 (AR) and sodium silicate (AR).

2.2. Digestion Methods

The digestion tests were performed in the salt bath reactor and oil bath reactor which contained six bombs. The reactor rotated in the speed of 48rpm and the heating mediums were molten salt and oil (Oil bath heating at 150℃ or oil bath heating for over 200℃ are selected) with a high precision of temperature controlling accuracy of ±1℃.

A certain amount of bauxite sample was weighed out by analytical balance. Pour the spent liquor into the bomb in several times together with the bauxite sample and keep stirring during the whole process. Cover the lid and make the lid tightly secured. Put the bomb into the salt bath or oil bath when the molten salt or the oil in the reactor reaching the reaction temperature. Then start the reactor, driving the bomb rotating with the shaft in the molten salt or oil bath. During the rotation process, the slurry in bomb was evenly blended.

Keep the temperature constant to the required time after the reactor reaching the digestion temperature. Cool the bomb rapidly, and then get the digested liquor and residue by solid-liquid separation. Get the red mud by vacuum filtration after washing the residue by 98℃ hot water. The concentration of Al_2O_3, N_T and N_K in digested liquor were measured by chemical titration. The solid compositions were determined by X-Ray Fluorescence (XRF).

2.3. XRF, XRD, LOI

Chemical composition analysis was performed on a Thermo Scientific ARL PERFORM'X 4200 wavelength dispersive X-Ray Fluorescence (XRF) system with molten method.

LOI (100-1000°C) was measured by weight loss of a dried sample using a muffle.

Mineralogical analysis was measured for bauxite samples and residue samples using a Shimadzu Corporation X-Ray Diffraction (XRD) XRD-7000 X-ray diffractometer.

3. Results and Discussion

3.1. Characterization of the Bauxites

The chemical analysis of the major elements present in three bauxites was shown in Table 1. Bauxite was rich in iron oxide, silica oxide and alumina. Mineralogical analysis allowed the identification of several mineral composition (Table 2) and the XRD diffraction charts were shown in Figure 1-3.

Table 1. Major chemical components of the three bauxites（wt%).

No.	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	Na_2O	CaO	K_2O	LOI
Bauxite-1	50.43	10.68	8.65	2.98	0.04	0.069	0.017	25.61
Bauxite-2	46.33	1.73	23.20	2.14	0.04	0.072	0.023	25.87
Bauxite-3	45.24	19.42	7.14	0.90	0.03	0.046	0.017	24.91

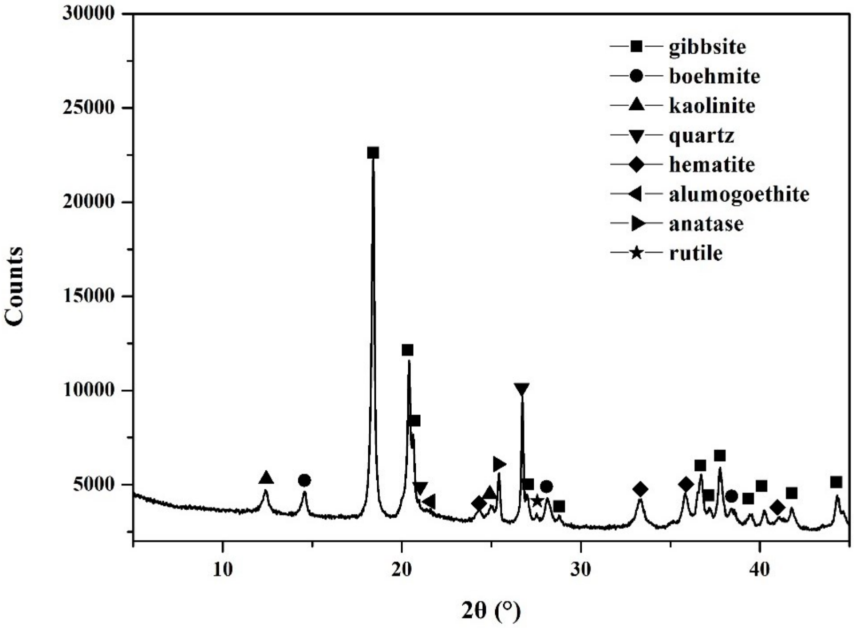

Figure 1. X-ray diffraction pattern of Bauxite-1

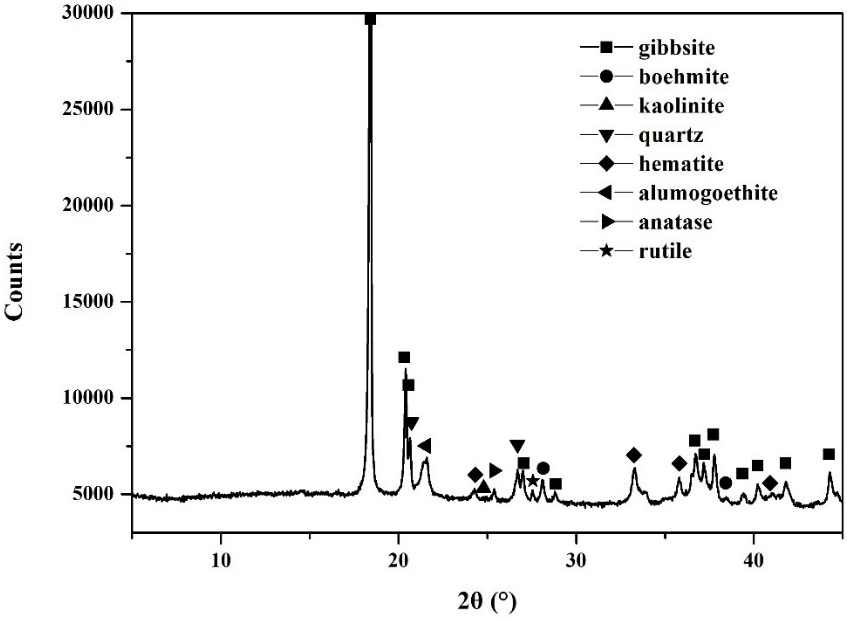

Figure 2. X-ray diffraction pattern of Bauxite-2.

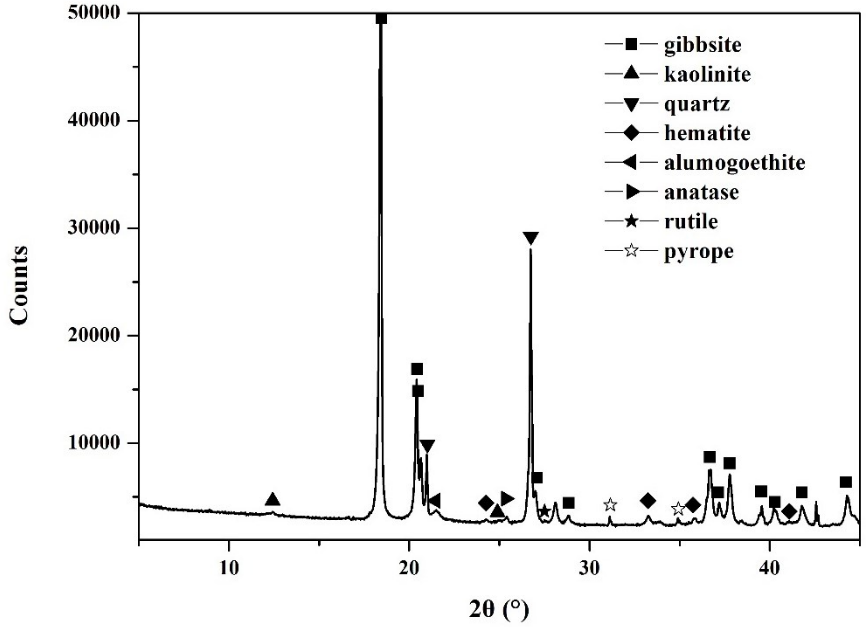

Figure 3. X-ray diffraction pattern of Bauxite-3.

Table 2. Mineralogical composition of the three samples（wt%).

No.	Gibbsite	Boehmite	Hematite	Alumogoethite	Kaolin	Rutile/ Anatase	Quartz
Bauxite-1	61.33	5.77	8.10	1.24	12.36	2.98	4.93
Bauxite-2	62.94	4.23	9.87	15.95	1.66	2.14	0.96
Bauxite-3	67.55	0	2.90	5.91	1.94	0.90	18.52

Figure 1-3 showed that all three kinds of bauxites were typical trihydrate type due to the strong characteristic peaks existing in the XRD chart. The characteristic diffraction peaks of boehmite were also found in Bauxite-1 and 2, but no characteristic diffraction peaks of boehmite were detected in Bauxite-3, while a strong characteristic diffraction peak of quartz was detected.

Table 2 indicated the presence of gibbsite, boehmite, kaolin, quartz, hematite and alumogoethite, etc. The quartz content in bauxite-3 was as high as 18.52%, quartz content in bauxite-1 was 4.93%, and quartz content in Bauxite-2 was only 0.96%. The phase composition of ore directly affects the choice of digestion process and production cost. Among them, silica minerals are the most harmful impurities in the production of alumina by Bayer process, including kaolinite, illite, quartz, chlorite, pyrophyllite and their hydrates. Silica in kaolinite is usually called low-temperature reactive SiO_2. It starts to reaction with spent liquor in the stage of slurry preparation and pre-desilication. It is the main harmful impurity in low-temperature Bayer process. Illite and quartz have good crystallinity and low reactivity. They begin to react slowly when the temperature is higher than 160 ~ 180 °C. In addition to silica minerals, another important phase affecting Bayer process production is iron minerals, especially, the goethite has adverse effects on digestion efficiency, settling and washing performance and product quality [4-5].

3.2. Available Alumina and Reactive Silica

There is no analytical technique that can accurately measure the gibbsite and boehmite in bauxite directly and the most common approach is experimental laboratory procedures (digestion or leaching tests) which can provide a good estimation of the bauxite mineralogy and the available alumina.

THA digestion test was performed with a final target A/C between 0.55 and 0.65 to ensure that no boehmite was dissolved but that there was still sufficient driving force to dissolve all gibbsite available, while TAA target A/C from 0.2 to 0.3. The THA, TAA and reactive silica results were given in Table 3.

Table 3. The THA, TAA and reactive silica results of three bauxites.

Items	Bauxite-1	Bauxite-2	Bauxite-3
THA	39.21	41.75	42.33
TAA	44.22	43.52	39.22
$R_{SiO2\ (150°C)}$	5.81	0.60	1.26

Digestion balances, using the "Tie element" method and calculating the alumina extraction based on the XRF analysis of both the bauxite feed and the residue mud, usually provides the most accurate determination of available alumina. The THA of bauxite-1 was 39.21%, while the TAA was 44.22%, and the reactive silica at 150°C was 5.81% measured by weak acid leaching of residue of THA. The THA, TAA and reactive silica of bauxite-2 were 41.75%, 43.52% and 0.60% respectively. The calculation results showed that there was a small amount of boehmite in Bauxite-1 and Bauxite-2 which had a good agree with the XRD chart in Figure 1-2.

In the Bayer process selection, it is impossible to judge whether the bauxite is suitable for low, medium or high temperature digestion process only by THA and TAA. This is because the content of active silica in the bauxite varies with different digestion temperatures. The quartz attack can cause alumina and soda losses by reacting with sodium aluminate solution at high temperature. The reaction of kaolin and quartz can be followed by Equations (1-3) [6].

$$Al_2O_3.2SiO_2.2H_2O + 6NaOH + aq \rightarrow 2NaAl(OH)_4 + 2Na_2H_2SiO_4 + aq \quad (1)$$

$$SiO_2 + 2NaOH + aq \rightarrow 2Na_2H_2SiO_4 + aq \quad (2)$$

$$6SiO_2 + 6NaAl(OH)_4 + Na_2X \rightarrow Na_6[Al_6Si_6O_{24}].Na_2X.6H_2O + 6H_2O \quad (3)$$

Which the X were CO_3^{2-}, SO_4^{2-}, Cl^- or $Al\ (OH)_4^-$

Alumina loss due to quartz attack is 0.5mol/mol based on the DSP composition. The relationship between boehmite and quartz attack should be considered using the high digestion temperature. So, it is important to calculate the quartz attack rate at the different temperature as showing in Figure 4. The quartz attack rate is related to the temperature, retention time, free caustic concentration and molar ratio of digestion liquor [7]. Figure 4 showed that quartz attack hardly reacted when the temperature was below 150°C. When the temperature was above 150~180°C, quartz began to react. The reaction ratio increases gradually, as the temperature rises. When the temperature was above 280~300°C, the reaction rate of quartz was close to 100%.

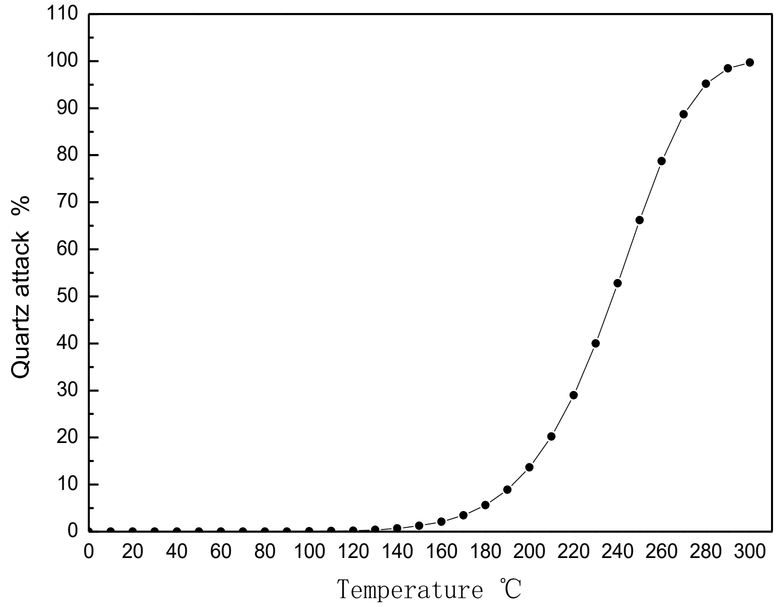

Figure 4. The quartz attack at different temperature.

Based on the above analysis, the ratio of reactive silica of three bauxites was calculated under three digestion conditions (150℃ 30 min, 245℃ 20 min, 280℃ 10 min), respectively, as shown in Figure 5.

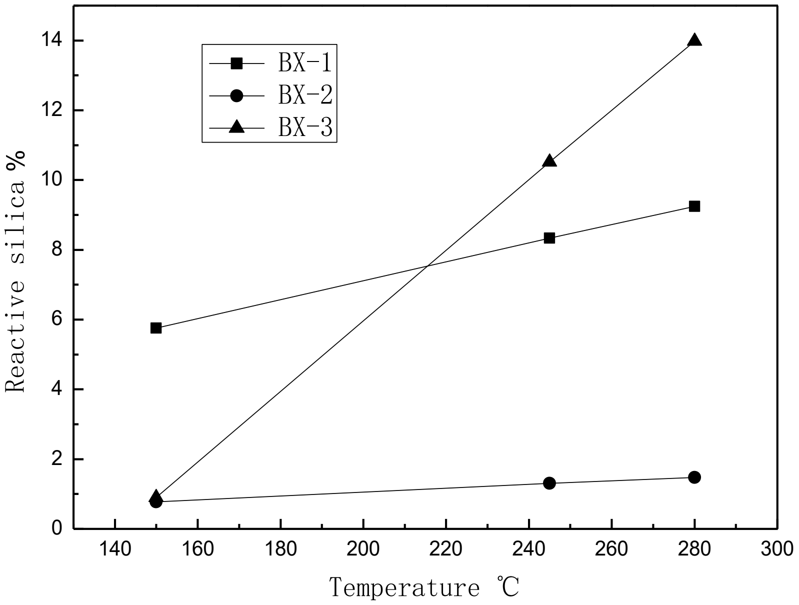

Figure 5. The reactive silica ratio of the three bauxites at different temperature.

Figure 5 indicated that the reactive silica of the three bauxites increased with the increase of temperature. Among them, the increase of bauxite-3 was the largest and that of bauxite-2 was the smallest.

3.3. Raw Materials Consumption Cost Model

A calculation model of raw material consumption cost was developed by SAMI in order to Bayer digestion process selection. The model was with the chemical and mineralogy composition of bauxites as input conditions, and the quartz attack rate, BAR, total soda loss, and mud factor were calculated under the different temperature. The lime addition affection, retention time and target molar ratio were also included in the model. The BAR and total soda loss were calculated by the model, as showing in Figure 6 and Figure 7.

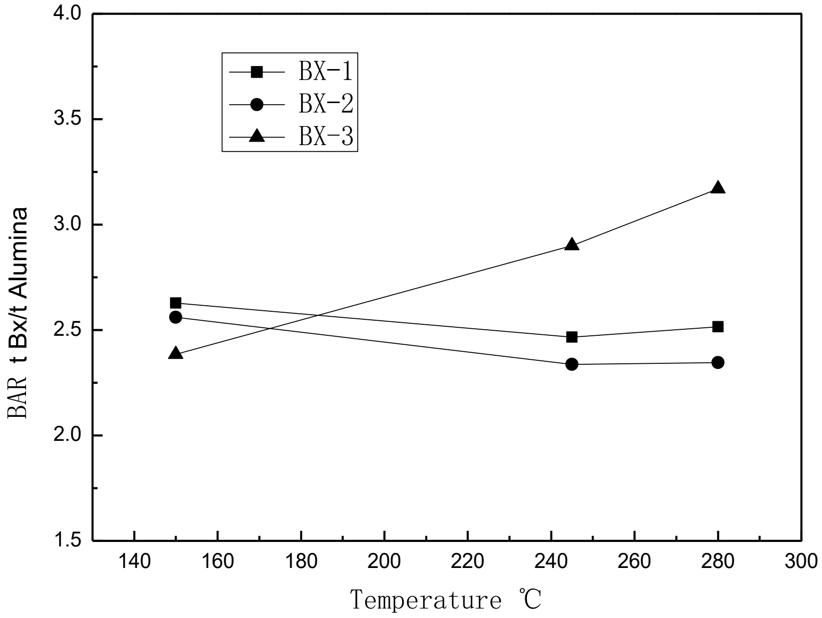

Figure 6. The BAR of the three bauxites at different temperature.

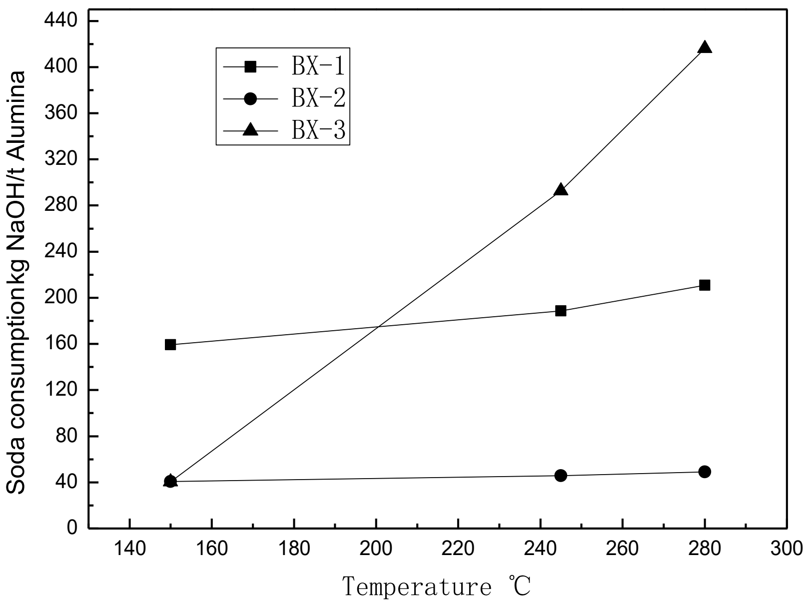

Figure 7. The total soda loss of the three bauxites at different temperature.

It can be seen from Figure 6 and Figure 7, the bauxite consumption and total soda loss of three kinds of bauxite samples showed different trends under different digestion conditions. The BAR of Bauxite-1 and Bauxite-2 decreased firstly and then increased slightly with the increase of temperature. The BAR of Bauxite-1 decreased from 2.63t Bx/t alumina at 150°C to 2.47t Bx/t alumina at 245°C and increased to 2.51t Bx/t alumina at 280°C. This was because Bauxite-1 contained a small amount of boehmite, which dissolved alumina from boehmite with the increase of temperature. meanwhile, the alumina loss and soda consumption increased due to the quartz attack. The boehmite basically dissolved completely at the digestion temperature of 245°C. The reaction rate of quartz increased resulting in higher BAR and total soda loss, with the temperature raised to 280°C.

The BAR was 2.63tBx/t alumina and the total soda loss was 159.36kg/t alumina at low temperature 150°Cwhen the BAR was 2.47 t Bx /t alumina and the total soda loss was 188.59kg/t alumina at medium temperature 245°C. At this time, the total soda loss increased with the increase of temperature and the decreased of BAR. raw material prices of bauxite price, caustic price, lime price, flocculant price, red mud storage cost and grinding cost were input in the model, and the raw materials consumption cost under different digestion conditions was calculated through the model, as shown in Figure 8.

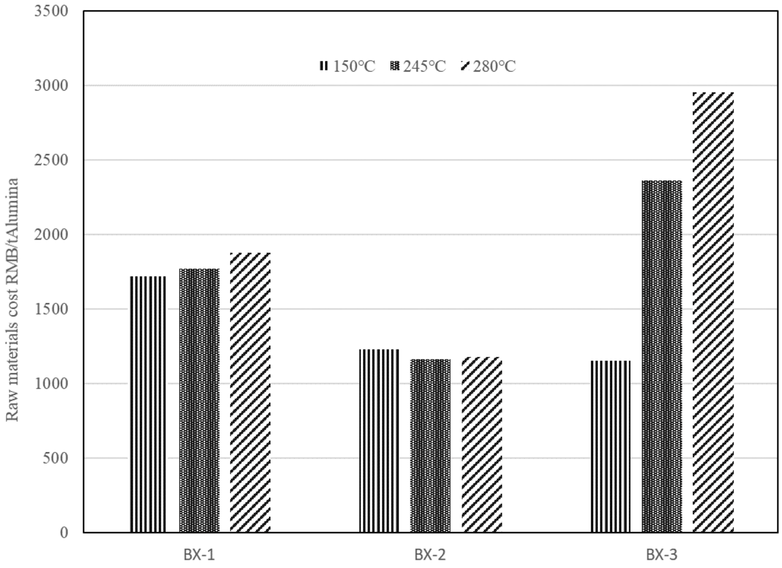

Figure 8. The raw materials cost of three samples at different temperature.

Figure 8 showed that the cost of raw material consumption of Bauxite-1 and Bauxite-3 was the lowest at 150°C, while the cost of raw material consumption of Bauxite-2 was the lowest at 245°C under the same benchmark raw material price.

4. Conclusions

Bauxite-1 and Bauxite-2 were typical gibbsite/boehmite mixed bauxite, and Bauxite-3 had a high quartz content without boehmite. The medium temperature digestion was a more effective digestion technology for the sample with high content of boehmite. Especially when the content of quartz was low, the alumina extracted from boehmite was enough to compensate for the loss of alumina caused by quartz reaction.

The mineralogical composition, especially the content of reactive silica content, had a great influence on the choice of dissolution process. The reaction rate of quartz was related to temperature, retention time, free caustic concentration and molar ratio of solution.

Based on the experimental data, the calculation models of raw material consumption for different bauxites were established. Under the same basic raw material price, low-temperature Bayer process was suitable for treating Bauxite-1 and Bauxite-3. When Bauxite-2 had the lowest raw materials consumption at medium temperature.

The appropriate digestion temperature could be preliminarily determined by the calculation model of raw materials consumption. In the actual engineering design process, besides the above process selection issues, the project investment, depreciation of fixed assets, the difficulty of raw materials acquisition, site location, water source and other issues needed to be considered comprehensively to determine the overall project design plan.

5. References

1. Gu Songqing, Chinese bauxite and its influences on alumina production in China, *Light Metals* 2008, 79-83.
2. Eric Tizon, Philippe Clerin and Benoit Cristo, Effect of predesilication and digestion conditions on silica level in Bayer liquor, *Light Metals* 2004, 9-14.
3. Edgar Gasafi, Alessio Scarsella, Vladimir Hartman, etc. The processing of high quartz bauxite, *Light Metals* 2013, 217-221.
4. Wilmon Wallen-Bryan, Characterization of goethites in poor-setting Jamaican Bayer muds, *Light Metals* 1998, 5-9.
5. Roach, G. and Jamieson, E., Effect of bauxite and digestion conditions on iron in SGA, *Proceedings of the 6th International Alumina Quality Workshop* 2002, 340-345.
6. Peter G. Smith, etc., The composition of DSP formed under predesilication and high temperature Bayer digestion conditions, *Light Metals* 2001, 1-7.
7. Oku, T., and Yamada, K, The dissolution rate of quartz and the rate of desilication in the Bayer liquor, *Light Metals* 1971, 31-45.