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Innovative technology for processing saprolitic laterite ores by hydrochloric acid atmospheric pressure leaching

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ABSTRACT

An innovative technology for processing saprolitic laterite ores from the Philippines by hydrochloric acid atmospheric leaching and spray hydrolysis is proposed. The factors that affect the hydrochloric acid atmospheric leaching of the laterite ores and spray hydrolysis of the atmospheric acid leach solution are investigated. Experimental results show that the leaching of Ni, Fe, and Mg is 98.9 wt%, 97.8 wt%, and 80.9 wt%, respectively, under optimal acid leaching conditions. The hydrolysis of Ni and Fe by the atmospheric acid leach solution approaches 100 wt% at the temperature range of 450–500 °C. Characterization results show that a serpentine mineral, nominally $Mg_3Si_2O_5(OH)_4$, is the major component and goethite, FeO(OH), is the minor one in the laterite ores. Treatment by hydrochloric acid atmospheric leaching breaks the mineral lattices of the laterite ores and makes amorphous silica the primary product in the atmospheric acid leach residue. The grade of Ni in the hydrolyzate increases to 4.55%. The hydrolyzate with high Ni content can be utilized for ferro-nickel production.

1. Introduction

Nickel is a strategic metal mainly utilized in the preparation of stainless steel and non-ferrous alloys with impact strength, corrosion resistance, and other electrical, heat, and magnetic properties (Li et al., 2012). The increased demand for nickel has depleted easily extractable Ni sulfide deposits and caused the mining industry to develop lateritic extraction technologies (Landers et al., 2009). Approximately 60% of land-based nickel reserves are contained in laterite ores (Luo et al., 2010). Laterite ores are iron-rich soil types formed under tropical climates through the prolonged mechanical and chemical weathering of ultramafic (ultra-basic) rocks (Loveday, 2008).

Traditional metallurgical technologies for laterite ore processing include pyrometallurgical refining (Jiang et al., 2013; Li et al., 2011), reduction roasting-ammoniacal ammonium carbonate leaching (Chander and Sharma, 1981; Ma et al., 2013a), high-pressure acid leaching (Johnson et al., 2005; Ma et al., 2013b; Whittington et al., 2003), and atmospheric pressure acid leaching (APAL) (McDonald and Whittington, 2008; Thubakgale et al., 2013; Wang et al., 2012). In particular, APAL for processing nickel laterite ores has become a research hotspot in hydrometallurgy because of the method's use of small equipment, mild reaction conditions, and low technical risk. However, the difficult separation of Ni from Fe in the acid leach solution and the large amount of acid consumption render the industrial application of APAL technology difficult (Zhang, 2012). The iron-containing mineral lattices of laterite ores must be broken to extract completely the Ni embedded in the lattices. Ni and Fe must be leached at the same time. This condition results in high iron concentration (>120 g/L) and low nickel concentration (2–3 g/L) in the acid leach solution. Traditional methods of removing iron from the acid leach solution, including neutralization, precipitation, and solvent extraction, could result in filtration difficulty, large entrainment loss of Ni, and large consumption of the extraction agent, respectively. Therefore, the process of solving the problems of large amount of acid consumption and difficult separation of Ni from Fe in the acid leach solution is the main hindrance in the industrial application of APAL technology.

With the above situation in mind, an innovative extraction technology called "atmospheric acid leaching-spray hydrolysis-reducing smelting ferro-nickel process" was developed by our research group to process saprolitic laterite ores from the Philippines (Guo et al., 2013). A pilot plant that tests 500 tonnes of raw ore per year was set up and has been operating since May 2013.

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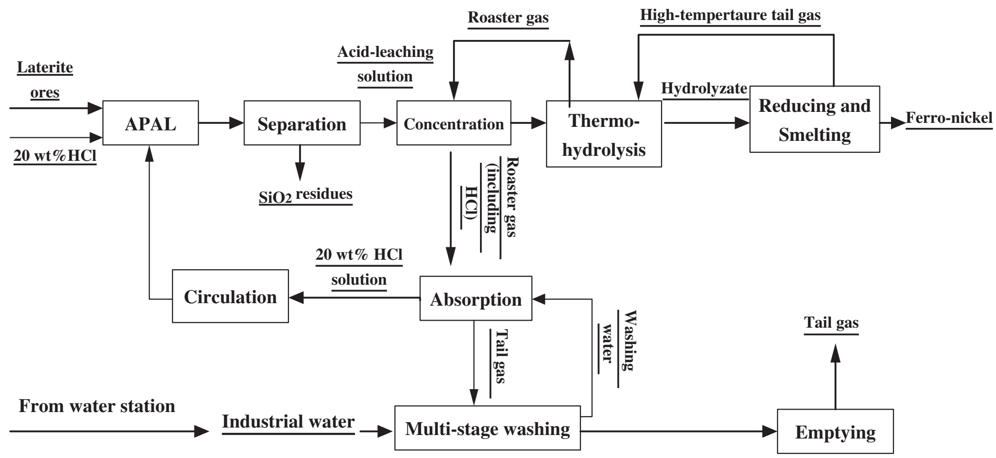

Fig. 1. The general process flow sheet of the new technology for processing the saprolitic laterite ores.

The general process flow of the new technology is shown in Fig. 1. This technology comprehensively separates valuable Ni and Fe from Si and Mg in the laterite ores and increases the grade of Ni in the hydrolyzate. It also reduces costs by recycling the acid media and recovering waste heat. The new process allows for the large-scale industrial application of laterite nickel ore resources.

The advantages of the new technology are as follows. First, the atmospheric acid leaching process efficiently extracts valuable Ni and Fe under mild operation conditions. Second, the grade of Ni in the hydrolyzate is increased because of the removal of some impurities (such as Si and Mg); thus, the production of ferro-nickel becomes easy. The reason is that all of the Si in the laterite ore are removed and form silica residues during the APAL process (Tables 2 and 7), and some of the Mg compounds (predominantly MgO and un-hydrolyzed $MgCl_2$) are generated with the hydrochloric acid as roaster gases and then collected into cyclone dust collectors during the spray hydrolysis process because of its lower density compared with the hydrolyzate (predominantly Fe_2O_3). Lastly, the hydrochloric acid media can be recycled during the acid regeneration process, and the high-temperature tail gas of the reducing-smelting ferro-nickel process can be utilized as the heat source for the spray hydrolysis process. This condition reduces raw material and energy costs.

The first and second parts of the new technology, namely, atmospheric acid leaching of saprolitic laterite ores from the Philippines by hydrochloric acid and spray hydrolysis of the atmospheric acid leach solution, are reported in detail in this study.

2. Experimental procedures

2.1. Materials

The saprolitic laterite ores utilized in this study were obtained from the Philippines. The laterite samples were crushed, and size analysis was performed by wet sieving, which indicated that fine fraction (74 μm) constituted 90 wt% of the samples. The results of typical composition analysis with an inductively coupled plasma–optical emission spectrometer (ICP–OES) are presented in Table 1. The X-ray diffraction (XRD) analysis results of the laterite samples are shown in Fig. 2. The results indicate that a serpentine mineral, nominally $Mg_3Si_2O_5(OH)_4$, is the major component that makes up the laterite samples; goethite, FeO(OH), is the minor one. The hydrochloric acid utilized in the experiment was of reagent grade. The water for the experiment was tap water, and the water utilized for analysis was purified with a water super-purification machine (Milli-Q, Millipore).

Table 1
Chemical composition analysis results of the saprolitic laterite ores.

Composition	Fe	Ni	Co	Mg	Si	Cr	Al
Content (wt%)	20.95	1.57	0.046	12.57	12.36	0.62	0.96

Table 2
Chemical composition analysis results of the atmospheric acid leach residues after washing.

Composition	Fe	Ni	Co	Mg	Si	Cr	Al
Content (wt%)	0.95	0.02	–	0.91	42.39	1.04	1.60

2.2. Experimental apparatus and procedures

2.2.1. Atmospheric acid leaching

Atmospheric acid leaching tests were performed in a 5 L enamel reactor with the temperature controlled by a programmable temperature controller with a precision of ±1 °C. The 20 wt% HCl solution and laterite samples calculated according to a specific acid-ore ratio were homogeneously mixed in the enamel reactor and heated to a preset temperature to react for a required amount of time with continuous agitation. After the reaction, the liquid–solid slurry was separated by a plate and frame filter into filtrate-rich in soluble Ni and Fe and filter cake-rich in Si. The filter cake was washed, dried, and then sampled for analysis.

2.2.2. Spray hydrolysis

Spray hydrolysis tests were performed in a calciner heated by the high-temperature tail gas from the reducing-smelting ferro-nickel process. The atmospheric acid leach solution was heated, oxidized, and concentrated to a certain concentration in a venturi preconcentrator by the high-temperature roaster gas from the calciner. Then, the concentrated acid leach solution was pumped into the calciner at a required spray rate (3–5 l/h) for hydrolysis at the required temperature. $FeCl_3$, $NiCl_2$, $MgCl_2$, and H_2O in the solution undergo the following main chemical reactions during the hydrolysis process.

$$2FeCl_3 + 3H_2O = Fe_2O_3 + 6HCl \tag{1}$$

$$NiCl_2 + H_2O = NiO + 2HCl \tag{2}$$