

Article

Reduction of Potassium in Alumina Product During Seeded Precipitation

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Abstract

In the alumina production process, potassium from bauxite transfers to the alumina product through digestion and precipitation, posing significant risks to the subsequent aluminum electrolysis. The current understanding of this transfer behavior, especially the distribution patterns of potassium, remains inadequate. This research examines the influence of key parameters—including K_2O concentration, seed addition amount, final precipitation temperature, and the molar ratio of the sodium aluminate solution—on the precipitation of potassium. The findings demonstrate that increasing the seed addition, the initial K_2O concentration in the solution, the final temperature, and the solution molar ratio all promote the precipitation efficiency of potassium. Moreover, it was observed that raising the seed addition, solution molar ratio, and final temperature effectively increases the proportion of coarse particles in the precipitated product. Conversely, a higher K_2O concentration leads to a greater fraction of fine particles. Under typical industrial conditions ($C_{OH^-} = 4.8$ mol/L, $K_2O = 70$ g/L, $\alpha_k = 1.53$, initial temperature of 75 °C, final temperature of 37 °C, seed addition of 700 g/L, and a precipitation duration of 40 h), only about 0.19% of the potassium from the initial solution transferred into the aluminum hydroxide product.

Keywords: potassium migration; seed precipitation; aluminum hydroxide crystals; sodium aluminate solution; decomposition rate



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1. Introduction

Aluminum is currently produced mainly through the electrolysis of alumina [1]. China is now one of the world's largest producers and consumers of alumina, which has led to the rapid depletion of high-quality bauxite in China [2]. The country now has to use low- and medium-grade bauxite (which contains potassium) with high impurities [3]. Currently, some enterprises use a mixture of low-grade bauxite and imported high-quality bauxite to produce alumina [4,5]. However, with the rapid development of China's aluminum industry, alumina production has increased, and China now needs to import large quantities of high-quality bauxite from Australia and Guinea every year [6]. This has also resulted in some of the alumina currently produced being of low quality (The K_2O content ranges from 0.01% to 0.1%).

Currently, the potassium ion content in the circulating mother liquor of some alumina plants using potassium-containing bauxite exceeds 75 g/L. Potassium enters the aluminum electrolysis production process through alumina products, resulting in a KF content exceeding 5% in the electrolyte [7–11]. As an extraneous impurity salt, KF integrates into the cryolite-based electrolyte system, altering its original composition. Due to differences in ionic radius and chemical properties between KF and the primary electrolyte component NaF, its introduction disrupts the ionic equilibrium within the system, lowers the liquidus temperature of the electrolyte, reduces the solubility of alumina, and modifies the composition and physicochemical properties of the electrolyte. Consequently, this leads to issues such as decreased current efficiency, reduced electrical conductivity, and a lower eutectic temperature [12–15]. Furthermore, as electrolysis proceeds, potassium ions preferentially discharge and dissolve into the cathode aluminum liquid, directly reducing the purity of primary aluminum. More critically, potassium exhibits strong permeability, infiltrating into the internal structure of the cathode carbon blocks. This leads to expansion and pulverization of the carbon materials and triggers destructive chemical reactions with refractory materials, which constitute the primary cause of early failure and reduced service life of electrolytic cells [16]. This will have a significant impact on the efficiency of aluminum electrolysis. Several methods have been proposed to mitigate the adverse effects of potassium on aluminum production processes. These include the roasting of bauxite, planetary ball milling combined with acid leaching, and other techniques to reduce potassium content within the Bayer process [17–20].

Since most alumina production in China involves high-temperature and high-pressure digestion, potassium ions gradually become enriched in the circulating solution [21–27]. Indeed, studies have shown that the presence of alkali metal cations can influence the seeded precipitation process [28]. It has even been suggested that the seed decomposition rate of potassium-containing sodium aluminate solutions is higher than that of potassium-free sodium aluminate solutions [29,30]. Jiang Youfa's research [31] indicates that the initial crystallization product under relatively low-temperature conditions (30 °C, 40 °C) is bayerite, while at higher temperatures (60 °C, 80 °C), a mixture of gibbsite and bayerite is formed. Alkali concentration shows no significant effect on the initial product. Chen Jinqing's [32] study demonstrates that under identical decomposition conditions, the decomposition rate of potassium aluminate solution is higher than that of sodium aluminate solution. Furthermore, the particle size distributions in sodium aluminate and potassium aluminate solutions exhibit significant differences over time. X-ray diffraction (XRD) analysis of the products reveals that the crystals formed during the decomposition of potassium aluminate solution possess a more complete crystallinity compared to those from sodium aluminate solution. The difference in nucleation rates between potassium aluminate and sodium aluminate solutions during seeded precipitation may be responsible for the observed variations in decomposition rate and particle size distribution [33,34]. Therefore, it is necessary to study the behavior of potassium in sodium aluminate solutions, particularly during the seeding process. However, previous studies have focused on the kinetics of the seeding process and on comparing pure sodium aluminate with potassium aluminate solutions. There have been few studies on the behavior of potassium in the seeding process of sodium aluminate solutions in an industrial setting. This paper therefore focuses on studying the behavior of potassium in the seeding process of sodium aluminate solutions under simulated industrial production conditions, giving information about control and utilization of potassium ion content in alumina production.

2. Experimental

When investigating the effect of potassium ions on the decomposition of sodium aluminate, the experimental conditions and influencing factors may vary. As the experimental process must align with actual production conditions, the following key factors should be considered: final decomposition temperature, seed crystal dosage and potassium content in the solution.

2.1. Experimental Methods and Equipment

For the preparation, analytically pure NaOH and KOH, as well as industrial aluminum hydroxide in distilled water, were used. The aluminum hydroxide (pre-washed and dried at 70 °C to remove attached alkali and moisture) and the required weights of NaOH and KOH were accurately weighed according to the experimental conditions. A certain amount of distilled water was added to a polytetrafluoroethylene container, and the NaOH and KOH were heated and dissolved. The weighed aluminum hydroxide was then slowly added to the container and dissolved under heating and stirring conditions. The detailed parameters are shown in Table 1. After the aluminum hydroxide was completely dissolved, the solution was made up to volume to obtain the stock solution. All reagents used in this experiment were of analytical grade and purchased from Tianjin Fengchuan Chemical Reagent Technology Co., Ltd., Tianjin, China.

Table 1. Detailed experimental parameters.

NaOH Mass (g)	KOH Mass (g)	Distilled Water Volume (mL)	Heating Temperature (°C)	Stirring Speed (r/min)	Heating Time (time)
132.4	83.4	1000	300	30	Until clarification

The prepared solution was placed in the split-seed reaction tank to be preheated. Once the predetermined temperature (75 °C) was reached, the crystal seeds were added and the reaction began. The aluminum hydroxide used as the crystal seed was sourced from Tianjin Fengchuan Chemical Reagent Technologies Co., Ltd., Tianjin, China. The particle size of the crystal seeds primarily ranged from 10–100 µm and they were not sieved. The Scanning electron microscopy (SEM) image of the crystal seeds and the corresponding size distribution graph are shown in Figures 1 and 2, respectively. Samples were taken at regular intervals. The samples were centrifuged and the clear liquid was analyzed for the Al₂O₃ and K₂O contents. The solid samples were washed with heated deionised water, filtered and dried three times. They were then stored for particle size analysis.

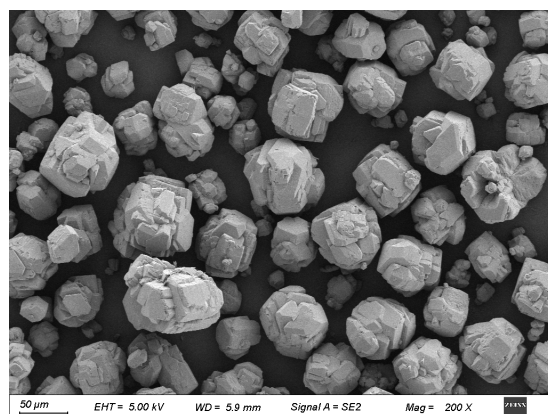


Figure 1. The SEM image of the crystal seeds.

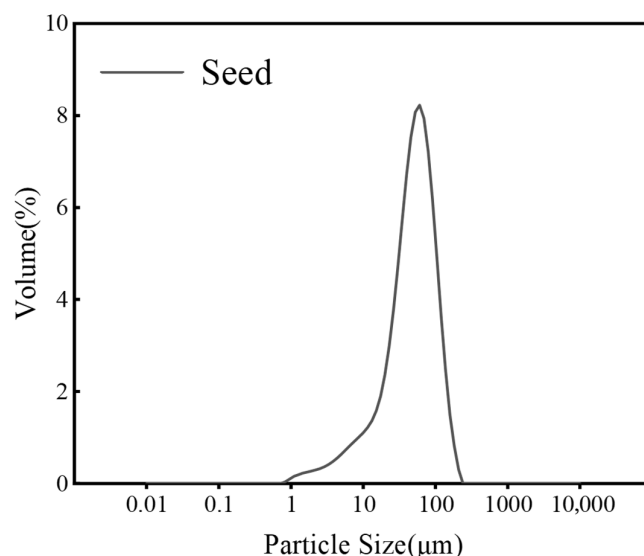


Figure 2. The particle size distribution diagram of the crystal seeds.

The equipment used in this experiment was a YSAWD-1 type seed decomposition tank, produced by Zhengzhou Yusong Intelligent Control Technology Co., Ltd., Zhengzhou, China, as shown in Figure 3. Temperature control was achieved through a water bath, with a working temperature range from room temperature to 100 °C and a control accuracy of ± 0.5 °C. Each vessel has an effective volume of 4×2 L and features a central sampling port in its sealed lid for convenient sampling. Each vessel is equipped with a stirring apparatus comprising two paddle stirrers, one upper and one lower, to enhance mixing efficiency. The maximum stirring speed is 200 rpm.



Figure 3. Photograph of the seed decomposition tank.

2.2. Analytical Method

The seed precipitation rate refers to the ratio of the precipitated alumina mass to the alumina mass in the initial solution during the seeded precipitation process. It is calculated as follows:

$$\eta = \frac{\left(\frac{1}{\alpha_{k1}} - \frac{1}{\alpha_{k2}} \right)}{\frac{1}{\alpha_{k1}}} = 1 - \frac{\alpha_{k1}}{\alpha_{k2}} \quad (1)$$

α_{k1} and α_{k2} refer to the causticity ratios of the initial sodium aluminate solution and the decomposed mother liquor, respectively. In this experiment, the caustic concentration is expressed in terms of the OH^- (C_{OH^-}) concentration rather than the Na_2O or K_2O concentrations, which are usually used. The corresponding solution causticity ratio (α_k) is expressed as $\alpha_k = \text{C}_{\text{OH}^-} / \text{CaAl}_2\text{O}_3$.

The concentrations of caustic alkali and alumina in the decomposed sodium aluminate solution and the mother liquor were determined according to the method described in Reference [35], allowing for accurate calculation of the decomposition rate at any given time. In a more realistic process, impurities must be present. Sodium aluminate solutions were prepared using NaOH and the corresponding mass of KOH to investigate the effect of potassium ions on the seeding process of sodium aluminate solutions without introducing other anions, thus simplifying the experimental system.

3. Results and Discussion

3.1. Effect of K_2O Concentration

Experiments were conducted to investigate the effect of K_2O concentration in solution on the seed decomposition rate of sodium aluminate solution, the product particle size and the potassium concentration in the product under the conditions of $C_{OH^-} = 4.8$ mol/L, α_k of 1.53, the initial decomposition temperature of 75 °C, end decomposition temperature of 37 °C, addition of crystal seed of 700 g/L, seeding time of 40 h, and the stirring speed of 120 r/min. The obtained results are shown in Figures 4–6.

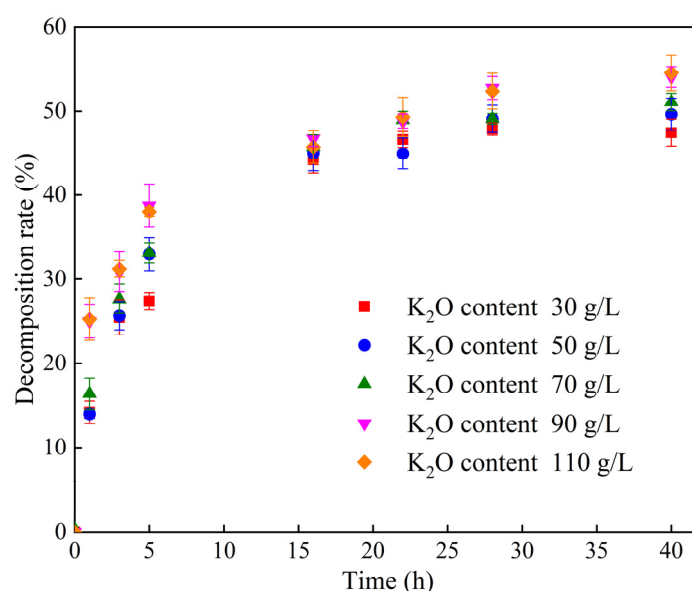


Figure 4. Relationship between K_2O concentration and decomposition rate of the sodium aluminate solution.

As demonstrated in Figure 4, an examination of the relationship between K_2O concentration and decomposition rate reveals that an increase in the concentration of potassium oxide results in a corresponding increase in the decomposition rate of the sodium aluminate solution. This finding suggests that the K_2O present in the sodium aluminate solution can enhance the decomposition process. When the precipitation duration is 40 h, the decomposition rate at a K_2O concentration of 110 g/L is 7.1% higher than that at a K_2O concentration of 30 g/L. However, the variation in the decomposition rate curves is relatively small between K_2O concentrations of 90 g/L and 110 g/L, indicating that when the K_2O concentration in the sodium aluminate solution exceeds 90 g/L, further increases in K_2O concentration have a negligible effect on enhancing the decomposition rate of the sodium aluminate solution. Moreover, the slope of the decomposition rate curve increases with higher K_2O concentrations, suggesting that raising the K_2O concentration can accelerate the decomposition rate of the sodium aluminate solution.

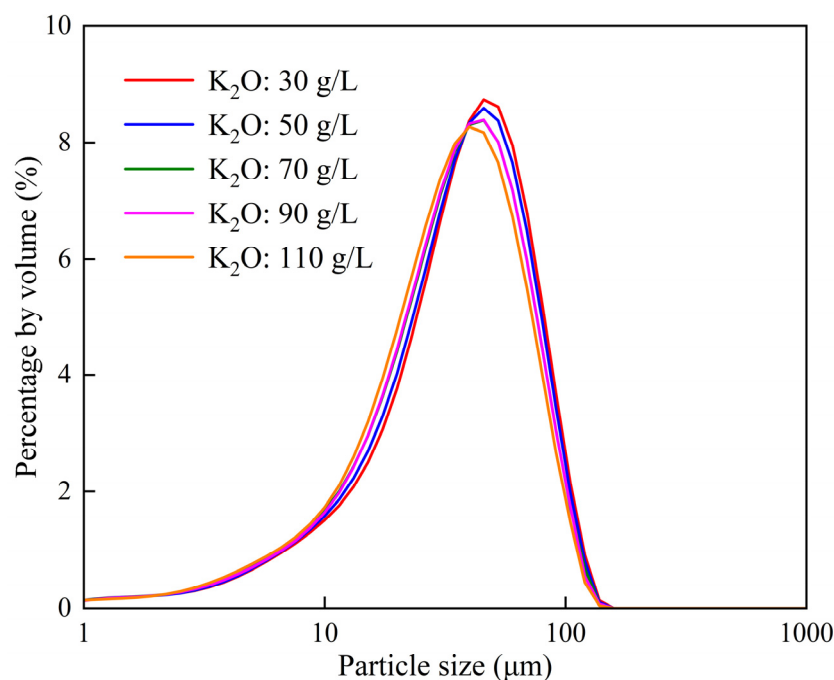


Figure 5. Particle size distribution of seed products at different K_2O concentrations.

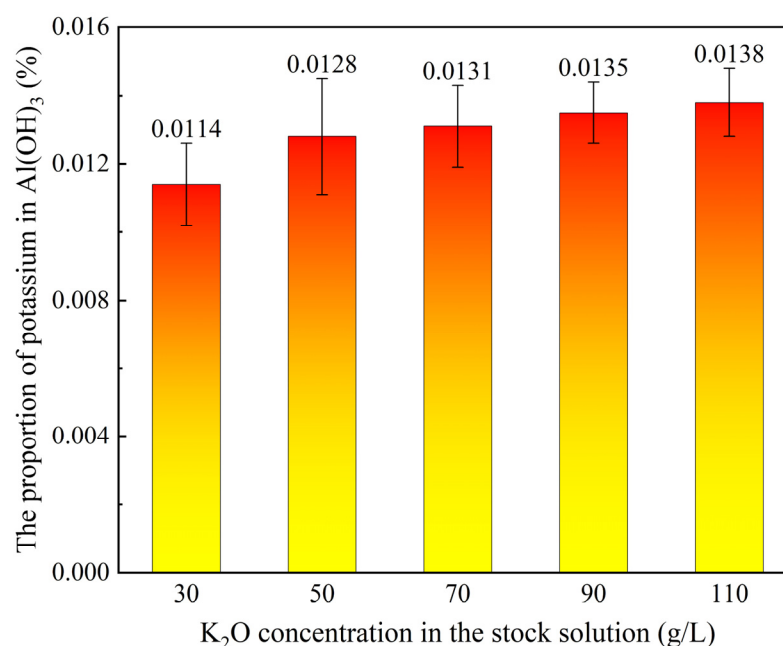


Figure 6. Mass percentage of potassium in seed fraction products at different K_2O concentrations.

As shown in Figure 5, which presents the particle size distribution of seeded precipitation products under different K_2O concentrations, it can be observed that under constant conditions of seed addition, initial and final decomposition temperatures, and decomposition time, the peak of the curve gradually decreases and shifts to the left with increasing K_2O concentration in the initial solution. Concurrently, the left side of the curve broadens, while the right side slightly shifts to the left. This indicates that as the K_2O concentration in the potassium-containing sodium aluminate solution increases, the content of coarse particles in the seeded product decreases, while the content of fine particles gradually rises. In other words, an increase in K_2O in the sodium aluminate solution promotes the refinement of particle size in the seeded precipitation product.

To investigate variations in potassium percentage content (Inductively coupled plasma (ICP) method) within the product, the potassium percentage content in seed fraction products was studied under fixed K_2O concentration conditions while other experimental variables remained constant. The experimental results are presented in Figure 6. As demonstrated in Figure 6, the potassium content of the products following the seeding of a sodium aluminate solution was found to be minimal, amounting to less than 0.014% (based on mass). Conversely, an increase in the K_2O concentration of the sodium aluminate solution was observed to result in an increase in the percentage of potassium in the product. This is attributed to more potassium co-precipitating with aluminum hydroxide. The maximum percentage of potassium was attained at a K_2O concentration of 110 g/L corresponded to 0.0138% (based on mass). It will reduce the current efficiency during the electrolysis process.

In order to further investigate the behavior of potassium in the seeding process of potassium-containing sodium aluminate solution, mass balance calculations of potassium were carried out on the seeded sodium aluminate solution, seeded mother liquor and product before and after seeding. The obtained results are associated with a K_2O concentration of 70 g/L in sodium aluminate solution and are shown in Table 2. In addition, the products were subjected to chemical composition analysis, and the results of the composition of some of the impurities are shown in Table 2. As demonstrated in Table 2, which presents the composition of K_2O in a sodium aluminate solution, it can be deduced that during the seeding process, potassium will be introduced into the product. When simulating 1 L of the seeded precipitation feed solution with a K_2O concentration of 70 g/L, the amount of potassium (calculated as K_2O) entering the product was 0.13 g, accounting for 0.19% of the initial K_2O . Meanwhile, 62.56 g of potassium (calculated as K_2O) remained in the precipitated mother liquor, representing 89.37% of the initial K_2O , with the remaining K_2O entering the attached liquor. These results indicate that the majority of K_2O transfers into the mother liquor during the seeded precipitation process, while only a small fraction is incorporated into the product.

Table 2. Composition of K_2O in sodium aluminate solution at a K_2O concentration of 70 g/L.

	Sodium Aluminate Solution	Mother Solution	Aluminum Hydroxide
K_2O mass (g)	70	62.56	0.13
K_2O concentration (%wt.)	100	89.37	0.19

As demonstrated in Table 3, potassium corresponds to the main impurity present in the sodium aluminate product. When sodium aluminate solution exists in potassium, the product of impurities in the composition of the product after conversion is compared to the requirements of GB/T 24487-2022 [36]. It is observed that, in addition to the potassium content being slightly higher (<0.01%), the rest of the requirements are met.

Table 3. Percentage of major impurities in aluminum hydroxide at K_2O concentration of 70 g/L.

	Na	Si	K	Ga	Fe
Content (%)	0.1053	0.0129	0.0131	0.0096	0.0095

In order to further investigate the effect of potassium ions on the seeded products of sodium aluminate solution, scanning electron microscopy was performed on the products when the concentration of K_2O in the seeded sodium aluminate solution was 70 g/L and 110 g/L. The scanning electron microscope photographs are displayed in Figures 7 and 8.

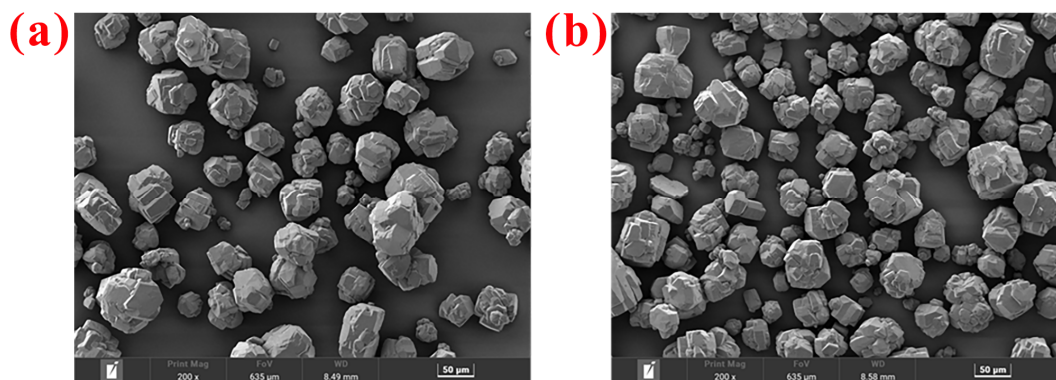


Figure 7. SEM images of products with K_2O concentration of 70 g/L (a) and K_2O concentration of 110 g/L (b).

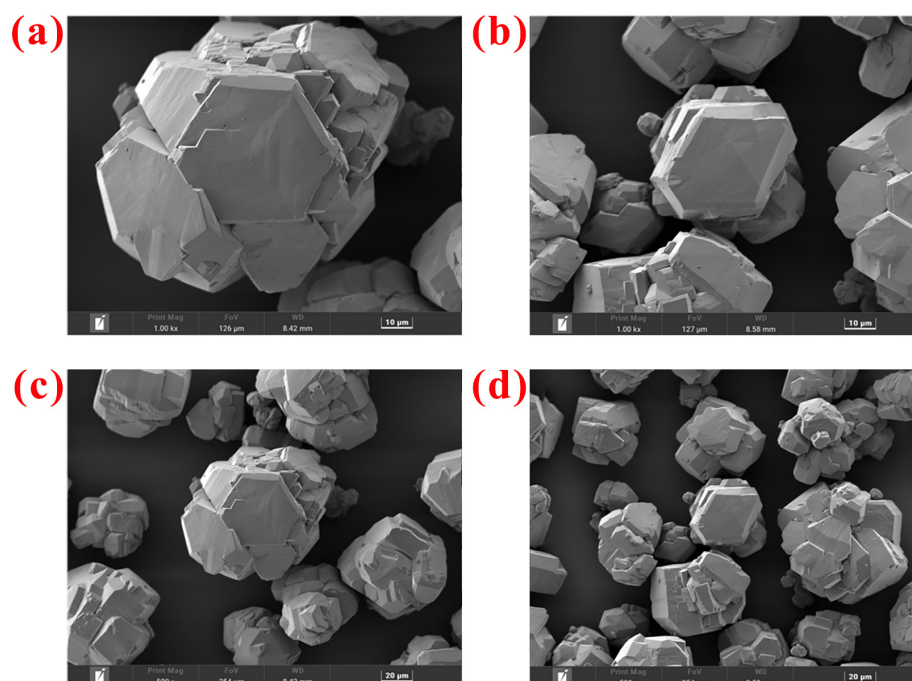


Figure 8. SEM images of products with K_2O concentration of 70 g/L (a,b) and K_2O concentration of 110 g/L (c,d). Panels (a,c) are at 1000 $\times$ magnification; (b,d) are at 500 $\times$.

The analysis of the SEM (ZEISS Gemini Sigma 300, Carl-Zeiss-Strasse 22, 73447 Oberkochen, Germany) provides a more intuitive understanding of the effect of varying potassium ion content on the products of the seed fraction. As shown in Figure 7, the left and right sides present the scanning electron microscopy (SEM) images of the products obtained after 40 h of decomposition under conditions of K_2O concentrations at 70 g/L and 110 g/L, respectively.

By comparing Figure 8a,c, as well as Figure 8b,d, it can be observed that the number of fine particles in the product is greater at a K_2O concentration of 110 g/L. Moreover, at the same magnification level, the particle size of the product is significantly smaller when the K_2O concentration is 110 g/L. This observation is consistent with the results obtained from the particle size analysis of the product.

3.2. Effect of Crystallization Seeding Amount

Experiments were conducted to investigate the effect of crystal seed addition on the decomposition rate, product particle size and the percentage of potassium in the product during the seeding process of sodium aluminate solution under the conditions of

$C_{OH^-} = 4.8 \text{ mol/L}$, α_k of 1.53, decomposition initial temperature of 75°C , decomposition end temperature of 37°C , K_2O concentration of 70 g/L , seeding time of 40 h , and stirring speed of 120 r/min . The results are shown in Figures 9–11.

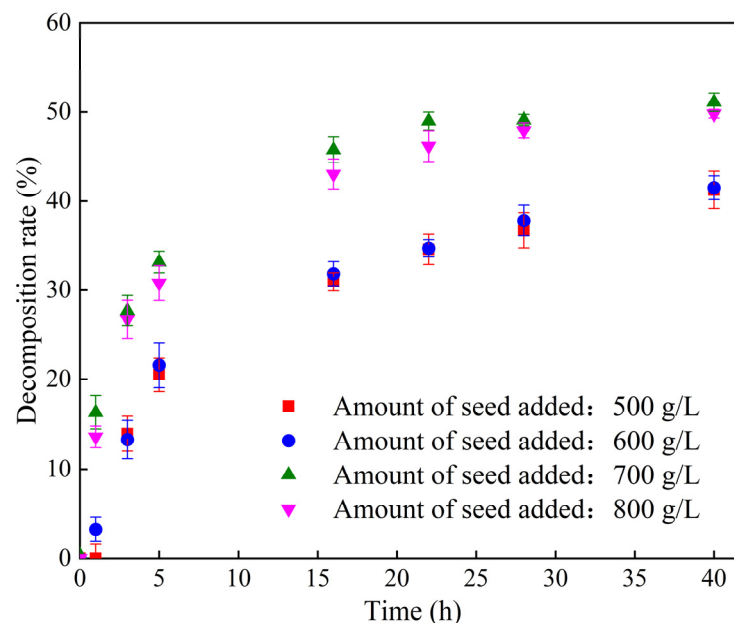


Figure 9. Crystalline seed addition versus decomposition rate of sodium aluminate solution.

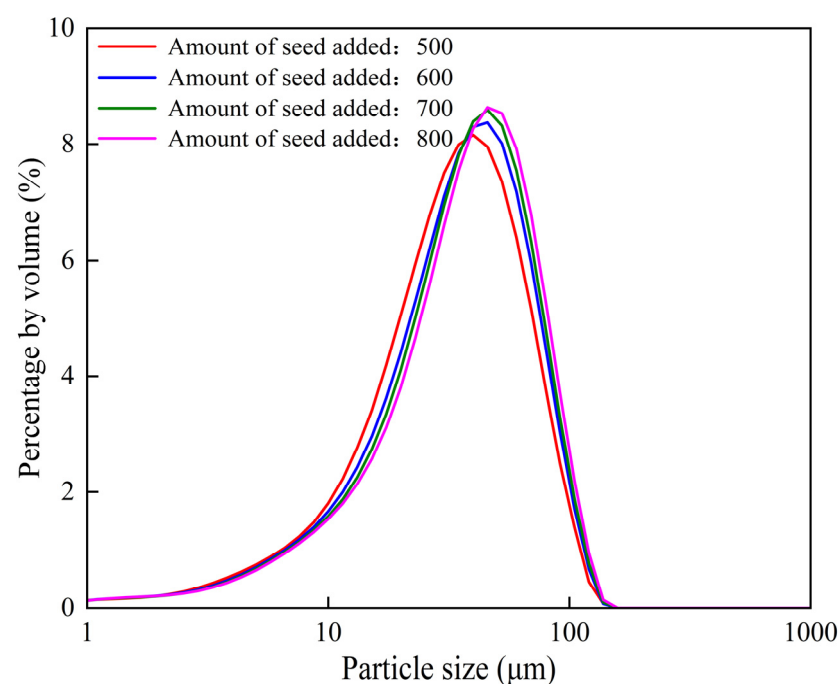


Figure 10. Particle size distribution of seed products under different crystal additions.

From Figure 9, which shows the effect of seed crystal addition amount on the decomposition rate of sodium aluminate solution, it can be observed that when the seed crystal addition amount is less than 800 g/L , under the same K_2O concentration, initial decomposition temperature, and final decomposition temperature conditions, the decomposition rate of the sodium aluminate solution increases with prolonged decomposition time and gradually stabilizes over time. As the seed crystal addition amount increases, the decomposition rate at the same decomposition time becomes higher, and the slope of the decomposition rate curve changes more significantly, indicating that a higher seed crystal

addition amount leads to better seeding decomposition performance. However, when the seed crystal addition amount is 800 g/L, the decomposition rate curve is essentially the same as that for the 700 g/L addition amount within the first 5 h of decomposition, but after 5 h, the decomposition rate curve falls below that of the 700 g/L condition. This suggests that the decomposition efficiency of the sodium aluminate solution is inferior at a seed crystal addition amount of 800 g/L compared to 700 g/L. It can be concluded that once the seed crystal addition amount exceeds 700 g/L, further increasing the seed crystal amount to improve the decomposition rate is no longer effective. Moreover, continuing to add more seed crystals may increase the load on the stirrer and even cause sedimentation, ultimately leading to a decline in the decomposition rate.

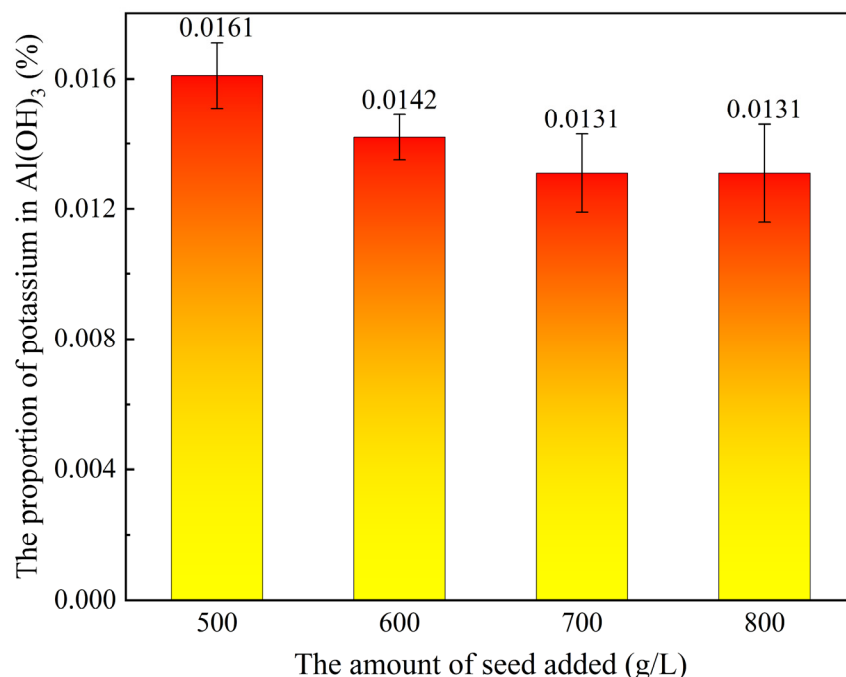


Figure 11. Mass percentage of potassium in seed products at different crystal additions.

Particle size distribution of aluminum hydroxide products was examined under varying seeding crystal concentrations. The experimental results are shown in Figure 10. As can be seen from the particle size distribution of the seeded products under the conditions of different crystal seed additions in Figure 10, with an increase in crystal seed concentration, the peak of the product particle size gradually increased and moved to the right, and the left side of the curve gradually became narrower. This indicates that with the increase in seed crystal dosage, the content of fine particles in the product after seeded precipitation from sodium aluminate solution decreases, while the content of coarse particles increases. That is to say, increasing the amount of seed crystals can promote the growth of product particles during seeded precipitation in sodium aluminate solution.

To investigate the variation in potassium percentage content within the product, the potassium percentage content in the seed fraction product was studied under different seed addition levels while keeping other experimental variables constant. The experimental results are shown in Figure 11. As demonstrated in Figure 11, the percentage of potassium in the seed products exhibited a decline with increasing crystal seed addition. This decline gradually stabilized at higher levels of crystal seed addition, with the percentage of potassium remaining constant at 700 g/L and 800 g/L. This indicates that increasing the seed addition can, to some extent, reduce the proportion of potassium in the product.

3.3. Effect of Temperature

Experiments were conducted to investigate the effect of the end temperature of decomposition on the decomposition rate of sodium aluminate solution, solid product particle size and potassium concentration under of $C_{OH^-} = 4.8$ mol/L, α_k of 1.53, the initial temperature of 75 °C, concentration of K_2O of 70 g/L, crystalline seed addition of 700 g/L, seeding time of 40 h, and stirring speed of 120 r/min. The obtained results are shown in Figures 12–14.

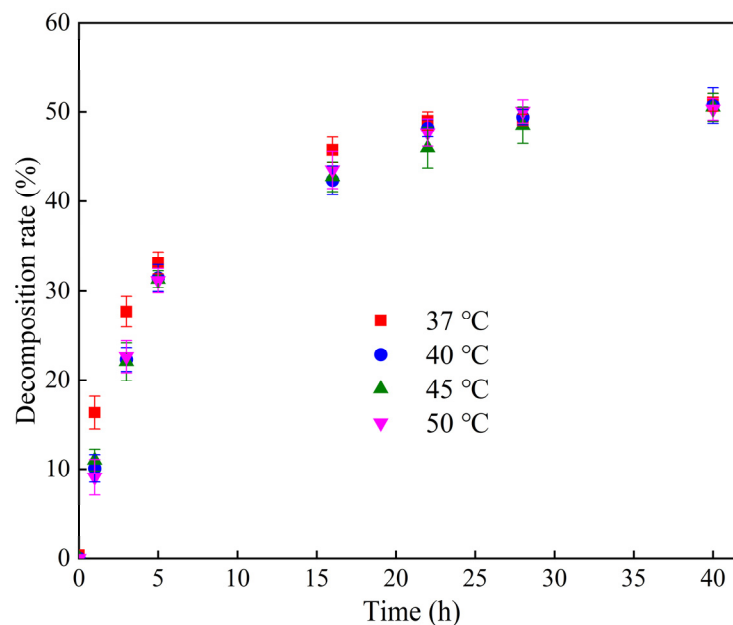


Figure 12. Decomposition end temperature versus decomposition rate of sodium aluminate solution.

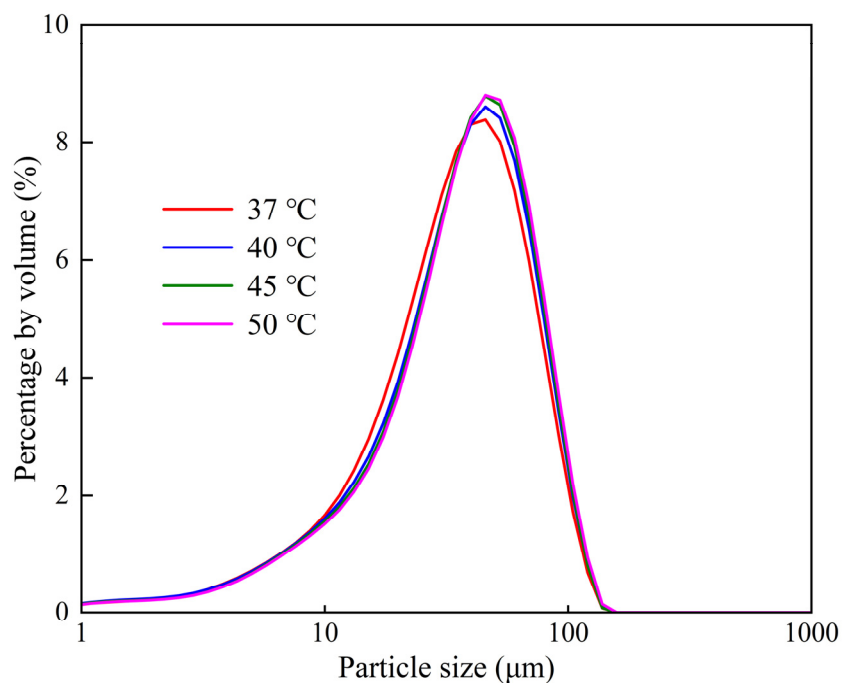


Figure 13. Particle size distribution of seed products at different end-of-decomposition temperatures.

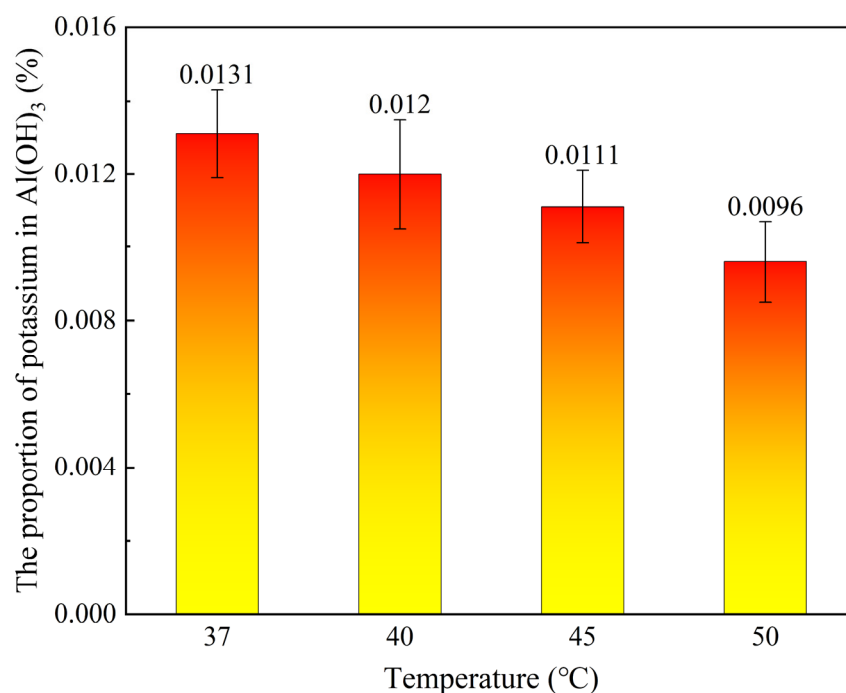


Figure 14. Mass percentage of potassium in seed products at different end-of-decomposition temperatures.

As can be seen from the relationship between decomposition final temperature and the precipitation rate of sodium aluminate solution in Figure 12, under the conditions of the same seed addition amount, initial decomposition temperature, K_2O concentration and decomposition time, the lower the decomposition final temperature, the higher the precipitation rate of sodium aluminate solution. Specifically, the precipitation rate at a seed precipitation duration of 40 h with a decomposition final temperature of 37 °C was 0.79% higher than that at 50 °C. In comparison with the variation in seed addition amount and K_2O concentration, the change in decomposition final temperature exerted a relatively minor effect on the precipitation rate. Furthermore, when the decomposition time was less than 30 h, a lower decomposition final temperature led to a steeper slope of the precipitation rate curve and a higher precipitation rate, which indicates that the decomposition rate of sodium aluminate solution increased with the decrease in decomposition final temperature within the initial 30 h of the decomposition process.

The experiment also investigated the mechanism by which the decomposition temperature, a key operational parameter, influences the final particle size distribution during the seeding process of sodium aluminate solution. The experimental results are presented in Figure 13. As illustrated in Figure 13, the particle size distribution of the seed products exhibits distinct variations under varying decomposition end temperatures. In the context of constant crystal seed addition, initial decomposition temperature, equivalent K_2O concentration, and equivalent decomposition time, the peak value of the particle size distribution curve demonstrates a gradual increase with elevation of end decomposition temperature. However, in comparison with variations in seed addition amount and K_2O concentration, temperature change exerts a relatively minor effect on the maximum frequency of particle size distribution. Concurrently, with the rise in the final temperature of decomposition, the peak of the particle size distribution curve exhibited minimal lateral movement, and the narrowing of both sides of the curve at elevated temperatures was negligible. This suggests that as the final temperature of decomposition increases, the coarse particles in the seed products undergo a slight increase, while the fine particles undergo a slight decrease.

Furthermore, experimental studies investigated the mechanism by which the decomposition temperature—a critical operational parameter—influences the percentage of potassium in the product during the seeding process of sodium aluminate solutions. The experimental results are presented in Figure 14. As can be seen from Figure 14, showing the potassium content in the seed precipitation products under different decomposition final temperature conditions, the potassium content in the products decreased gradually with the increase in the decomposition final temperature of the sodium aluminate solution. At an end-temperature of decomposition of 50 °C, the percentage content of potassium in the products was found to be 0.0096%, which is in accordance with the stipulated percentage content of potassium in GB/T 24487-2022 (<0.01%) after conversion [36]. This indicates that increasing the decomposition final temperature can reduce the potassium content (mass fraction) in the products.

3.4. Effect of α_k on the Decomposition Rate of Potassium-Containing Sodium Aluminate Solutions and Aluminum Hydroxide Products

Experiments were carried out to investigate the effect of seeding sodium aluminate solution α_k on the decomposition rate of sodium aluminate solution seeding process, product size distribution, and the percentage of potassium in the product, under the conditions of $C_{OH^-} = 4.8$ mol/L, decomposition initial temperature of 75 °C, decomposition end temperature of 37 °C, K_2O concentration of 70 g/L, crystal seed addition of 700 g/L, seeding time of 40 h, and stirring speed of 120 r/min. law, the results are shown in Figures 15–17, respectively.

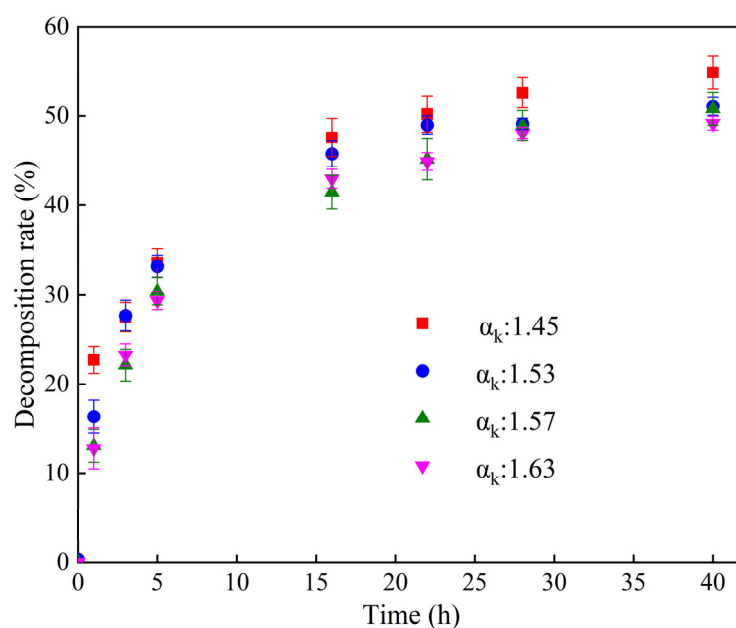


Figure 15. Relationship between sodium aluminate solution α_k and decomposition rate of sodium aluminate solution.

As demonstrated in Figure 15, an inverse relationship exists between α_k of the decomposition of the sodium aluminate solution and the decomposition rate of the sodium aluminate solution. Under conditions of identical crystal species addition, constant temperature at the beginning and end of decomposition, equivalent K_2O concentration, and equivalent decomposition time, the decomposition rate declines with increasing α_k in the decomposition of the sodium aluminate solution. When α_k is elevated from 1.45 to 1.63, and under the condition of a 40-h decomposition time, the decomposition rate diminishes from 54.87% to 49.18%, representing a 5.69% reduction compared to the decomposition of

the sodium aluminate solution. The decomposition rate exhibited a decline from 54.87% to 49.18% under the condition of decomposition time of 40 h, which corresponded to a 5.69% reduction. This finding suggests that a reduction in α_k of the decomposition of sodium aluminate solution can enhance the decomposition rate of sodium potassium aluminate-containing solutions.

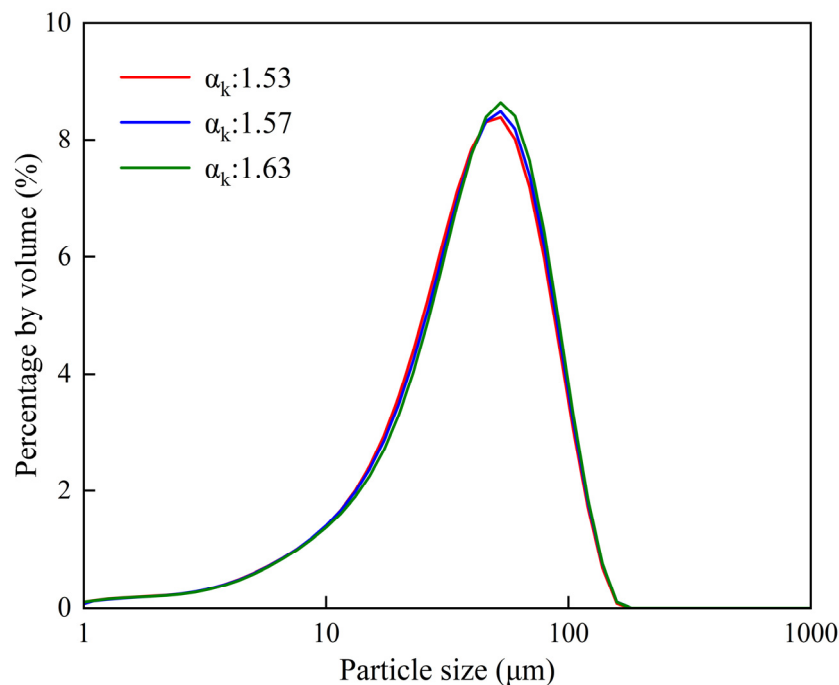


Figure 16. Particle size distribution of seed fraction products under different α_k conditions.

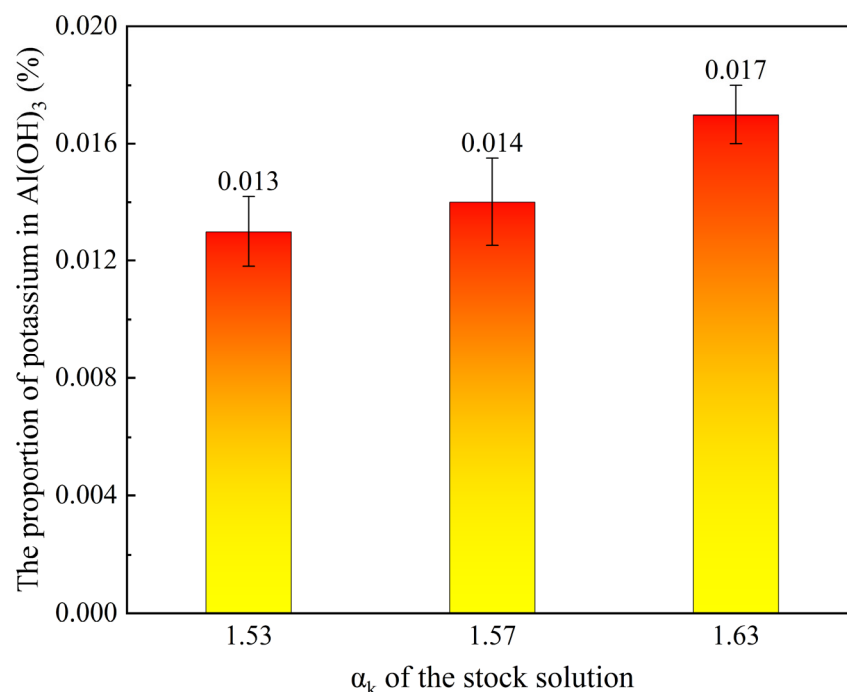


Figure 17. Percentage of potassium in seed products under different conditions of decomposition of sodium aluminate solution α_k .

Furthermore, experimental studies investigated the mechanism by which the key operational parameter α_k influences the particle size distribution of products during the sodium aluminate solution seeding process. The experimental results are presented in

Figure 16. As illustrated in Figure 16, the particle size distribution of the seed fraction products under varying α_k conditions reveals a clear trend. In the context of constant crystal seed addition, temperature at the initiation and conclusion of decomposition, constant K_2O concentration, and consistent decomposition time, an increase in α_k results in a gradual increase in the peak value of the product particle size distribution curve. Concurrently, the left side of the curve shifts towards the right. This finding suggests that an increase in α_k in the sodium aluminate solution is associated with an increase in coarse particles in the product and a decrease in fine particles. It can thus be concluded that an increase in the magnitude of α_k in the sodium aluminate solution is indicative of an increase in the proportion of coarse particles in the product.

Furthermore, experimental studies investigated the mechanism by which α_k , a key operational parameter, influences the percentage of potassium in the product during the sodium aluminate solution seeding process. The experimental results are presented in Figure 17. As demonstrated in Figure 17, the percentage content of potassium in the seeded product is observed to increase in accordance with the increasing value of α_k of the decomposition of the sodium aluminate solution. At an α_k of 1.63, the percentage content of potassium in the product reaches a maximum of 0.0171%. When considered in conjunction with Figure 15, it becomes evident that a reduction in the α_k of the sodium aluminate solution, within an implementable range, results in an increase in the decomposition rate, concurrently with a decrease in the percentage content of potassium in the product.

Our next phase of research will focus on developing a novel method for potassium extraction from Bayer liquor based on the sodium tetraphenylborate ($C_{24}H_{20}BNa$) complexation reaction. The specific research contents include: systematically optimizing the process parameters of the complexation reaction (such as pH, temperature, reaction time, and reagent ratio), investigating the influence mechanisms of impurity ions in the complex Bayer liquor matrix on the selective complexation of potassium, developing efficient solid-liquid separation and complex decomposition processes to achieve potassium resource recovery, and constructing a predictive model for the potassium extraction process using response surface methodology.

4. Conclusions

This study systematically investigated the effects of initial K_2O concentration, seed crystal addition amount, decomposition final temperature, and initial solution α_k on the seeded precipitation process of potassium-containing sodium aluminate solution. The following conclusions were drawn:

(1) Increasing the seed crystal addition amount and initial K_2O concentration, or decreasing the decomposition final temperature and initial α_k , all contribute to enhancing the alumina decomposition rate during seeded precipitation.

(2) The particle size distribution of the precipitated product is influenced by multiple factors: as the seed crystal addition amount, decomposition final temperature, and initial α_k increase, the proportion of coarse particles in the product gradually rises; whereas, with an increase in the initial K_2O concentration, the content of fine particles tends to increase.

(3) Effective approaches to reduce the potassium content in the product include: decreasing the initial K_2O concentration, lowering the initial α_k , increasing the seed crystal addition amount, and appropriately raising the decomposition final temperature.

(4) Under industrial production conditions ($C_{OH^-} = 4.8$ mol/L, $K_2O = 70$ g/L, $\alpha_k = 1.53$, initial decomposition temperature = 75 °C, final temperature = 37 °C, seed crystal addition = 700 g/L, precipitation time = 40 h), results indicate that only about 0.19% of potassium transfers from the initial decomposition solution to the aluminum hydroxide product. The majority of potassium enriches the mother liquor, leading to a

continuous increase in potassium concentration in the mother liquor throughout the seeded precipitation process.

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References

1. Sun, L.; Zhang, S.; Zhang, S.; Liu, J.; Xiao, K. Geologic characteristics and potential of bauxite in China. *Ore Geol. Rev.* **2020**, *120*, 103278. [\[CrossRef\]](#)
2. Rodionova, I.A. The shifts in the spatial structure of the world bauxite industry and Guinea’s position in the industry. *Rev. Espac.* **2020**, *798*, 1015.
3. Yin, Z.; Wu, G.; Zhang, L.; Lu, X. Progress in research and development of alumina production technology for low grade bauxite in China. In Proceedings of the 35th International ICSOBA Conference, Hamburg, Germany, 2–5 October 2017; pp. 289–299.
4. Liu, W.; Zhou, D.; Zhao, Z. Progress in Application of Energy-Saving Measures in Aluminum Reduction Cells. *JOM* **2019**, *71*, 2420–2429. [\[CrossRef\]](#)
5. Saevarsdottir, G.; Kvannd, H.; Welch, B.J. Aluminum Production in the Times of Climate Change: The Global Challenge to Reduce the Carbon Footprint and Prevent Carbon Leakage. *JOM* **2020**, *72*, 296–308. [\[CrossRef\]](#)
6. Zhang, B.; Jiang, Y.; Guo, S.; Zhou, F. The influence of bauxite resource change in China on layout of world alumina industry. *Light Met.* **2014**, *7*, 1–5.
7. Sun, X. Effect of high potassium and lithium electrolyte on aluminum reduction production and improvement measures. *Light Met.* **2018**, *12*, 26–29.
8. Lin, S.Y.; Liu, R.Q.; Li, W.H.; Sun, W.; Hu, Y.H. Clean desulfurization of sulfur-rich tungsten concentrates by reverse flotation. *J. Clean. Prod.* **2020**, *244*, 118876. [\[CrossRef\]](#)
9. Zhao, Q.; Miller, J.D.; Wang, X.M. Recent Developments in the Beneficiation of Chinese Bauxite. *Miner. Process. Extr. Metall. Rev.* **2010**, *31*, 111–119. [\[CrossRef\]](#)
10. Chen, Z.D.; Gong, X.Z.; Wang, Z. Sulfur removal from ionic liquid-assisted coal water slurry electrolysis in KNO₃ system. *J. Fuel Chem. Technol.* **2013**, *41*, 928–936. [\[CrossRef\]](#)
11. Gong, X.Z.; Zhuang, S.Y.; Ge, L.; Wang, M.Y. Desulfurization kinetics and mineral phase evolution of bauxite water slurry (BWS) electrolysis. *Int. J. Miner. Process.* **2015**, *139*, 17–24. [\[CrossRef\]](#)
12. Lv, X.; Shuang, Y.; Li, J.; Chen, S.; Lai, Y.; Zhang, H.; Liu, Y. Physicochemical Properties of Industrial Aluminum Electrolytes Enriching Li and K: The Liquidus Temperature. *Metall. Mater. Trans. B* **2017**, *48*, 1315–1320. [\[CrossRef\]](#)
13. Wang, J.; Li, C.; Chai, D.; Zhou, Y.; Fang, B.; Li, Q. *Light Metals*; Springer: Berlin/Heidelberg, Germany, 2018; pp. 621–626.
14. Yang, J.; Tian, Y.; Jiang, W.; Yang, B.; Chen, X.; Liu, D.; Xu, B.; Dai, Y. Study on effect of Al-O-C compound in alumina carbothermal reduction. *Light Met.* **2013**, *2016*, 689–693.

15. Yan, H.; Liu, Z.; Ma, W.; Huang, L.; Wang, C.; Liu, Y. KF-NaF-AlF₃ System: Liquidus Temperature and Phase Transition. *JOM* **2020**, *72*, 247–252. [\[CrossRef\]](#)
16. Li, J.; Fang, Z.; Lai, Y.; Lü, X.; Tian, Z. Electrolysis expansion performance of semigraphitic cathode in [K₃AlF₆/Na₃AlF₆]-AlF₃-Al₂O₃ bath system. *J. Cent. South Univ. Technol.* **2009**, *16*, 422–428. [\[CrossRef\]](#)
17. Sizyakov, V.; Bazhin, V.Y.; Sizyakova, E. Feasibility study of the use of nepheline-limestone charges instead of bauxite. *Metallurgist* **2016**, *59*, 1135–1141. [\[CrossRef\]](#)
18. Wang, H.; Feng, Q.; Tang, X.; Zuo, K.; Liu, K. Insights into Alkali-Acid Leaching of Sericite: Dissolution Behavior and Mechanism. *Minerals* **2017**, *7*, 196. [\[CrossRef\]](#)
19. Kumar, A.; Tanvar, H.; Dhawan, N. Processing of Mica for Extraction of Alumina and Potash Values. *Trans. Indian Inst. Met.* **2020**, *73*, 23–33. [\[CrossRef\]](#)
20. Bagani, M.; Balomenos, E.; Pnias, D. Nepheline syenite as an alternative source for aluminum production. *Minerals* **2021**, *11*, 734. [\[CrossRef\]](#)
21. Yin, Z.; Zhao, Q.; Chen, Q.; Yin, Z. Study of the desilication process of illite reacted with sodium aluminate solution. *Light Met.* **2005**, *12*, 10–13.
22. Hu, X.L.; Chen, W.M.; Xie, Q.L. Desulfuration of high sulfur bauxite by oxidation roasting. *J. Cent. South Univ.* **2010**, *41*, 852–858.
23. Wu, H.F.; Chen, C.Y.; Li, J.Q.; Lan, Y.P.; Wang, L.Z.; Quan, B.L.; Jun, H.X. Digestion mechanism and crystal simulation of roasted low-grade high-sulfur bauxite. *Trans. Nonferr. Metal. Soc.* **2020**, *30*, 1662–1673. [\[CrossRef\]](#)
24. Bulut, G.; Arslan, F.; Atak, S. Flotation behaviors of pyrites with different chemical compositions. *Miner. Metall. Proc.* **2004**, *21*, 86–92. [\[CrossRef\]](#)
25. Chimonyo, W.; Corin, K.C.; Wiese, J.G.; O'Connor, C.T. Redox potential control during flotation of a sulphide mineral ore. *Miner. Eng.* **2017**, *110*, 57–64. [\[CrossRef\]](#)
26. Blight, K.; Ralph, D.E.; Thurgate, S. Pyrite surfaces after bio-leaching: A mechanism for bio-oxidation. *Hydrometallurgy* **2000**, *58*, 227–237. [\[CrossRef\]](#)
27. Owusu, C.; Quast, K.; Addai-Mensah, J. The use of canola oil as an environmentally friendly flotation collector in sulphide mineral processing. *Miner. Eng.* **2016**, *98*, 127–136. [\[CrossRef\]](#)
28. Li, J.; Prestidge, C.A.; Addai-Mensah, J. The influence of alkali metal ions on homogeneous nucleation of Al(OH)₃ crystals from supersaturated caustic aluminate solutions. *J. Colloid Interface Sci.* **2000**, *224*, 317–324. [\[CrossRef\]](#)
29. Xie, F.; Chen, W. Effects of potassium ions on seed decomposition in sodium aluminate solution. *Light Met.* **2018**, *2*, 9–13.
30. Addai-Mensah, J. The Fouling Behaviour of Sodium Aluminosilicate Polytypes in High Ionic Strength Caustic Media Heat Exchangers. *Dev. Chem. Eng. Miner. Process.* **2006**, *14*, 323–336. [\[CrossRef\]](#)
31. Jiang, Y.; Liu, C.; Luo, M.; Xue, J.; Li, P.; Yu, J. Polymorphic transformation of aluminum hydroxide during spontaneous decomposition of supersaturated potassium aluminate solution. *Chin. J. Nonferrous Met.* **2019**, *29*, 606–616.
32. Chen, J. Study of the Effect of Potassium Ions on the Seeded Precipitation of Sodium Aluminate Solutions. Ph.D. Thesis, Central South University, Changsha, China, 2004.
33. Padilla, R.; Vega, D.; Ruiz, M.C. Pressure leaching of sulfidized chalcopyrite in sulfuric acid-oxygen media. *Hydrometallurgy* **2007**, *86*, 80–88. [\[CrossRef\]](#)
34. Liu, Z.W.; Yan, H.W.; Ma, W.H.; Xie, K.Q.; Xu, B.Q.; Xiong, P. Digestion behaviors of sulfur-containing minerals and desulfuration during alumina production process. *Miner. Eng.* **2021**, *173*, 107234. [\[CrossRef\]](#)
35. Wei, J. Basic Research on Resource Utilization of Aluminum Dross. Master's Thesis, Kunming University of Science and Technology, Kunming, China, 2022.
36. GB/T 24487-2022; Alumina. China Standards Press: Beijing, China, 2022.

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