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Short communication

Recovery of gibbsite from secondary aluminum production dust by caustic leaching

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ABSTRACT

The disposal of aluminum bearing dust can cause heat and gases, as well as the potential generation of leachate from landfills. In this research, we suggested a two-step process - leaching and precipitation - for recovering gibbsite from secondary aluminum production dust. First, a sodium aluminate solution, containing about 20 g/L of aluminum, was prepared using 1 M of sodium hydroxide leaching. Precipitation of the gibbsite was then conducted for 30 min after a pH adjustment. As the results indicate, the overall aluminum recovery rate was about 87% by weight after leaching and precipitation, and the major component of the precipitate was $Al(OH)_3$ based on an X-ray diffraction(XRD) analysis.

1. Introduction

The main benefit of secondary aluminum production is its low energy consumption compared to the primary aluminum production (International Aluminum Institute, 2017; Altenpohl et al., 1998). For this reason, the amount of secondary aluminum production in the US has outpaced the primary aluminum production since 2001 (Kelly and Matos, 2014). Based on current trends, waste generation from secondary aluminum production will increase rapidly. Currently, dust generated from secondary aluminum production is being disposed of in MSW landfills, causing many different problems owing to aluminum-related reactions, such as the generation of heat, liquid leachate, and gases (Calder and Stark, 2010). Therefore, the recovery of aluminum from secondary aluminum production dust could be a solution relieving such environmental problems and ensuring a better sustainable metal production. Several researchers have investigated ways to obtain hydrogen gas for fuel cell applications from waste aluminum under different conditions (Dupiano et al., 2011; Wang et al., 2009; Soler et al., 2007). However, there have been few discussions on the recovery of aluminum from secondary aluminum production dust. In this study, we presented a two-step process for recovering gibbsite from such dust.

2. Experimental

This study mainly focused on a two-step process for the recovery of aluminum as gibbsite. Based on our preliminary research, a 1 M sodium hydroxide solution can dissolve more than 80% of aluminum after 10 min of leaching at 60 °C (Jung and Mishra, 2016). In this study, 25 g of secondary aluminum production dust, containing about 21.9 wt% of aluminum, as based on an X-ray fluorescence (XRF) analysis, was leached with 250 mL of a 1 M sodium hydroxide solution at room temperature. A rotating magnetic stir bar was used to agitate the solution at 500 rpm. After 1 h of leaching, the leach solution was vacuum filtered to separate the solid residues from the sodium aluminate solution. The chemical composition of leach solution was analyzed using an inductively coupled plasma atomic emission spectroscope (ICP-AES).

For the precipitation test, 50 mL of the sodium aluminate solution was transferred to a 100 mL size beaker. Then, 1 M of nitric acid was added in a dropwise manner while monitoring the pH of the solution. Precipitation was applied for 30 min after the pH adjustment to 10.5, and a rotating magnetic stir bar was used to mix the solution at 500 rpm. After 30 min of precipitation, the precipitates were vacuum filtered and rinsed with DI water three times. The filtered precipitates were dried for 12 h in a drying oven at 80 °C. The chemical phases of the dried precipitates were analyzed through X-ray diffraction (XRD). The chemical composition of the solution after precipitation was also analyzed using ICP for the mass balance during precipitation. Chemical equilibrium software, VisualMINTEQ, was utilized to obtain a speciation diagram.

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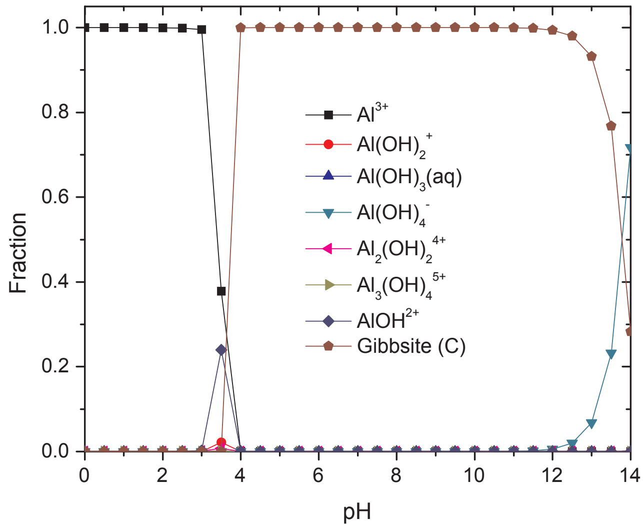

Fig. 1. Leaching of aluminum production dust: (a) Aluminum dissolution rate by time; (b) Aluminum speciation diagram at 0.1 M of Al^{3+} using VisualMINTEQ.

Table 1
Chemical composition of as received secondary aluminum production dust and its leach solution.

As-received sample (XRF)		Leach solution (ICP)	
Element	Composition, wt.%	Element	Concentration, g/L
Al	21.9	Al	20.21
Si	4.4	K	0.45
Fe	2.9	Si	0.22
Ca	2.3	S	0.06
Cu	1.7	Ca	0.01

3. Results and discussion

3.1. Preparation of sodium aluminate solution

As-received secondary aluminum production dust, which had a large number of aluminum metal pieces, was used to prepare a concentrated sodium aluminate solution. The reaction equation between aluminum and the sodium hydroxide solution is as follows:

$$Al + 3H_2O(l) + NaOH \rightarrow NaAl(OH)_4 + 1.5H_2(g) \quad \Delta H = -106.9\ \text{kcal/mol at } 25\,^{\circ}C \quad (1)$$

Table 2
Mass balance during gibbsite precipitation.

Five major elements	Leach solution pH 12.6, 50 mL	Leach solution pH 10.5, 50 mL	Recovered as precipitate from 50 mL leach solution
Al	1.011 g	0.056 g	0.955 g
K	0.022 g	0.016 g	0.006 g
Si	0.011 g	0.000 g	0.011 g
S	0.003 g	0.002 g	0.001 g
Ca	0.001 g	0.000 g	0.001 g

The exothermic reaction between aluminum and sodium hydroxide spontaneously increases the temperature of the leach solution, and thus we obtained approximately 90% of aluminum dissolution within 20 min, as shown in Fig. 1(a). Based on the XRF results as shown in Table 1, the sample showed five major elements, namely, Al, Si, Fe, Ca, and Cu, and the aluminum content was about 21.9% by weight. After 1 h of leaching, the leach solution was analyzed using ICP, the results of which showed aluminum content of approximately 20.2 g/L. Therefore, the percentage of aluminum dissolution was about 92.3%. Owing to the selective leaching characteristic, sodium hydroxide selectively dissolved the aluminum from the sample, and left the other impurities, such as Si, Fe, Ca, and Cu, within the residue.

3.2. Thermodynamic study of gibbsite precipitation

An aluminum speciation diagram was plotted using the chemical equilibrium software, VisualMINTEQ, as shown in Fig. 1(b). Detailed information regarding the reactions between the species and calculation has been revealed through several studies (Panias et al., 2001; Bensadok et al., 2008). As shown in Fig. 1(b), gibbsite was in a stable chemical phase at a pH of 4–12. When the pH of the solution was further increased to above 12, the formation of $Al(OH)_4^-$ was observed from the diagram. Because the sodium aluminate solution described in Section 3.1 had a pH of 12.6, we focused on the gibbsite precipitation by changing the pH of the leach solution from 12.6 to 10.5 to create more thermodynamically favorable conditions for the gibbsite precipitation.

3.3. Gibbsite precipitation through pH adjustment

For the gibbsite precipitation, the pH of the leach solution was changed from 12.6 to 10.5 by adding 1 M of nitric acid in a dropwise manner. Fig. 2(a) shows the precipitates obtained from the test. The chemical phases of the dried precipitate were $Al(OH)_3$ and $Al_{3.85}Si_{0.15}$

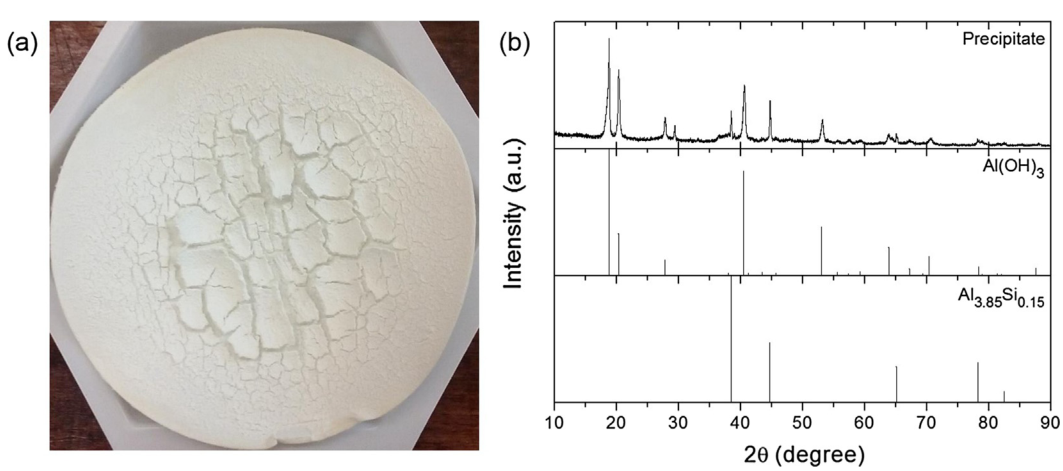

Fig. 2. Gibbsite precipitation: (a) filtered precipitate after drying; (b) XRD analysis of precipitate.

according to the XRD results, as shown in Fig. 2(b). Based on the mass balance analysis conducted during precipitation, as shown in Table 2, small amounts of silicon and potassium were also precipitated with the aluminum. Therefore, small $Al_{3.85}Si_{0.15}$ peaks can be observed from the XRD data; however, the amounts of these impurities, Si and K, were less than 2 wt%. Based on the results, about 94% of aluminum in the solution was recovered as precipitates within 30 min of precipitation. The overall aluminum recovery rate with the proposed two-step process was about 87% by weight. Several parameters, such as the temperature, impurity level, acid to caustic ratio, and precipitation kinetics, can be critical to the optimization of the gibbsite precipitation. Thus, further research, regarding these parameters needs to be conducted to determine the feasibility of this process.

4. Conclusion

In this research, aluminum in secondary aluminum production dust was recovered as gibbsite using leaching and precipitation methods. Approximately 92% of the aluminum was selectively dissolved using 1 M of sodium hydroxide after 1 h of leaching. An aluminum speciation diagram shows that $Al(OH)_4^-$ reached a stable phase after sodium hydroxide leaching at pH 12.6, and the stability of this product was closely related to the pH of the solution. Therefore, the precipitation of gibbsite was obtained by changing the pH of the solution. After 30 min of precipitation at pH 10.5, approximately 94% of the aluminum was recovered as gibbsite. Using a two-step process, the overall aluminum recovery rate reached about 87% based on the weight of the starting material. Through this study, we demonstrated the recovery of aluminum as gibbsite from secondary aluminum production dust. Because secondary aluminum production dust causes disposal problems in many landfill sites, this study suggests a possible way to alleviate environmental problems and the reuse of the waste material as a secondary metal source.

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