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Optimization of Hydrochemical Leaching Process of Kaolinite Fraction of Bauxite with Response Surface Methodology

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Abstract: A technology for the hydrochemical processing of the kaolinite fraction of bauxite has been developed, and it involves preliminary chemical activation in a sodium bicarbonate solution and alkaline leaching in a recycled high-modulus solution with the addition of an active form of calcium oxide. Chemical activation allows for the transformation of the difficult-to-explore kaolinite phase to form easily soluble phases of dawsonite, sodium hydroaluminosilicate and bemite. An active, finely dispersed form of calcium oxide was obtained as a result of CaO quenching in Na_2SO_4 solution at elevated temperature and pressure. Using a central composite design (CCD) via response surface methodology (RSM), the technological leaching mode was achieved. The influence on the leaching process was studied by adjusting the CaO/SiO_2 ratio, temperature, alkaline solution concentration and duration. It was found that the determining factors are the concentration of the leaching solution and the temperature. At a stable CaO/SiO_2 ratio, a combination of these two factors determines the duration of the process to achieve the predicted degree of recovery. The results of experiments carried out using the developed model of the leaching process confirmed the validity of the calculated indicators, with an error of 2.01%. In an optimal technological mode at a Na_2O leaching solution concentration of 260 g/L, a temperature of 260 °C, a CaO/SiO_2 ratio of 1.5 and a leaching time of 5 h, the extraction of Al_2O_3 into the solution was 89.7%, which is close to the value of 87.9% predicted by the model.

Keywords: bauxite; kaolinite fraction; response surface methodology; alkaline leaching; factors

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Citation: Abikak, Y.; Bakhshyan, A.; Dyussenova, S.; Gladyshev, S.; Kassymzhanova, A. Optimization of Hydrochemical Leaching Process of Kaolinite Fraction of Bauxite with Response Surface Methodology. *Processes* **2024**, *12*, 1440. https://doi.org/10.3390/pr12071440

Academic Editor: Kun Huang

Received: 6 June 2024
Revised: 6 July 2024
Accepted: 7 July 2024
Published: 10 July 2024

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1. Introduction

In the processing of low-quality gibbsite–kaolinite bauxite, various technologies are used that result in preliminary enrichment with the separation of the difficult-to-discover fine kaolinite fraction into waste. Various methods of mechanical, chemical and flotation enrichment of bauxite are used [1,2]. Analyses of scientific and technical information showed that the extraction of aluminum from the kaolinite fraction of bauxite was impossible with the usual alkaline hydrometallurgical method since kaolin is a chemically stable compound. Existing methods for processing the fine kaolinite fraction (FKF) involve the use of acid technologies or sintering, the disadvantages of which include the need for expensive acid-resistant equipment and high energy consumption [3–12]. To develop a hydrochemical process for FKF, research was carried out with various technologies, including preliminary chemical activation with a solution of sodium bicarbonate, alkaline opening with the addition of an active form of calcium oxide and the regeneration of the leaching solutions to produce alumina and silicate products (Figure 1).

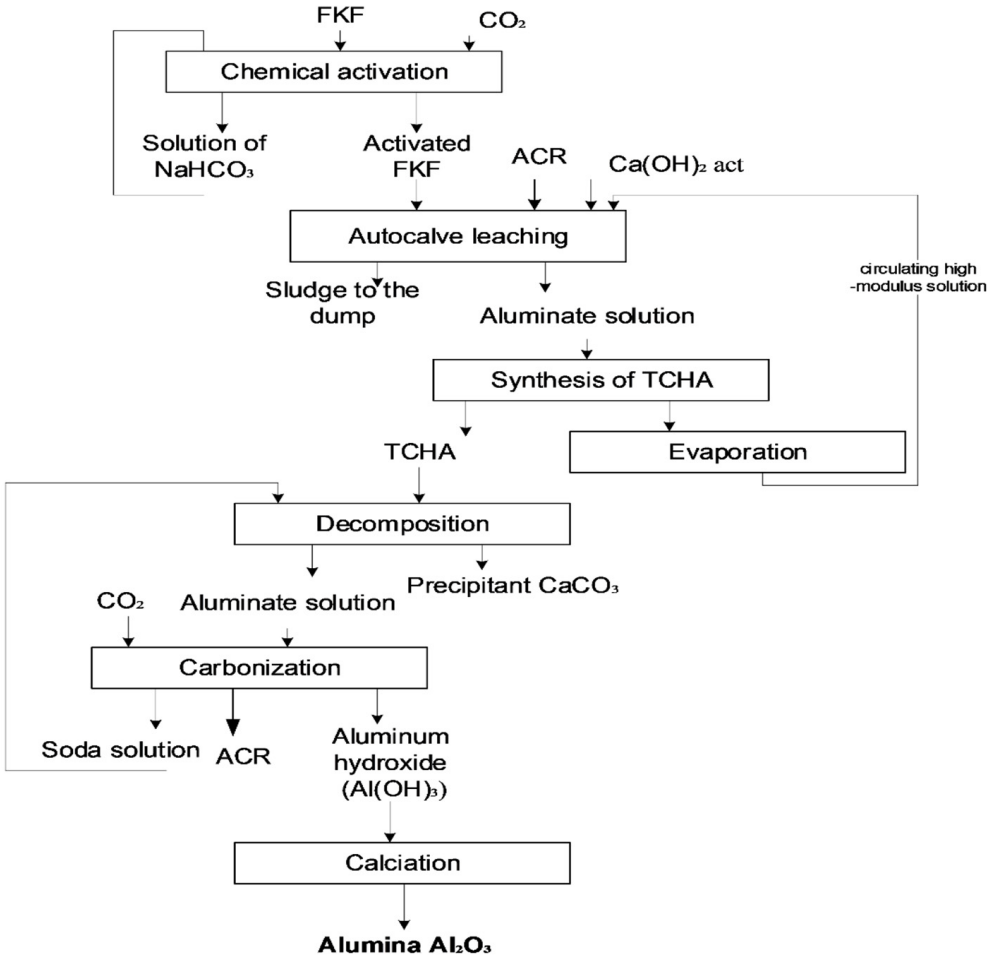


Figure 1. Hydrochemical processing of FKF.

The fundamental difference between these developed technologies is preliminary chemical activation and the use of the active calcium oxide, which makes it possible to carry out the hydrochemical alkaline processing of difficult-to-open FKF [13,14]. Preliminary chemical activation includes treating the FKF with a solution containing 120–150 g/dm^3 of sodium bicarbonate at a temperature of 120–160 °C [15]. When activated, the components of aluminosilicate raw materials react with a solution of sodium bicarbonate and form hydrocarbonate compounds; then, due to high temperature, they decompose to form carbonates, which serve as the basis for a new, easily soluble mineral structure. The required content of sodium bicarbonate in the solution is selected by taking into account its solubility limit. The processing temperature was determined experimentally and involved the use of an autoclave. At the same time, energy consumption is significantly lower compared to the use of the firing operation of aluminosilicate raw materials at a temperature of 950 °C. At temperatures below 120 °C, the rate of phase transformation processing is low. Increasing the processing temperature above 160 °C is unjustified, since this does not lead to additional changes. In the developed technology, FKF is leached in high-modulus solution (HMS) with the addition of an active form of calcium oxide in the form of fluff lime, obtained by slaking CaO in a Na_2SO_4 solution. Calcium oxide in the form of fluff lime is a widely used substance, the properties and activity of which depend on its dispersity. Highly dispersed calcium oxide is widely used for the preparation of building materials, various types of cements, bricks, etc. Thus, nanomodified cement pastes obtained by adding up to 1.5 wt. % CaO nanopowder have a denser structure and improved mechanical properties compared to control samples without the addition of CaO nanopowder. There is a known method for producing fluff lime, which involves the interaction of a water–lime suspension at a

temperature of 96–98 °C at atmospheric pressure [16]. The disadvantage of this method is that only 71.1% of the calcium oxide powder has a particle size of less than 1 micron. The method for producing fluff lime [17] involves grinding and mixing a water–lime suspension at atmospheric pressure and a temperature of 20–22 °C. However, according to this method, only 66.8% of the calcium oxide powder has a particle size of less than 1 micron. There is a method for producing fluff lime, which includes grinding quicklime, placing it in a layer of 6–8 cm and subjecting it to heat treatment with saturated water steam at normal atmospheric pressure at a temperature of 250–300 °C for 7–10 h [18]. According to this method, only 71.5% of the calcium oxide powder has a particle size of less than 1 micron. In the developed technology, the active form of calcium oxide is obtained by quenching CaO in a solution containing sodium sulfate. The interaction of the water–lime suspension is carried out at a temperature of 100–200 °C and under high pressure in an autoclave. An increase in temperature leads to an intensification of the quenching process and an improvement in the quality of the product—an increase in the degree of dispersion of the powder compared to low-temperature quenching [18]. In the developed method, lime slaking is carried out at elevated temperature and pressure in an autoclave in a solution containing Na_2SO_4, which makes it possible to obtain a highly dispersed powder, and the increased pressure slows down the process of coarsening fine particles. Under normal conditions, calcium oxide does not react with sodium sulfate to form calcium sulfate. Under the conditions of the developed method, the presence of calcium sulfate was determined based on the physicochemical results. Design of experiments (DoE), which is a tool for modeling the leaching process, was used in this research. Modeling has been used in various leaching operations to gain an understanding of the process and subsequently help in decision making. Several models have been employed over the years for the leaching of various minerals. These models include shrinking core models (SCMs), kinetic models, reaction models, thermodynamic models, empirical and semi-empirical models, variable activation energy models, geochemical models and thermodynamic models [19]. The purpose of this work is to optimize the process of leaching of FKF in high-modulus recycled aluminate solution with the addition of active form of calcium oxide using response surface methodology, which determines the influence of factors on the system of technological variables—concentration of alkaline solution, the amount of calcium additive from the ratio of CaO/SiO_2, temperature and duration of the process.

2. Materials and Methods

The initial raw material for the experiments was a finely dispersed kaolinite fraction (FKF), isolated from bauxites of the Krasnogorsk deposit at the Pavlodar Aluminum Plant (Kazakhstan). The amount of FKF in bauxite is 50–60%. Currently, FKF is not processed and is stored due to a lack of effective technology.

X-ray fluorescence spectra were determined with a Venus 200 spectrometer with wave dispersion (PANalyical B.V., Holland, (PANalyical, Almelo, The Netherlands)). Chemical analyses were performed with an optical emission spectrometer with inductively coupled plasmas (Optima 8300 DV, PerkinElmer, Waltham, MA, USA). The random errors were 2.0%. X-ray diffraction studies were performed with a D8 Advance instrument (Bruker, Billerica, MA, USA) with Cu Kα radiation at 40 kV and 40 mA. Chemical activation of the FKF was carried out via thermochemical treatment [15] in a solution containing 120 g/dm^3 NaHCO3 at a temperature of 200 °C for 60–90 min. After chemical activation, hydrochemical leaching of the FKF was carried out with the addition of active calcium oxide in an aluminous alkaline solution (g/dm^3: Na_2O_{tot} 245.0; Na_2O_{kaus}t 11.4; Al_2O_3 13.43; temperature 220–280 °C, duration 1.0–6.0 h, ratio L:S = 4:1 and ratio CaO/SiO_2 = 1.0–2). Leaching was carried out in an autoclave with constant mechanical stirring. The active form of calcium oxide was prepared by obtaining a finely dispersed powder of slaked lime in a solution containing 20 g/dm^3 Na_2SO_4 at a temperature of 200 °C for 2 h [14].

Experimental Design

The design of experiments (DoE) with response surface methodology (RSM) is a powerful tool for evaluating and optimizing hydrometallurgical processing parameters. This mathematical and statistical method is also used to construct a second-degree model (Equation (1)) showing the relationship between the response (metal recovery) and the independent variables (target parameters).

$$y = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ii} x_i^2 + \sum_{i=1}^{k-1} \sum_{j=i+1}^{k} b_{ij} X_i X_j \quad (1)$$

Here, y is the predicted response value; b_0 is a constant; b_i, b_{ii} and b_{ij} are linear coefficients, quadratic terms and interactions, respectively; and k is the number of factors.

Response surface methodology (RSM) investigates the relationships among several independent variables and one or more response variables [20,21]. Based on the results of the leaching experiments, a reasonable range for each experimental parameter was chosen for the experimental design. The total number of experiments (N) was determined with Equation (2):

$$N = 2k + 2k + n_0 \quad (2)$$

where k is the number of experimental parameters and n_0 is the number of repetitions at the center points. The interactions that significantly affected the Al_2O_3 recovery rate included four parameters: the leaching time (A), temperature (B), Na_2O concentration and CaO/SiO_2 ratio (Tables 1 and 2).

Table 1. Parameters and corresponding levels in optimization experiments.

	ID	Parameters	Range
Variable Parameters	1	Leaching Time	1–6 h
	2	Temperature	220–280 °C
	3	Na_2O Concentration	220–300 g/L
	4	CaO/SiO_2	100–200%
Fixed Parameters	5	Pulp Density	20%
	7	Stirring Rate	300 RPM

Table 2. Parameters for Al_2O_3 leaching in the DoE.

Process Parameters	Units	Symbols	Low Level	High Level
Leaching Time	H	A	1	6
Temperature	°C	B	220	280
Na_2O Concentration	g/L	C	220	300

3. Results

The chemical and phase composition of FKF from the XRF analysis is shown in Table 3 and Figure 2.

Table 3. Chemical analysis results for FKF.

XRF Analysis Results (%)								
Fe_2O_3	SiO_2	MgO	Al_2O_3	CaO	TiO_2	Na_2O	K_2O	Other
16.9	19.6	0.26	39.8	1.45	3.4	0.18	0.06	18.35

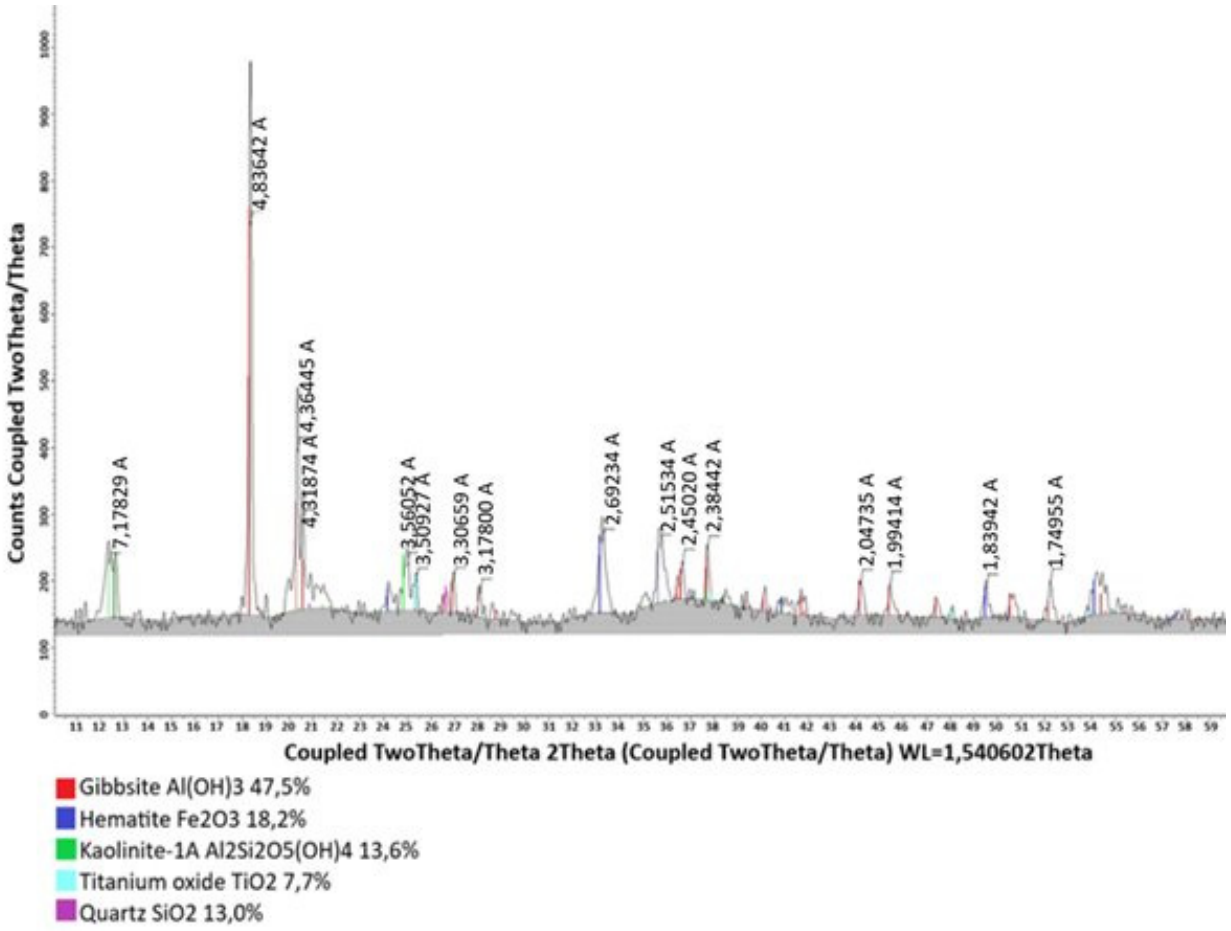


Figure 2. X-ray phase analysis of fine kaolinite fraction of bauxite.

The chemical activation of FKF was carried out using thermochemical treatment in an autoclave in a $NaHCO_3$ solution at a temperature of 200 °C (Table 4). The results of changes in the phase composition of FKF after chemical activation are given in Table 4.

Table 4. Phase composition of FKF depending on the duration of chemical activation.

Name of Phases	Content, %			
	Duration, min			
	Initial	30	60	90
Gibbsite	47.5	40.8	31.2	-
Kaolinite-1A	13.6	34.9	45.1	-
Hematite	18.2	18.2	18.2	8.5
Anataz	7.7	6.1	5.5	-
Quartz	13.0	-	-	-
Dawsonite	-	-	-	57.7
Sodium hydroaluminosilicate	-	-	-	33.9

As a result of chemical activation, the original aluminum-containing phases gibbsite and kaolinite disappear with the formation of dawsonite, sodium hydroaluminosilicate and boehmite. The complete disappearance of gibbsite and kaolinite occurs at a duration of 90 min. Due to the fact that, according to X-ray phase analysis data, quartz was not included in the composition of the new phases, we can conclude about its transition to the X-ray amorphous state. The chemistry of the formation of new phases can be represented in the form of the following equations: interaction of gibbsite with sodium hydrogen carbonate

to form dawsonite (1) and interaction of kaolinite with sodium hydrogen carbonate to form sodium hydroaluminosilicate (2):

$$Al_2O_3 \cdot 3H_2O + 2NaHCO_3 = 2NaAlCO_3(OH)_2 + 2H_2O \quad (3)$$

$$3Al_2O_3{\cdot}2SiO_2\ (OH)_2 + 6NaHCO_3 + 4SiO_2 = 3(Na_2O{\cdot}Al_2O_3{\cdot}2SiO_2 \cdot H_2O) + 6CO_2 + 3H_2O \quad (4)$$

Chemical analysis and X-ray image of the FKF after chemical activation lasting 90 min is shown in Table 5 and Figure 3.

Table 5. Chemical analysis of FKF after chemical activation.

XRF Analysis Results (%)								
Fe_2O_3	SiO_2	MgO	Al_2O_3	CaO	TiO_2	Na_2O	K_2O	Other
16.9	19.6	0.26	39.8	1.45	3.4	6.7	0.06	11.8

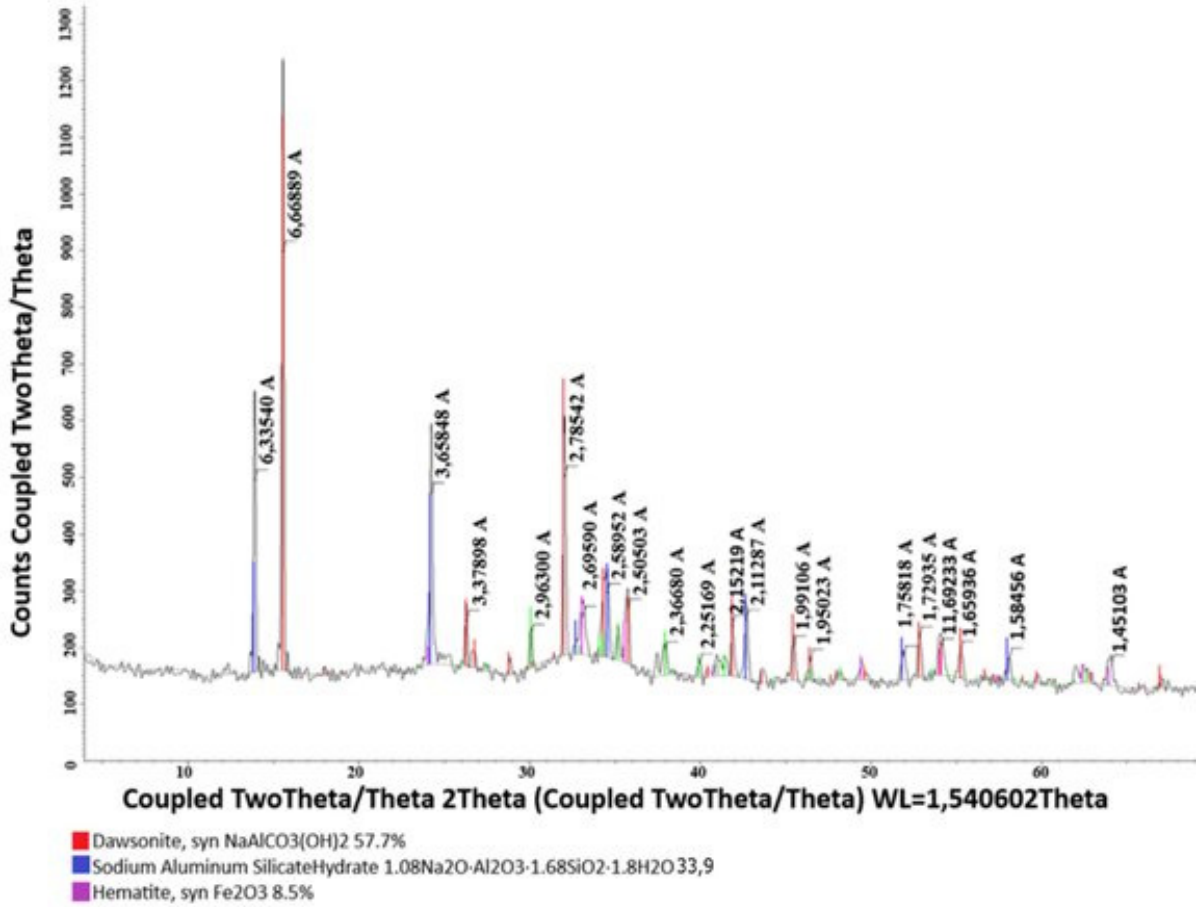
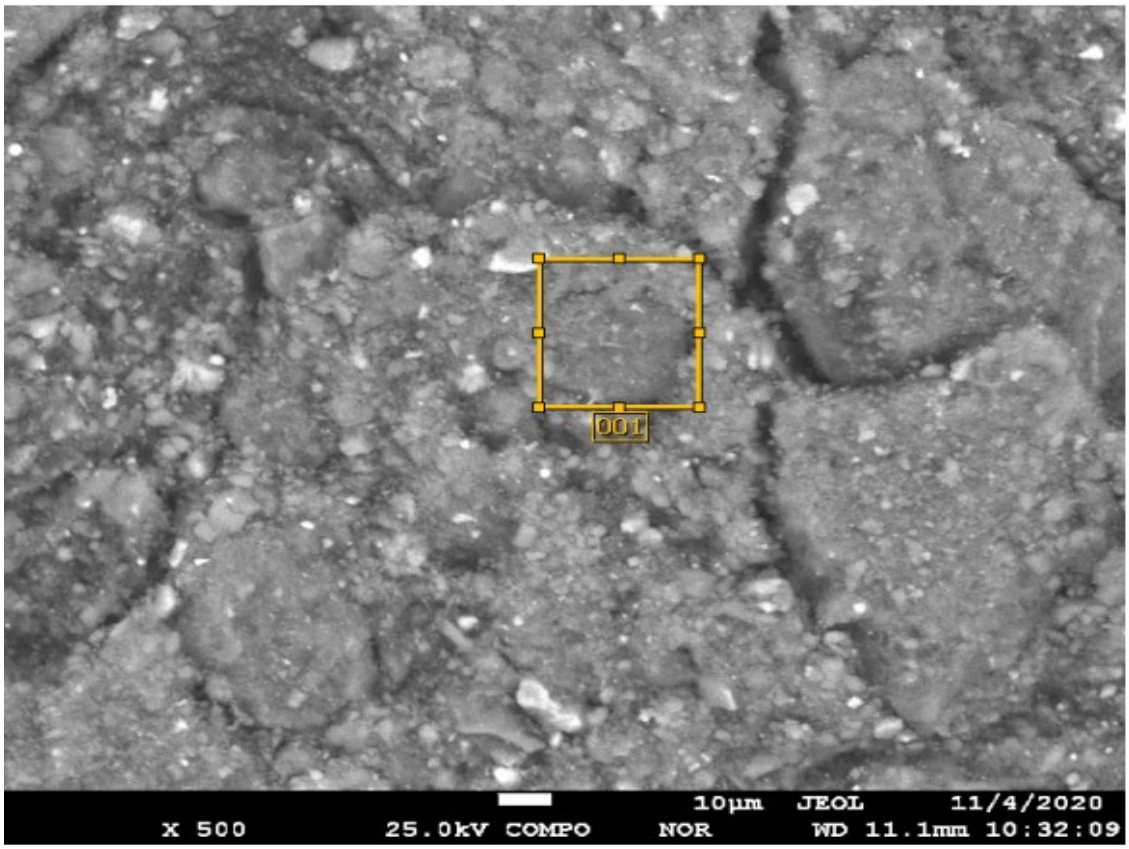
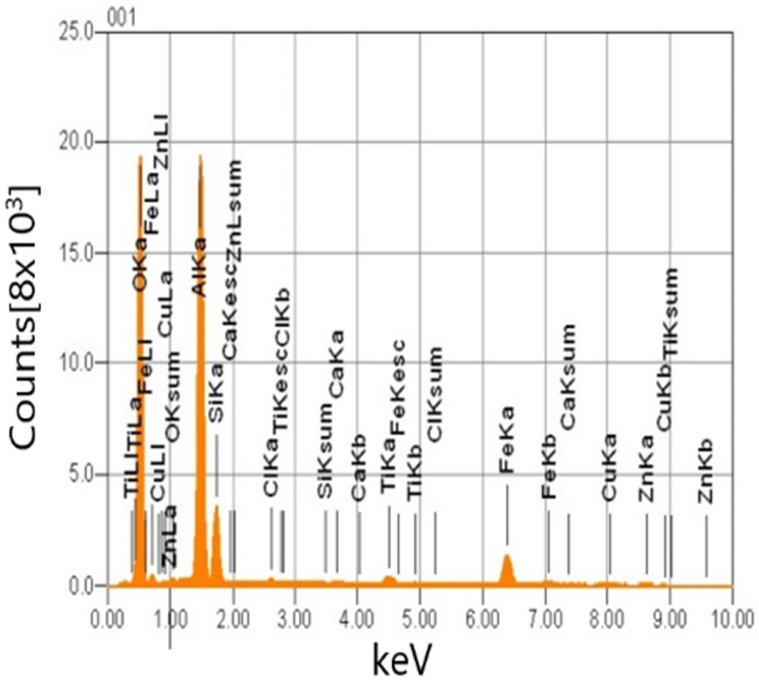


Figure 3. X-ray image of FKF after chemical activation.

Scanning electron microscopic analyses of FKF samples before and after chemical activation are presented in Figures 4 and 5.

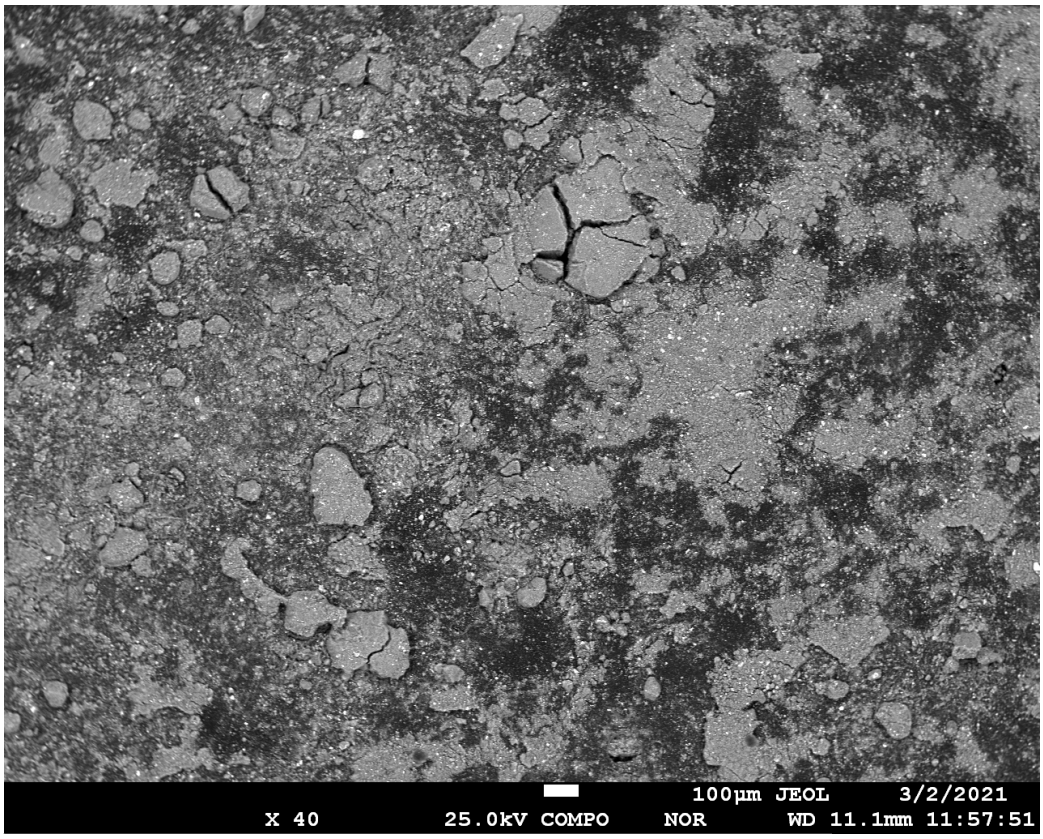
Scanning electron microscopic analyses of FKF after chemical activation (Figure 5) confirmed the presence of Na_2O in its material composition. Visually, it is possible to observe the loose structure in comparison with the initial one (Figure 4). In Figure 4, the sample is represented by clay lumps in which kaolinite is the binder.

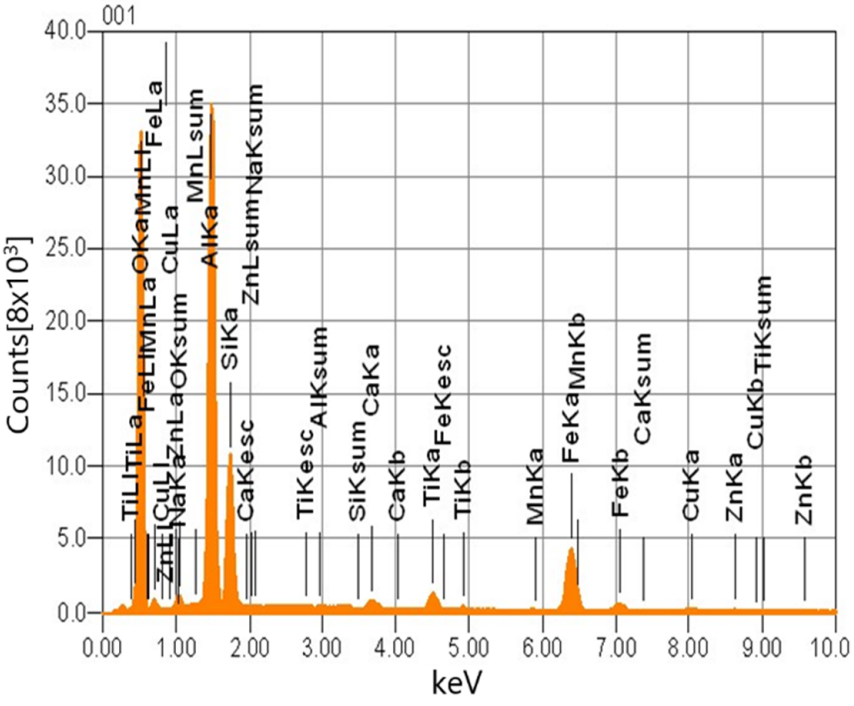




El	ms%
O	68.09
Al	10.35
Si	4.2
Cl	0.21
Ti	2.14
Fe	13.97
Cu	0.57
Zn	0.47
Total	100

Figure 4. Scanning electron microscopic analyses of initial FKF.





El	ms%
O	58.06
Al	12.1
Si	5.2
Ti	2.54
Fe	14.1
Cu	0.5
Zn	0.5
Na	7.0
Total	100

Figure 5. Scanning electron microscopic analyses of FKF after chemical activation.

Statistical Analysis and Interpretation of Responses

The results of the experimental data of the FKF leaching process obtained from the design of the planned model are presented in Table 6.

Table 6. Central composite design matrix for four variables and one response (Al_2O_3).

Runs	Leaching Time (H)	Temperature (°C)	Na_2O Concentration (g/L)	CaO/SiO_2	Al_2O_3 (%)
1	3.50	250	260	150	78
2	1.00	230	260	150	66.1
3	1.00	230	220	100	55.8
4	3.50	250	260	150	76.6
5	6.00	280	300	100	67.5
6	6.00	220	220	100	65.4
7	6.00	220	260	150	60.4
8	1.00	250	260	150.	66.5
9	6.00	240	220	200	63.8
10	3.50	230	220	150	77.1
11	3.00	220	260	150	72
12	1.00	280	220	200	63.8
13	1.00	240	220	100	61.2
14	1.00	240	220	200	55.2
15	3.50	250	260	150	75.4
16	6.00	240	300	100	68.3
17	3.50	230	220	150	61.4
18	1.00	280	300	200	69.7
19	3.50	280	260	150	75
20	6.00	240	300	200	67.1
21	1.00	220	300	200	65.2
22	1.00	240	300	100	60.2
23	3.50	260	260	150	77.8
24	3.50	220	260	150	70
25	6.00	240	220	100	67.2
26	3.50	230	260	200	71.8
27	5.00	260	260	150	87.9
28	3.50	230	300	150	81.7
29	6.00	280	300	100	66.7
30	1.00	220	300	100	41.3

Based on the results of the planned experimental design, the key experimental parameters, namely the leaching time, temperature, concentration of Na_2O and ratio of CaO/SiO_2, were investigated with the central composite design (CCD) method in the Design Expert 7.0 model. Table 6 shows the results of the DoE, including the effects of combining different parameters and their corresponding leaching efficiencies. The results showed that the leaching efficiencies of Al_2O_3 were 41.3–87.9%, and the maximum yield was 87.9%. Analysis of variance (ANOVA) was used to identify the most influential parameters and their interactions. The modified quadratic model was also used to predict the efficiency of Al_2O_3 recovery. The codes used in the equations and their corresponding parameters were A (leaching time), B (temperature), C (Na_2O concentration) and D (CaO/SiO_2). A second-order regression model with a coefficient of $R^2 = 0.6886$ was used for Al_2O_3 leaching. For Al_2O_3 recovery, the predicted R^2 of 0.4805 was in reasonable agreement with the adjusted R^2 of 0.6074 (Table 7). "Adeq Precision" measured the signal-to-noise ratio. A ratio greater than 4 was desirable [22]. Our ratio of 10.202 indicated adequate signal strengths. This model can be used to navigate the design space. The model equation created with real values was expressed as

$$Al_2O_3\ (\%) = 76.48 + 3.30 \times A + 4.72 \times B + 1.35 \times C + 1.40 \times D + 3.4 \times C \times D - 11.70 \times A^2 \quad (5)$$

The results from Table 8 show that all parameters had a significant effect on the Al_2O_3 recovery efficiencies. A p value of less than 0.05 indicated statistical significance, which proved the importance of the model and the parameters [23]. In this case, A, B, C, D and A^2 were significant model terms. Values greater than 0.1000 indicated that the model terms were not significant.

Table 7. ANOVA for response surface model (Al_2O_3).

Std. Dev.	5.67	R-Squared	0.6886
Mean	67.87	Adj R-Squared	0.6074
CV%	8.35	Pred R-Squared	0.4805
PRESS	1231.37	Adeq Precision	10.202

Table 8. Analysis of variance table of Al_2O_3.

Source	Sum of Squares	df	Mean Square	F Value	*p*-Value Prob > F	
Model	1632.15	6	272.02	8.48	<0.0001	Significant
Leaching Time	189.17	1	189.17	5.89	0.0234	
Temperature	266.07	1	266.07	8.29	0.0085	
Na_2O Concentration	30.75	1	30.75	0.96	0.3378	
CaO/SiO_2	28.62	1	28.62	0.89	0.3548	
CD	159.18	1	159.18	4.96	0.0360	
A2	890.19	1	890.19	27.74	<0.0001	
Residual	738.13	23	32.09			
Lack of Fit	611.18	19	32.17	1.01	0.5615	Not significant
Pure Error	126.95	4	272.02	8.48	<0.0001	

Figure 6 shows the relationship between the predicted and actual leaching efficiencies. The blue points are the minimum output values, and the red points are the maximum output values. It is obvious from these data that the regression models were effective since the experimental and forecasted values matched well. This conclusion was drawn from the fact that the majority of the intersections between the experimental and predicted values were near the median line.

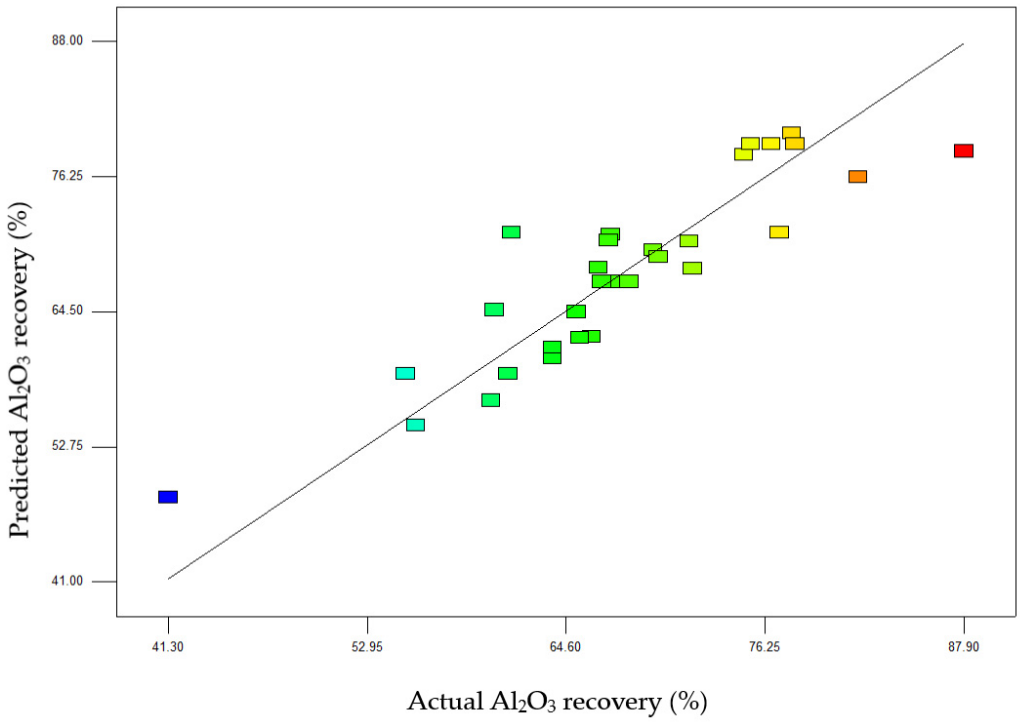
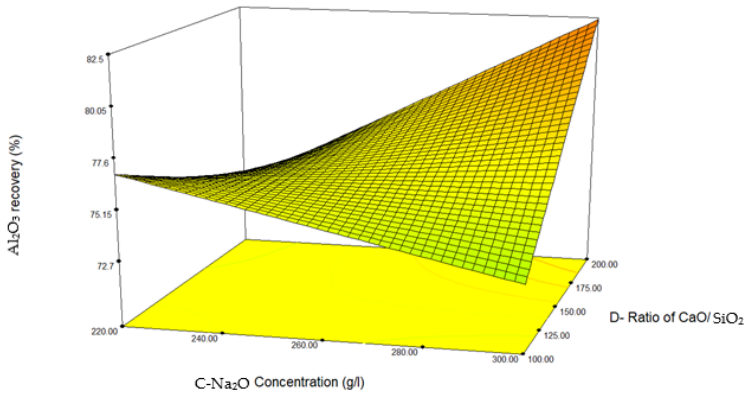


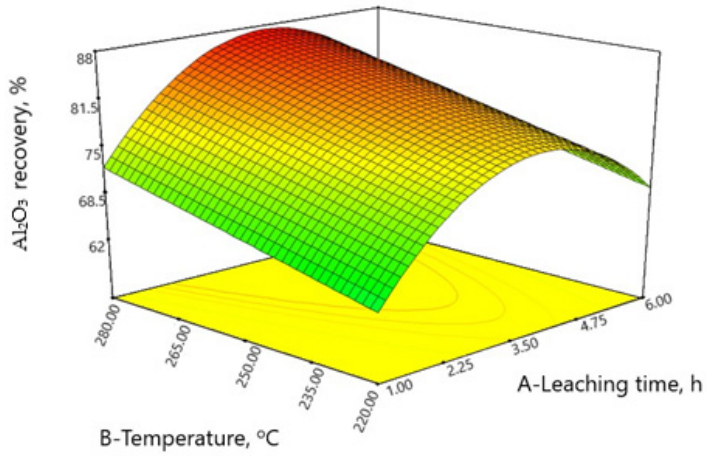
Figure 6. Experimental and predicted leaching efficiency. The color difference in the square shows the recovery of Al_2O_3 from low (green) to high (red).

To study the relationships among the variables and the responses, three-dimensional response surface plots were constructed for the regression model. Figure 7 shows the three-

dimensional response surface plots of the experimental parameters with high reciprocities. As shown in Figure 7a,b, the interaction of CD had a significant effect on the response, and the effects of C (the Na_2O concentration) and D (the CaO/SiO_2 ratio) had greater impacts on the Al_2O_3 leaching efficiency than the other factors, as did A (leaching time) and B (temperature), which were the same as the F values in Table 2. When the ratio of CaO/SiO_2 is low, high Na_2O concentration leads to an increase in pulp viscosity, which hinders the leaching process. A viscous system requires an increased flow rate of the ratio of CaO/SiO_2 to obtain the desired results. Increasing the flow rate of the ratio of CaO/SiO_2 reduces the efficiency of the process. With increasing temperature, the reactivity of metals also increases. However, at a temperature of 260 °C, the system comes to a thermodynamic equilibrium and further increase does not lead to an increase in leaching efficiency. The results showed that the predicted model reflected the relationships between the experimental and predicted results well. Therefore, RSM was also used to optimize the leaching conditions. The obtained optimal experimental parameters were 260 °C, a 260 g/L Na_2O concentration, a 1:1 ratio of CaO/SiO_2 and a leaching time of 5 h. The predicted leaching efficiency was 87.9%, while the experimental result with the optimum experimental parameters was 89.7%. Due to the closeness of the results, the experimental parameters were optimized with the RSM.



(**a**)



(**b**)

Figure 7. Three-dimensional plots of interaction variables: (**a**) Na_2O concentration and the ratio of Ca/SiO_2; (**b**) temperature and the leaching time.

All the fixed parameters used were the values of the mean point and the relevant interaction parameters versus the response. Figure 7a shows that for a fixed leaching time and temperature, decreasing the Na_2O concentration and increasing the CaO/recovery ratio increased the Al_2O_3 recovery efficiency. Figure 7b shows a maximum recovery of Al_2O_3 of 87.5%, at which three parameters were adjusted, and the leaching time set with these values was observed [24].

The constructed response surface model allows, when organizing the leaching process, for the control of input parameters, such as Na_2O concentration, temperature, CaO/SiO_2 ratio and leaching time, and for the evaluation of output parameters [21]. Response surface software (Design Expert 7.0) provided several different leaching solutions, and their costs were then compared. When the leaching temperature time was longer, the heating cost was increased. The optimization process involved using the DoE parameters and results to determine the optimal responses. Consistent with the findings of previous investigations, input variable ranges, namely a Na_2O concentration of 220–300 g/L, a temperature of 220–280 °C, a CaO/SiO_2 ratio of 1–2 and a leaching time of 1–6 h, were entered into the Design Expert program to predict the efficiency of Al_2O_3 recovery. The program generated several solutions, one of which was selected based on its desirability, with a value close to 1 considered appropriate [25].

The optimized prediction parameters were 260 g/L Na_2O concentration, 260 °C, a CaO/SiO_2 ratio of 1.5 and a leaching time of 5 h. The corresponding recovery efficiency for Al_2O_3 based on these parameters was 89.7%, with a desirability score of 0.916.

To validate the predicted responses generated by the program, two experimental tests were carried out under the specified optimum conditions. The predicted and experimental results are shown in Table 9.

Table 9. Predicted and experimental results under optimum conditions.

Leaching Time	Temperature °C	Na_2O Concentration	CaO/SiO_2 Ratio	Provision from the Optimization		Experimental Results
				Al_2O_3	Desirability	Al_2O_3
5	260	260	1.5	87.9	0.916	89.7

The experimental alumina recovery rate was only 2.01% above the predicted value. These results were in close agreement with the predicted values, confirming the validity and reliability of the model. Leaching of the FKF with the addition of active calcium oxide resulted in waste sludge and an aluminate solution.

Chemical composition of the aluminate solution, g/dm^3: Na_2O_{tot} 250.1; Na_2O_{kaust} 11.2; Al_2O_3 38.09; SiO_2.

Chemical composition of dump sludge, wt.%: Al_2O_3 5.74; SiO_2 18.9; Fe_2O_3 10.3; CaO 28.35; Na_2O 1.1; TiO_2 4.0; and other 31.61.

An X-ray image of waste leaching sludge is presented in Figure 8.

The chemistry of the process of hydrochemical leaching of FKF in HMS with the addition of the active form of calcium oxide, taking into account the results of the X-ray phase analysis, can be expressed using the following equations:

– As a result of the interaction of dawsonite with the active form of calcium oxide, calcium carbonate precipitate and sodium aluminate are formed, which passes into solution:

$$NaAlCO_3(OH)_2 + Ca(OH)_2 \rightarrow NaAl(OH)_4 + CaCO_3\ ; \quad (6)$$

– As a result of the interaction of sodium aluminum silicate, amorphous silica (obtained as a result of chemical activation) and the active form of calcium oxide, a precipitate consisting of katoite and sodium–calcium–hydrogen silicate is formed, and sodium aluminate passes into the solution:

$$2(Na_2O{\cdot}Al_2O_3{\cdot}\ SiO_2{\cdot}4H_2O) + SiO_2 + 5Ca(OH)_2 \rightarrow 2NaAl(OH)_4 + 3CaO{\cdot}Al_2O_3{\cdot}SiO_2{\cdot}4H_2O + Na_2{\cdot}2CaO{\cdot}2\,SiO_2{\cdot}H_2O + \ 4H_2O \quad (7)$$

Amorphous silica was formed in the FKF as a result of the chemical activation operation.

According to the developed technology (Figure 8), further processing of the aluminate leaching solution to obtain Al_2O_3 is associated with carrying out operations under the specified conditions for the synthesis of tricalcium hydroaluminate (TCHA), its decomposition in a soda solution to obtain an aluminate solution for the carbonization separation of $Al(OH)_3$ and its calcination. The waste sludge obtained as a result of leaching can serve as a raw material for construction materials.

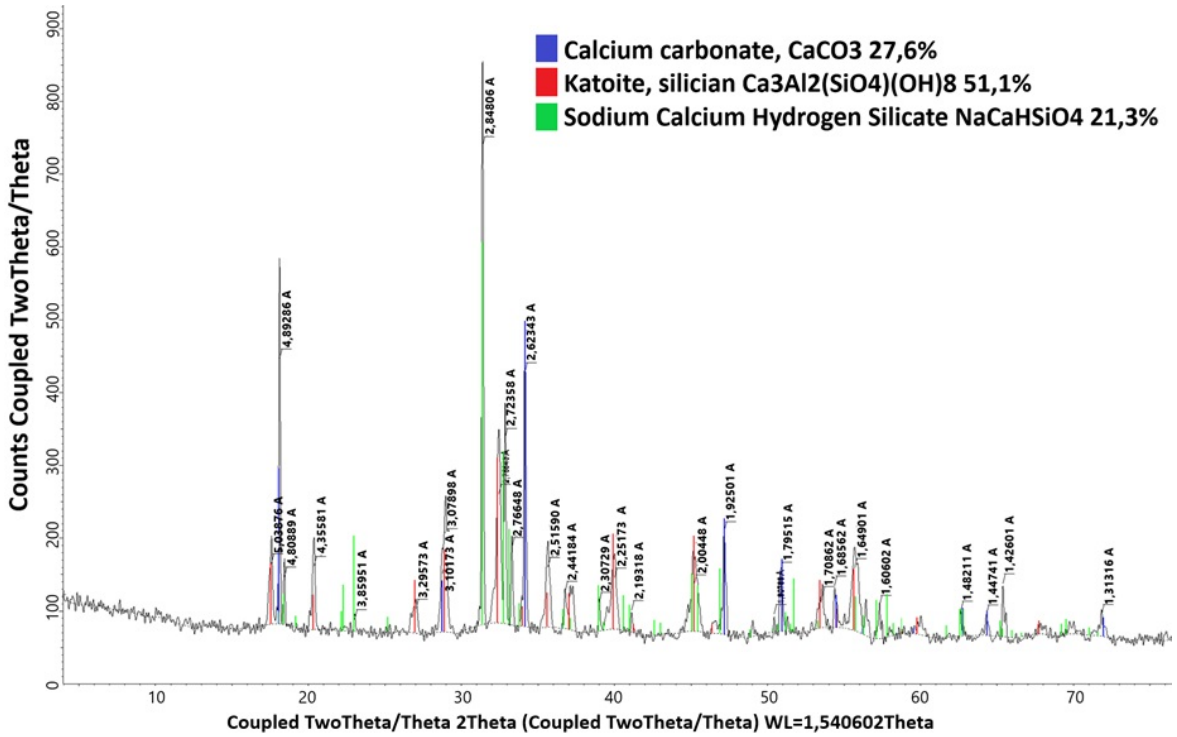


Figure 8. X-ray image of waste leaching sludge.

4. Conclusions

A technology for the hydrochemical processing of the kaolinite fraction of bauxite has been developed, involving preliminary chemical activation in a solution of sodium bicarbonate and alkaline leaching in a circulating high-modulus solution with the addition of an active form of calcium oxide. Using the response surface methodology, this technological mode was optimized. The influence of the concentration of the alkaline solution, the CaO/SiO_2 ratio, temperature and duration on the leaching process was studied. It was found that the determining factors are the concentration of the leaching solution and temperature. With a stable CaO/SiO_2 ratio, a combination of these two factors determines the duration of the process to achieve the predicted degree of recovery. This is because the temperature determines the thermodynamic possibility of the process of formation of certain phases, and the concentration of the leaching solution determines the degree of extraction of components. The combination of these factors determines the duration and the result of the process. The results of experiments carried out using the developed model of the leaching process confirmed the validity of the calculated indicators, with an error of 2.01%. In the optimal technological mode at a Na_2O leaching solution concentration of 260 g/L, a temperature of 260 °C, a CaO/SiO_2 ratio of 1.5 and a leaching time of 5 h, the extraction of Al_2O_3 into the solution was 89.7%, which is close to the value of 87.9%

predicted by the model. Modeling can provide reliable data for pre-feasibility studies, which simplifies the decision-making process. The development and successful application of the proposed model will add value to the alumina refinery feedstock expansion chain.

Author Contributions: Conceptualization, S.D. and S.G.; methodology, A.B.; software Y.A.; validation, S.G., Y.A. and A.B.; formal analysis, A.K.; investigation, Y.A.; resources, S.G.; data curation, S.D.; writing—original draft preparation, Y.A.; writing—review and editing, Y.A.; visualization, A.K.; supervision, A.K.; project administration, S.G.; funding acquisition, S.D. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP14869208).

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

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