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Leaching kinetics of mechanically activated boron concentrate in a NaOH solution

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ABSTRACT

Mechanical activation is an effective pretreatment method that can change the properties of boron concentrates, thus promoting B_2O_3 leaching from samples. Four boron concentrate samples were milled for 0, 10, 30, and 60 min and leached in a NaOH solution at various leaching temperatures and initial NaOH concentrations. We investigated the main control steps for leaching and obtained the kinetic parameters. We discuss the influences of the specific surface area and surface free energy on the apparent rate constants. During the early-stage leaching (0–20 min), the leaching process was controlled by a combination of the surface chemical reaction and diffusion through the product layer; however, the surface chemical reaction was the main controlling step with an apparent activation energy of 29.37–39.77 kJ/mol. During the late-stage leaching (> 40 min), the leaching process of the milled samples was controlled by a combination of the surface chemical reaction and diffusion through the product layer; in contrast, that of the unmilled sample was controlled by the surface chemical reaction and showed a high apparent activation energy of 69.14 kJ/mol. With increasing milling time, the apparent activation energy and reaction order decreased, thus reducing the dependence on temperature and NaOH concentration. The leaching rate constants were related to the specific surface area, surface free energy, and other properties, such as crystal amorphization and chemical bonds stability. After milling for 60 min, the surface free energy increased from 26.88 to 33.99 mJ/m^2, and the Lewis acid component increased from 0 to 3.31 mJ/m^2, promoting the absorption of the solvent and OH^- in the leaching solution, which also accelerated the leaching rate.

1. Introduction

Boron ore reserves in China are abundant, but most have a low boron content and a complex mineralogy; such minerals are known as lean ores. Ludwigite is one of the most representative lean ores (Li et al., 2014a,b), and cannot be used as raw mineral for the extraction of boron directly. But its product, boron concentrate, which is obtained by performing a magnetic and gravity separation treatment (Zhu, 2012), is used by the Chinese boron industry as a substituted material to produce boron. However, the boron yield is extremely low because of the low B_2O_3 activity. Therefore, suitable processing technologies are needed to enhance the activity of boron concentrate and the extraction of boron from this mineral (Liang et al., 2017; Xu et al., 2017; Jiang et al., 2016).

Traditional roasting processes cannot increase the activity of the boron concentrate to the desired values (Jiang et al., 2016) and usually fail to enhance the B_2O_3 leaching ratio beyond 80% after 2 h of alkaline leaching. In addition, this method also causes over-burning to occur during industrial production. In addition, the depletion of fossil fuel resources and emission of pollutants, such as NO_X and SO_2 (Xu et al., 2017; Jiang et al., 2016), during the roasting process are significant concerns.

Mechanical activation (MA) is a procedure that improves hydrometallurgical processes by increasing the surface area of the minerals and reducing their crystallinity (Basturkcu et al., 2017; Baláž, 2003); this method can substantially accelerate the extraction of desirable components from various ores (Alex et al., 2014a,b,c; Baláž, 2008, 2003, Baláž et al., 2000; Ficeriová et al., 2002; Mulak et al., 2002), even under industrial conditions. Because MA does not need to be carried out in a high-temperature environment, it can overcome the flaws of the roasting method mentioned above. The B_2O_3 leaching ratio can be enhanced to 89.47% from boron concentrate after MA (Xu et al., 2017); however, it only reached 83.00% using the optimized roasting method (Zhang, 2015).

Studying the extraction of valuable metals from minerals and

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Table 1
Parameters of probe liquids and their contact angles to different samples.

Probe Liquid	γ Surface tension/(mJ/m^2)				θ Contact angle/(°)	
	γ_{SV}	γ_{SV}^{LW}	γ_{SV}^{+}	γ_{SV}^{-}	Untreated	60-min-milled
n-Hexane	18.43	18.43	0	0	0	0
Diiodomethane	50.8	50.8	0	0	62.74	62.82
Ethylene glycol	48	29	1.92	47	76.22	43.91
Ultrapure water	72.5	21.5	25.5	25.5	85.13	82.39

Table 2
Particulate characteristics of different samples of boron concentrate used.

Milling time/min	Characteristic diameters/μm			Specific surface area/(m^2/g)	Amorphization extent/%	
	d_{10}	d_{50}	d_{90}		Using Eq. (1)	Using Eq. (2)
0	1.31	13.20	68.36	15.65	0.0	0.0
10	0.70	2.52	6.12	20.28	15.8	7.1
30	0.74	4.90	27.68	24.18	21.7	19.1
60	0.74	6.23	28.23	27.70	24.1	23.0

d_x – x% of the particles below this size.

determining the kinetic parameters of leaching processes are the critical outcomes of physicochemical investigations in hydrometallurgy (Yao et al., 2011). The alkaline leaching process of szaibelyite is controlled by the chemical reaction (Qin et al., 2015), and the water-leaching process for sodium-roasted boron concentrate and the microwave-roasted alkaline-leaching process are controlled by both the chemical reaction and solid-product layer diffusion, but solid-product layer diffusion is predominant (Zhang, 2015; Zhu, 2012).

We studied the leaching kinetics of samples milled for different periods at various temperatures and initial NaOH concentrations to elucidate the reaction mechanism of alkaline leaching, to compare the leaching kinetics of different boron concentrate samples milled for different periods, and to establish the relationship between their properties and leaching behaviors; we evaluated the apparent rate constants, apparent activation energies, and reaction orders of different samples. In addition, some properties of the samples and their leaching

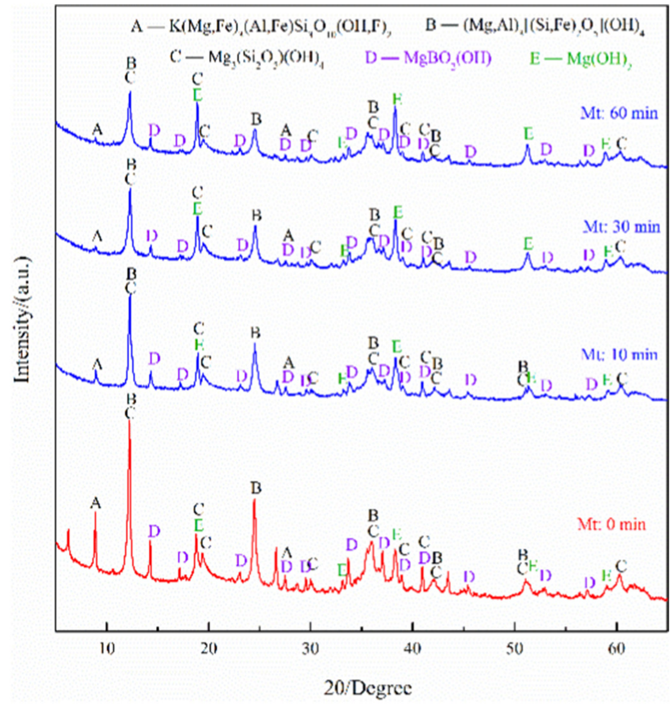

Fig. 2. XRD patterns of the leaching residue of boron concentrate milled at different times after leaching for 40 min (Mt: milling time).

residues are compared, and our conclusions will explain the leaching kinetics and the effects of the sample properties on the apparent rate constants.

2. Materials and methods

2.1. Materials

The boron concentrate used in this study was provided by Fengcheng Chemical Group Co., Ltd., China. The preparation and characterization of the raw mineral have been reported (Xu et al.,

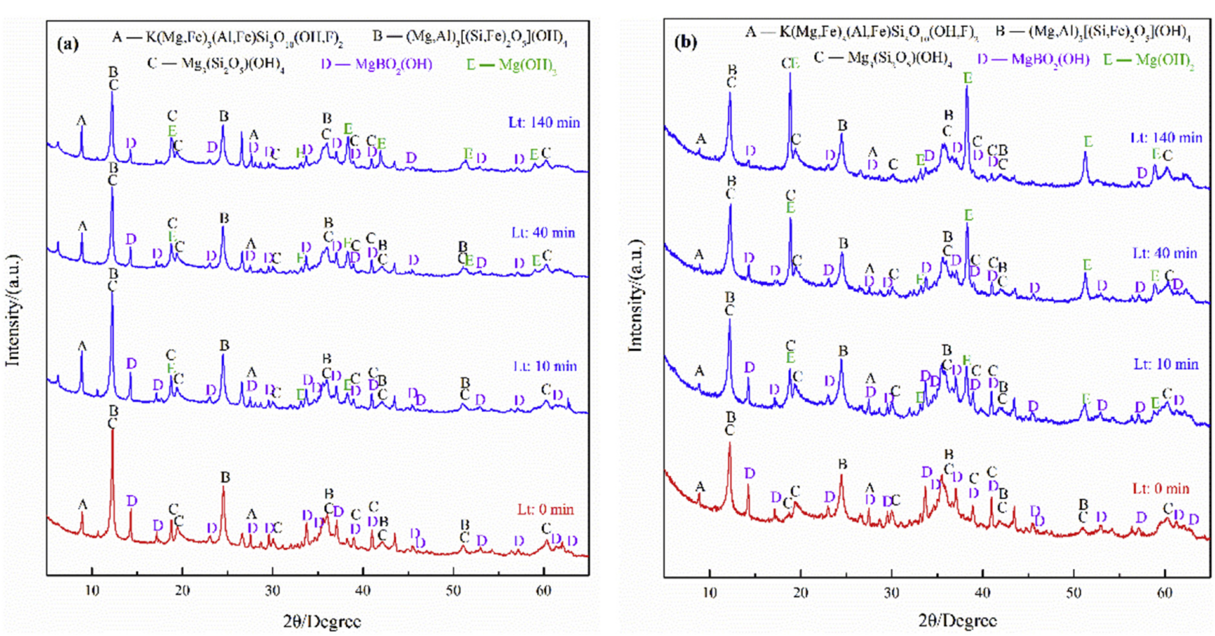

Fig. 1. XRD patterns of leaching residues after leaching for different durations: (a) leaching residues of the raw mineral and (b) leaching residues of the 60-min-milled sample (Lt: leaching time).