Digestion Laws of Alumina and Organic Carbon in High-Organic Bauxite

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Abstract

A typical low-grade, high-organic bauxite was used to investigate the impacts of lime dosage, digestion temperature, digestion time, molecular ratio of digested liquor (α_k), and caustic soda concentration of spent liquor on the digestion behaviour of alumina and organic carbon in the bauxites. The results demonstrated that the digestion rates of alumina and organic carbon initially increased and then decreased with the increase in lime dosage. Both alumina and organic carbon digestion rates increased with rising digestion temperature. The digestion time, molecular ratio of digested liquor, and caustic soda concentration in recycled spent liquor had negligible impacts on the alumina digestion rate. However, the organic carbon digestion rate first increased and then decreased with extended digestion time and rose initially with increasing caustic soda concentration before stabilizing. In order to achieve higher alumina digestion rates and lower organic carbon digestion rates, with optimal digestion conditions, the actual alumina digestion rate reached approximately 73.2 %, corresponding to a relative digestion rate of around 96.3 %, and the organic carbon digestion rate was about 15 %. This study provides valuable insights for the utilization of similar low-grade, high-organic bauxites.

Keywords: High organic content, Low-grade bauxite, Digestion behaviour.

1. Introduction

As a leading producer of alumina, China's dependence on imported bauxite for alumina production reached as high as 63 % in 2024. However, due to the high prices and transportation costs associated with imported bauxite, inland alumina producers in Shanxi, Henan, Guizhou, and other regions in China have been compelled to use inexpensive but extremely poor low-grade bauxites. Some alumina producers employing the Bayer process have started using bauxite with alumina-to-silica ratios (A/S) below 4.0 [1, 2]. Some of these low-grade bauxites also have high organic content. The effective management of organics is critical for ensuring safe and stable alumina production. Although numerous studies have addressed the removal of organics in alumina production, assessing the digestion behaviour of organic carbon during bauxite digestion is a prerequisite for effectively balancing organic inputs and outputs in the production process and determining the scale of necessary organic removal operating units. Therefore, in the processing of low-grade, high-organic bauxite, it is essential to monitor not only alumina digestion but also the digestion of organics.

In this study, a low-grade bauxite with high organic impurity content was selected as raw material to investigate alumina digestion behaviours. Concurrently, the digestion behaviours of organic carbon in the bauxite were also studied, aiming to provide guidance and reference for alumina refineries seeking quality improvement and efficiency enhancement.

2. Material and Method

2.1 Test Raw Materials

2.1.1 Bauxite

The A/S ratio of the bauxite used in the test was 4.16, and its chemical composition and phase composition are shown in Tables 1 and 2.

Table 1. Chemical composition of bauxite (%).

Al_2O_3	SiO_2	Fe_2O_3	TiO_2	K_2O	Na_2O	CaO	MgO	LOI	TOC
49.85	11.97	20.74	2.05	0.81	0.032	0.057	0.93	11.94	0.48

Table 2. Phase composition of bauxite.

Phase	wt %	Phase	wt %
Diaspore	48.5	Goethite	7.0
Chlorite	22.0	Hematite	4.0
Illite	7.5	Pyrite	1.1
Kaolinite	4.0	Anatase	1.7
Quartz	1.5	Rutile	0.3

2.1.2 Lime

After primary crushing treatment, the lime is mixed evenly and split before the samples are ground, passing through 100-mesh screen, sealed in bags, and then stored in a dryer. The chemical composition of the lime samples is shown in Table 3.

Table 3. Chemical composition of lime (%).

$CaO_{总}$	CaO_f	SiO_2	MgO
90.61	79.63	1.71	1.40

2.1.3 Circulating Spent Liquor

The chemical composition of the circulating spent liquor used in the test is shown in Table 4.

Table 4. Chemical composition of circulating spent liquor (g/L).

Na_2O_T	Na_2O_K	Al_2O_3
259.30	224.16	131.28

2.2 Test Method

For the simulated working conditions of the bauxite used in the digestion test, it is divided into two stages: pre-desilication is performed first, before high-pressure digestion. The pre-desilication of bauxite is carried out in a steel autoclave heated by glycerol, and the high-pressure digestion of the pre-desilicated slurry is carried out in a steel autoclave heated by molten salt. According to the proportioning requirements, add a certain proportion of spent liquor for digestion, bauxite, and lime to the autoclave, after agitating the slurry evenly, cover and seal it, place it in a steel frame that can rotate, put it in an oil bath that has been heated to a preset temperature, and agitate immediately for pre-desilication. When the preset time is reached, remove the steel ball and immediately place it in water to rinse off the glycerol adhering to the steel ball, then place it in a molten salt furnace that has reached the set temperature for digestion. Remove the steel ball after the preset digestion time is reached, immediately place it in water to cool rapidly, and then separate digestion liquor from bauxite residue by using vacuum filtration, and analyse the chemical composition of the digestion liquor, and the chemical composition of bauxite residue is analysed after it's washed and dried.

3. Results and Discussion

3.1 The Impact of Lime Dosage on the Digestion Results of Bauxite

The lime dosage is calculated based on the percentage of dry ore weight. After the addition of a specific quantity of spent liquor, the slurry undergoes pre-desilication at 90 °C for 6 hours. Upon completion of the pre-desilication process, the steel autoclave is transferred to a molten salt furnace maintained at 265 °C for digestion, which lasts 60 minutes. The test results are shown in Figures 1, 2 and 3.

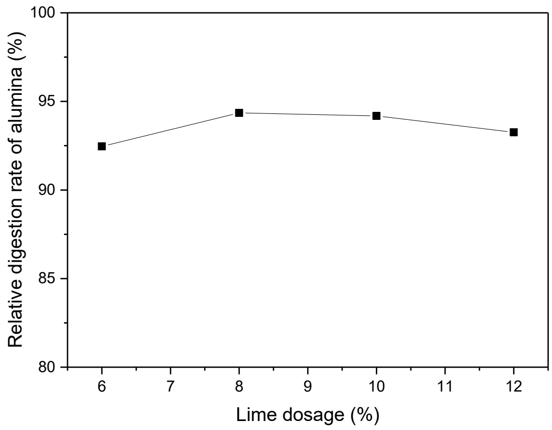

Figure 1. The impact of lime dosage on the digestion rate of alumina.

It can be seen from Figure 1 that the digestion rate of alumina first increases and then decreases as the lime dosage increases, indicating that there is a balance point in terms of the role of lime in both eliminating alumina digestion resistance and causing alumina loss. Based on the test data, the appropriate lime dosage for digestion of bauxite is around 9 %.

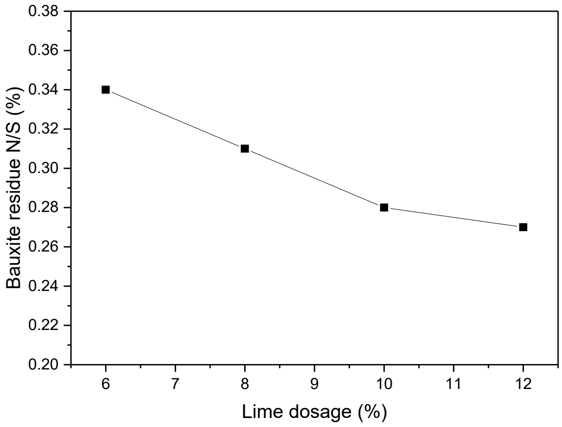

Figure 2. The impact of lime dosage on the N/S ratio of digested bauxite residue.

Results shown in Figure 2 indicate that the N/S ratio of digested bauxite residue shows a significant downward trend as the lime dosage increases, and it shows a slowing downward trend when the lime dosage exceeds 10 %. In consideration of the impact of lime dosage on the digestion rate of alumina from the ore, an appropriate lime addition within the range of 8 to 10 % can be slightly increased during the digestion process in order to reduce soda consumption.

The correlation curve between the digestion rate of organic carbon and the lime dosage under the above digestion conditions is shown in Figure 3.

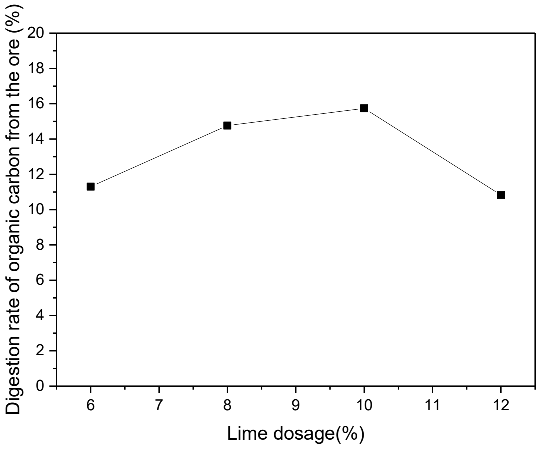

Figure 3. The impact of lime dosage on the digestion rate of organic carbon

Experimental data shown in Figure 3 suggest that the reaction rate of organic carbon from the ore first increases and then decreases as the lime dosage increases. Under the front-end test conditions, the digestion rate of organic carbon from the ore increases significantly from 11.30 to 14.76 %. In the mid-end test, the digestion rate of organic carbon from the ore increases slowly, and the reaction rate of organic carbon is 15.74 % when the lime dosage is 10 %. Meanwhile, the digestion rate of organic carbon from the ore shows a significant downward trend when the lime dosage further increases. When the lime dosage is 12 %, the organic carbon digestion rate dropped to 10.83 %. Therefore, for digestion and material preparation, the digestion rate of organic carbon from the ore changes by approximately 15 % when the lime dosage in the ore is around 9 %.

3.2 The Impact of the Molecular Ratio of Digestion Liquor on the Digestion Results

The lime dosage is set at 8 % of the dry ore weight. After the aforementioned pre-desilication, the ore undergoes digestion test at a temperature of 265 °C for 60 minutes. The impact of different molecular ratios of digestion liquors on the ore digestion results is observed. The test results are shown in Figures 4 and 5.

As can be seen from Figure 4, the actual digestion rate of alumina increases as the molecular ratio of digestion liquor increases, and it remains basically unchanged after the molecular ratio of digestion liquor is greater than 1.45. The actual digestion rate of alumina is 73.35 % and the relative digestion rate is 96.53 % when the molecular ratio of digestion liquor is 1.50. The molecular ratio of digestion liquor has no significant impact on the digestion rate of alumina when it is greater than 1.35. Based on the test results and production practice, the appropriate molecular ratio of digestion liquor is approximately 1.37 for the bauxite digestion.

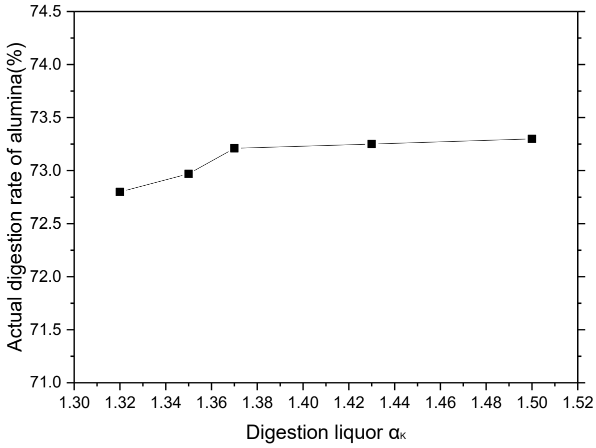

Figure 4. Impact of the molecular ratio of digestion liquor on digestion results.

The correlation curve between the digestion rate of organic carbon from the ore and the molecular ratio of digestion liquor under the above digestion conditions is shown in Figure 5.

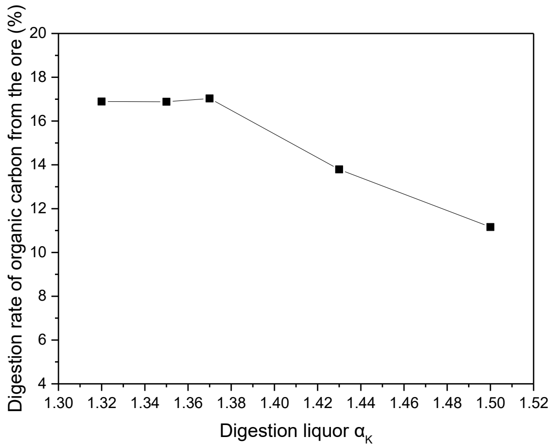

Figure 5. Impact of the molecular ratio of digestion liquor on the digestion rate of organic carbon from the ore.

It can be noticed, in Figure 5, that when the molecular ratio of digestion liquor is lower than 1.37, it has little impact on the digestion rate of organic carbon from the ore, which is around 17 %; when the molecular ratio of digestion liquor is greater than 1.37, the digestion rate of organic carbon from the ore shows a significant downward trend. When the molecular ratio of digestion liquor is between 1.37 and 1.40, the digestion rate of organic carbon from the ore is approximately 15 %.

3.3 The Impact of Digestion Temperature on Digestion Results

The lime dosage, molecular ratio of digestion liquor and digestion time are set. The ore is digested at different temperatures after pre-desilication under the aforementioned conditions (see Figures 6 and 7).

It can be seen, from Figure 6, that when the digestion temperature is below 265 °C, the digestion rate of alumina gradually increases as the temperature increases; when the digestion temperature exceeds 265 °C, the digestion rate of alumina remains essentially unchanged as the temperature increases, which is approximately 73 %. Therefore, a digestion temperature of approximately 265 °C is adequate to achieve a high digestion rate of alumina. Under this temperature, the relative digestion rate can exceed 96.40 %.

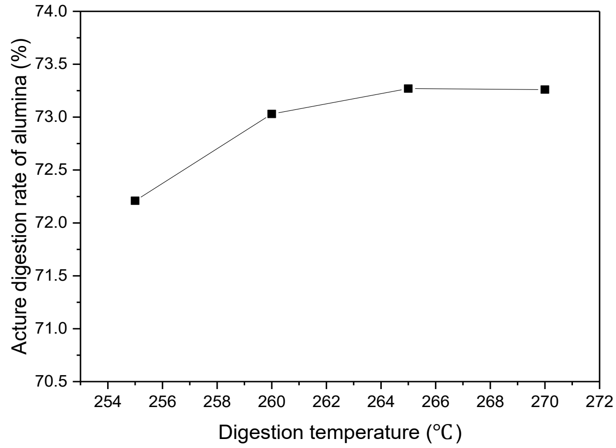

Figure 6. The impact of digestion temperature on the digestion rate of alumina.

The correlation curve between the digestion rate of organic carbon and the digestion temperature under the above digestion conditions is shown in Figure 7 below.

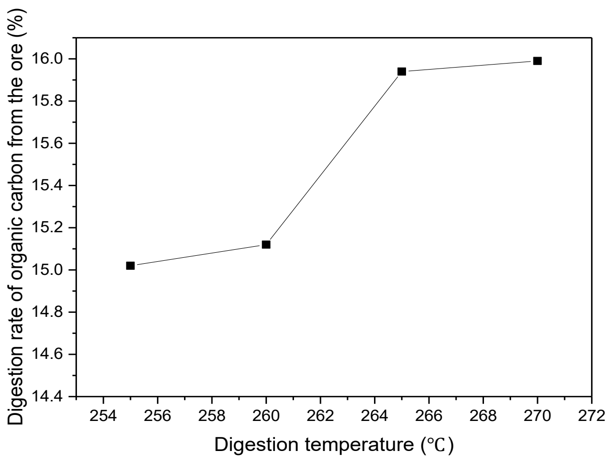

Figure 7. The impact of digestion temperature on the digestion rate of organic carbon.

Results shown in Figure 7 suggest that the reaction rate of organic carbon from the ore increases gradually at first, then rises rapidly, and finally increases slowly again with the elevation of digestion temperature. When the reaction rate of organic carbon increases rapidly, the digestion temperature rises from 260 to 265 °C, and the reaction rate of organic carbon from the ore increases from 15.12 to 15.94 %. When the digestion temperature is further increased, the reaction rate of organic carbon tends to stabilize.

3.4 The Impact of Digestion Time on Digestion Results

The lime dosage, digestion temperature and other conditions are set. The results of alumina digestion tests conducted after pre-desilication of the ore under the aforementioned conditions, at varying digestion times, are presented in Figure 8.

As shown in Figure 8, when the digestion time of the ore is less than 40 minutes at the set digestion temperature, the digestion rate of alumina gradually increases as the digestion time extends; and then the digestion rate of alumina from the ore remains essentially unchanged as the digestion time extends, with the actual digestion rate of alumina remaining at around 73.05 %, and a relative digestion rate of around 96.50 %. To enhance the operational efficiency of the equipment while ensuring an adequate digestion rate of alumina, a digestion time of 50 minutes is deemed sufficient. Under these conditions, the actual digestion rate of alumina reaches approximately 73 %, with a relative digestion rate of about 96 %.

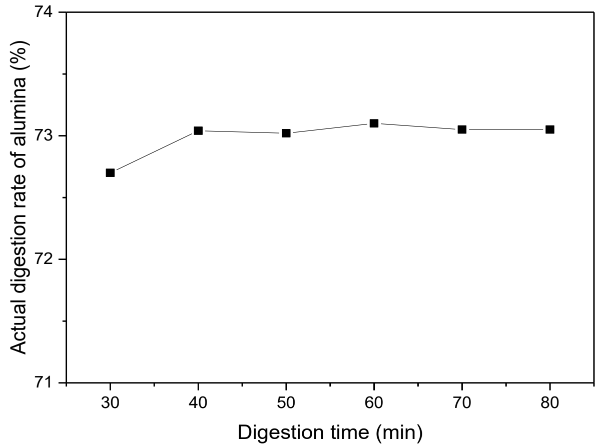

Figure 8. Impact of digestion time on the digestion rate of alumina.

The correlation curve between the digestion rate of organic carbon from the ore and digestion time under the above reaction conditions is shown in Figure 9.

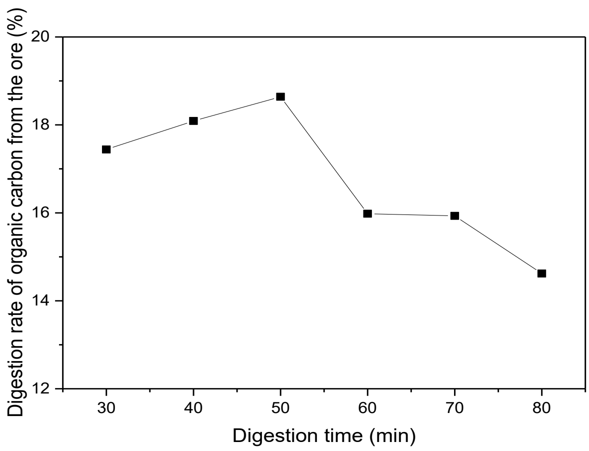

Figure 9. Impact of digestion time on the digestion rate of organic carbon.

As can be seen from Figure 9, when the digestion time is less than 50 minutes at the set digestion temperature, the reaction rate of organic carbon gradually increases as the digestion time extends. Subsequently, with the extension of digestion time, the digestion rate of organic carbon from the ore exhibits a gradual decline. When the digestion time reaches 60 minutes, the digestion rate of organic carbon is approximately 16 %. Based on the results of the digestion rate of organic carbon from the ore, it is advisable to extend the digestion duration to as close as possible to 60 minutes, while maintaining a minimum of 50 minutes, in order to minimize the amount of organic matter entering the digestion solution.

3.5 The Impact of the Caustic Soda Concentration of Spent Liquor on Digestion Results

The digestion temperature, digestion time, digestion liquor α_k, and lime dosage and other conditions are set. After the ore undergoes pre-desilication under the aforementioned conditions, the caustic soda concentration of spent liquor is adjusted, and the results of alumina digestion test are shown in Figure 10.

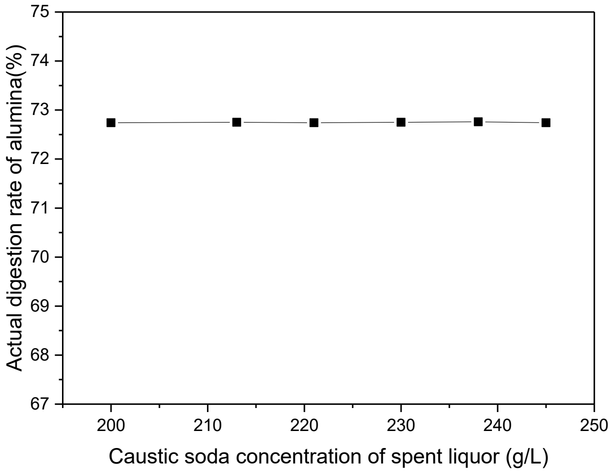

Figure 10. Impact of spent liquor caustic concentration on the digestion rate of alumina.

As can be seen from Figure 10, the actual digestion rate of alumina is approximately 73 % under the set digestion conditions, and the relative digestion rate is approximately 96 %, indicating that the caustic soda concentration of spent liquor has little impact on the digestion results of alumina from the ore. The appropriate caustic soda concentration of spent liquor is approximately 220 g/L in order to reduce evaporation load and energy consumption while enhancing soda recycling efficiency.

The correlation curve between the digestion rate of organic carbon and the caustic soda concentration of spent liquor under the above digestion conditions is shown in Figure 11.

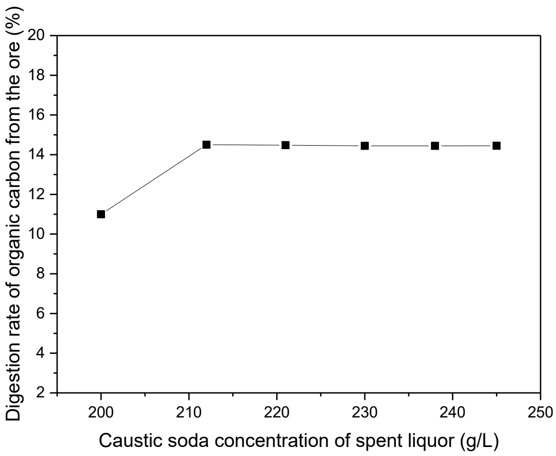

Figure 11. Impact of spent liquor caustic concentration on organic carbon digestion rate.

It can be seen from Figure 11 that the digestion rate of organic carbon first increases and then remains basically unchanged as the caustic soda concentration of spent liquor increases. Specifically, the digestion rate of organic carbon from the ore increases from 11 to 14.50 % when the caustic soda concentration of spent liquor increases from 199 to 212 g/L. Later as the caustic soda concentration of spent liquor continues to increase further, the digestion rate of organic carbon remains essentially unchanged, stabilizing at around 14.50 %.

3.6 Comparison of the Digestion Performance of Bauxite in this Study with Other Bauxites of the Same Type

The digestion temperature, digestion time, digestion liquor α_k, lime dosage, caustic soda concentration in circulating spent liquor and other conditions are set. The digestion rates of alumina and organic carbon from the diaspore used in this study were compared with those of several other diaspore. The results of these tests are summarized in Table 5.

According to the comparison between the bauxite used in this study and bauxite 1 in Table 5, under the same digestion conditions, when the content of diaspore in the ore phase and the A/S ratio of the ore are similar, there is little difference between the digestion rates of alumina in the two ores, but the digestion rates of organic carbon differ significantly. According to the comparison between the bauxite used in this study and bauxite 2, there is significant difference in the content of organic carbon in the ores, but the digestion rates of organic carbon are almost the same. The content of organic carbon in bauxite 1 and bauxite 2 is similar, but the digestion rates of organic carbon vary greatly. The digestion results of these different ores indicate that the digestion efficiency of organic carbon is not directly correlated with its content in the ore. Instead, it may be more closely influenced by the type and occurrence state of organic carbon within the ore. Furthermore, neither the content of organic carbon nor its digestion rate shows a direct relationship with the digestion rate of alumina from the ore.

Table 5. Comparison of the alumina and organic carbon digestion performance between the bauxite used in this study and other bauxites.

Types of ores	The main phase composition and chemical composition of bauxites							Test results		
	Diaspore (%)	Chlorite (%)	Gibbsite (%)	Al_2O_3 (%)	SiO_2 (%)	A/S	TOC (%)	Actual digestion rate of alumina (%)	Relative digestion rate of alumina (%)	Digestion rate of organic carbon (%)
The ore in this study	48.5	22.0	/	49.85	11.97	4.16	0.48	70.37	92.61	15.72
Bauxite 1	49.0	41.0	/	50.98	10.99	4.64	0.18	71.56	91.23	33.21
Bauxite 2	60.0	20.0	/	57.83	7.94	7.28	0.22	77.86	90.26	15.11
Bauxite 3	38.5	33.0	3.0	41.34	7.93	5.21	0.03	75.03	92.84	7.43

4. Conclusions

1) To achieve a high alumina digestion rate while minimizing the digestion of organic carbon from the ore, it is essential to systematically compare the digestion conditions and outcomes to identify the optimal process. Under the selected optimal conditions within the scope of this test, the actual alumina digestion rate reaches approximately 73.2 %, with a corresponding relative digestion rate of approximately 96.3 %.

2) When the bauxite is digested and prepared for production under appropriate lime addition conditions, the organic carbon digestion rate from the ore ranges between 14.76 % and 15.74 %. When the molecular ratio of the digestion solution is below 1.37 and the caustic concentration of the spent liquor exceeds 210 g/L, these parameters have minimal influence on the organic carbon digestion rate. As the digestion temperature increases, the reaction rate of organic carbon in the ore exhibits a pattern of gradual increase, followed by a rapid rise, and then another gradual increase. With prolonged digestion time, the reaction rate initially increases and subsequently decreases. Under the optimal digestion conditions for alumina in the ore, the reaction rate of organic carbon is approximately 15 %.

5. Possible Further Research

1) In order to make a scientific and comprehensive technoeconomic assessment, track specific indicators of the ore in the production of alumina, including technical and economic indicators.

2) Conduct deep optimization of the process parameters that affect the digestion of alumina from the ore based on the test results, further reducing bauxite and soda consumption.

3) Follow up the accumulation and changes of organics in sodium aluminate liquor in the production, and conduct research and application on technologies for the economical and efficient removal of organics.

6. Acknowledgments

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