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Transformation and leaching kinetics of silicon from low-grade nickel laterite ore by pre-roasting and alkaline leaching process

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Abstract: The mineralogical phase transformation of a low-grade nickel laterite ore during pre-roasting process and the extraction of silicon during alkaline leaching process were investigated. The results indicate that the reaction activity of nickel ores is effectively improved by pre-roasting at 650 °C for 2 h, because of the transformation of lizardite into magnesium olivine and protoenstatite. When finely ground ore samples (44−61 μm) pre-roasted firstly react with sodium hydroxide solution (60 g/L) with a solid/liquid ratio of 1:5 at 140 °C for 120 min, the extraction of silicon can reach 89.89%, and the other valuable elements of magnesium, iron and nickel are accumulated in the solid residues. The leaching kinetics of nickel laterite ore can be described successfully by the diffusion through the product layer control model. The activation energy is calculated to be 11.63 kJ/mol and the kinetics equation can be expressed as $1-3(1-x)^{2/3}+2(1-x)=13.53\times10^{-2}\exp[-11.63/(RT)]t$.

Key words: low-grade nickel laterite ore; silicon extraction; mineralogical phase transformation; alkaline leaching kinetics

1 Introduction

In recent years, there has been an increasing attention for the development and utilization of nickel laterite ores, along with the rapid growth in stainless steel demand and the gradual depletion of sulfide ore reserves [1,2]. It is calculated that the laterite ore reserves which account for about 70% of the world's land-based nickel resources can be used as the dominant source of nickel [3,4]. However, only 40% of the world's nickel production is from nickel laterite ores currently [5]. The main reasons for limiting the development and utilization of the laterite ores are the economic factors of treating processes. Therefore, developing reasonable, feasible and economic techniques for treating nickel laterite ores has become a very urgent task.

Laterite ore deposits are formed by the chemical weathering of nickeliferous peridotite rock under humid climates [6,7]. Through long weathering processes, Ni^{2+} replaces Mg^{2+} and Fe^{2+} in the lattice of corresponding silicates and ferric iron oxides, and is closely in conjunction with iron oxide and silicate minerals [8]. The concentration of nickel in an ore-body is very low, and typical nickel content in Chinese laterite ore is less than 1%. The complex mineralogical structure has prevented nickel grade from being preconcentrated by some physical beneficiation means [9,10]. Thus, pyrometallurgical or hydrometallurgical methods are exploited for processing low-grade laterite ores.

The pyrometallurgical techniques including pre-reduction and reductive smelting in electric arc furnaces (EAFs) for production of Fe−Ni alloys are well suited for treating saprolitic laterite ores [11]. The primary disadvantage of these processes is that they require considerable energy expenditure which is two to three times higher than that for treating the sulfide ores [12].

High pressure acid leaching (HPAL), atmospheric (acid) leaching (AL) and heap leaching (HL) are referred as the prevailing technologies for hydrometallurgical

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processing of laterite ores [13]. However, they are more appropriate for treating limonite ore that has high iron content but low garnierite content. The leach liquor always contains significant concentrations of soluble iron and magnesium or aluminium, and these metal impurities need to be subsequently purified [14−16].

In recent years, ZHAI and MU [17,18] have proposed an approach for treating Chinese nickeliferous laterite ores. In this process, high concentration alkaline or molten sodium hydroxide system, carbonation decomposition and ammonia leaching are used for sequential extracting and separating silicon, magnesium, nickel and iron, so as to realize comprehensive utilization of nickeliferous laterite ores. Contrast with acid leaching methods, this process exhibits numerous advantages such as high reactivity, elimination of SO_2, high selectivity and good application prospect. The dosage of alkaline is a key factor for treating laterite ores, which determines the economy and environmental protection of the whole process. However, rare research results on alkaline leaching of laterite ores have been reported so far, and the transformation behavior and control steps of valuable components are necessary to be studied further.

Thus, in this work, a Chinese low-grade nickel laterite ore located in Sichuan Province, China, was used as the raw materials. The pre-roasting of nickel ores was conducted followed by leaching with sodium hydroxide solution to extract silicon element for preparing silica. The process can not only achieve the utilization of silicon element to reduce the discharge of solid waste, but also accumulate magnesium and nickel in the leaching residues as an important secondary source. The mineralogical phase transformation of nickel laterite ore during pre-roasting was studied. The effects of different variables, such as leaching temperature, leaching time, sodium hydroxide concentration, particle size and solid/liquid ratio (w/v) on the extraction of silicon were investigated. Different kinetics models were used to analyze the leaching kinetics of laterite ores to obtain Arrhenius activation energies and kinetics equation.

2 Experimental

2.1 Materials

A low-grade nickel laterite ore collected from Sichuan Province, China, was selected as the representative ore samples in this study. The ore samples were sieved and divided into four size fractions ranging from 44 to 178 μm using Tyler standard sieve. The chemical analysis of each size fraction conducted by X-ray spectrometer is listed in Table 1. Analytical grade sodium hydroxide was used as the leaching reagent in all experiments.

X-ray diffraction equipment using Cu K_α radiation was employed to identify the mineralogical components of ore samples from 10° to 70°. The results in Fig. 1 indicate lizardite ($Mg_3Si_2O_5(OH)_4$) and quartz (SiO_2) as major mineral phases, as well as hematite (Fe_2O_3) and trevorite ($NiFe_2O_4$) as minor phases.

Table 1 Main chemical compositions of nickel laterite ores at different size fractions

Particle size/μm	Mass fraction/%					
	SiO_2	MgO	Fe_2O_3	Al_2O_3	NiO	Cr_2O_3
150−178	35.66	17.81	29.33	4.94	1.12	0.46
104−124	36.27	17.32	29.46	4.87	1.16	0.43
74−89	36.74	16.44	29.75	4.68	1.15	0.48
44−61	36.29	17.79	29.80	4.82	1.14	0.44

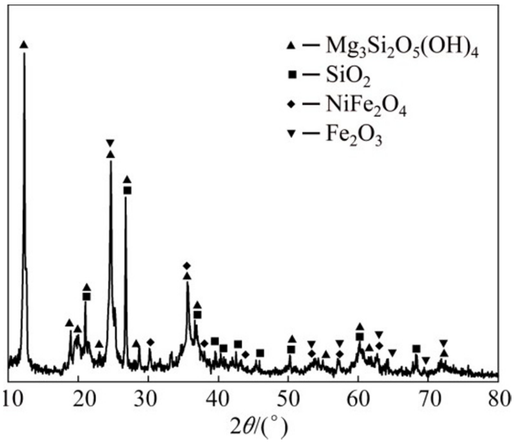

Fig. 1 XRD pattern of nickel laterite ores

2.2 Experimental procedure

The ore samples pre-roasted at a desired temperature in a muffle furnace for 2 h were used for leaching silicon. The leaching experiments were performed in a 1 L round-bottom, Teflon, three-neck flask, which was fitted with a condenser, a mechanical stirrer and a plastic funnel for adding the samples. Firstly, a certain concentration of sodium hydroxide solution (800 mL) was poured into the flask, which was heated in a thermostatic oil bath at a stirring speed of 600 r/min. Once the temperature reached predetermined value, the desired amount of ore samples were added from the plastic funnel into the flask. At definite time intervals, 1 mL sample was withdrawn and immediately dissolved into 100 mL deionized water. The slurry was filtered to collect the liquid samples. The silicon concentration in liquid samples was measured by standard titration method.

The chemical compositions, mineralogical components, specific surface area, DTA/TG curves, and surface morphology of samples were detected using X-ray spectrometer (S-max, Rigaku), X-ray diffraction equipment (Rigaku-Ultima IV, Japan), BET surface area