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Original Research Paper

Effect of nickel laterite agglomerate properties on their leaching performance

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ABSTRACT

Heap leaching is a widely used extraction method for low-grade minerals including nickel and cobalt. Agglomeration of fine mineral particles as a precursor to heap leaching is an important means of enhancing leaching rates and metal recoveries. Single pellet leaching behaviour of three nickel laterite ores, namely siliceous goethitic (SG), goethitic (G) and saprolitic (SAP) was investigated to assess the effect of pellet properties (binder type, binder content, porosity and dryness) on its stability, initial leaching rate and maximum Ni recovery. The column leaching performance of agglomerates of the same ores was also investigated. Both single pellet and column leaching tests showed that the ore mineralogy played a major role in the Ni extraction rate, with G-type of ore the lowest. The Ni extraction rate was also found to be directly related to the pellet/agglomerate dryness and the highest rate was obtained at an intermediate degree of dryness due to the better wetting and diffusion of acidic lixiviant into the pores in between the particles. However, no significant effect of drying on the stability of the agglomerates (measured by agglomerate slump in the column) was found in column leaching. For G type of ore, mixing it with high clay ores during agglomeration is recommended to enhance its robustness during leaching process.

1. Introduction

The majority of the world's nickel resources occur as laterite ores which are exceptionally complex, low grade and expensive to treat using conventional smelting and high temperature/pressure autoclave methods. Heap leaching is a process employed in the minerals industry to extract valuable metals from low-grade ores at relatively low capital and operational cost. Practically all heap leaching operations use agglomeration as an intermediate stage between mineral crushing and its stacking [1]. Agglomeration helps to increase permeability by eliminating the migration of fine-grained particles downwards in the heap, thereby lessening the channeling and ponding effects. Good agglomerates in a heap should survive the aggressive acid leaching conditions without disintegration over long period of time and have good permeability, which leads to better interfaces between the leach solution, air, and ores, resulting in improved metal recovery.

There are numerous publications about agglomeration of copper ore heap leaching (e.g., [2,3]) and to a less extent on gold ore. However, significant technical challenges such as low agglomerate strength under wet conditions, low nickel recovery remain for nickel laterite heap leaching process, preventing its adoption in industry.

In this work, single pellet leaching behaviour of three nickel laterite ores, namely siliceous goethitic (SG), goethitic (G) and saprolitic (SAP) ores was investigated to assess the effect of pellet properties (binder type, binder content, porosity and dryness) on its stability, initial leaching rate and maximum nickel recovery. Furthermore, column leaching behaviour of agglomerates made from these ores was investigated. The knowledge obtained from single pellet and column leaching studies can then be used to inform industry for producing agglomerates with optimum properties for enhanced heap leaching.

2. Experimental

2.1. Materials

The materials used in single pellets were samples of siliceous goethitic (SG), goethitic (G) and saprolitic (SAP) nickel laterites that had been crushed to −2 mm in size. For the column leach tests, the agglomerates were produced in a lab drum granulator by using the crushed – 2 mm SG ore and other three types of ROM nickel laterite, which is – 15 mm in size. The full chemical and mineralogical details of the ores can be found in our previous publications

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[4–6] and Table 1 listed the key mineralogical components of each type of ore. Sulphuric acid solution (44 wt.%) and water were used as binders for single pellet tests. For column leach tests, 30 wt.% sulphuric acid solutions were used as a binder.

2.2. Pellets, agglomerates and leaching column preparation

In order to study the effect of different parameters such as binder type, binder content, porosity and dryness on pellet stability and leaching rate, single pellets were made under controlled conditions so that the effect of the above mentioned properties can be monitored precisely. The porosity of the pellets was preset and was controlled through adding a certain wet mass of the ore and binder mixture into a fixed volume press (20 mm in diameter and 15 mm in height). The total mass of the ore and binder mixture for each pellet was calculated from the density of the ore and binder, the preset porosity as well as the pellet volume.

The procedures for making the single pellets were as follows. Nickel laterite and liquid binder with pre-determined proportions were mixed in a glass bowl first. The required wet mass of the mixture was then loaded into the chamber of the stainless-steel press with a 20 mm diameter. The ram was placed in position and pushed down until it was tightly up against a 15 mm spacer. Then the load was released and the pellet was gently pushed out. The wet pellets were either dried in oven at 110 °C (oven dried, OD) for 24 h or left to dry at ambient temperature for 72 h (air dried, AD). In some cases, the pellets were air dried for 24 h.

The agglomerates for column leaching were produced in a batch, laboratory scale, 316 stainless steel agglomerator (0.3 m in diameter and 0.2 m in length) at a fixed rotational speed of 60 rpm. 30 wt.% sulphuric acid solution was used as binder. The agglomeration process followed exactly the procedures described by Nosrati et al. [7] and are presented briefly here. Firstly, the ore and known amount of binder were pre-mixed in a tray by quickly hand spraying the latter. A plastic spatula was used to homogenize the mixture. The binder contents for different types of ore are 25 wt.% (SG), 18 wt.% (G) and 20 wt.% (SAP) respectively. The different amounts of binder content used in this work were pre-determined as the optimum required to generate agglomerates in the size range 5–40 mm at 14 min of agglomeration time. The differences in binder content required are due to the variation in the initial moisture content, ore mineralogy and size/surface areas of the feed particles. All the agglomerates were either dried for 48 h at ambient temperature, prior to loading in the columns or freshly made agglomerates from −2 mm feed. Two columns with freshly made and dried SG agglomerates with a feed size of – 2 mm were run. Another three columns loaded with – 15 mm feed agglomerates were tested in order to investigate the effect of mineralogy on the leaching performance.

2.3. X-ray micro-ct scans

X-ray tomography analysis was conducted on the pellets before and after leach using Skyscan 1072 and 1076 high-resolution X-ray micro-tomography (Skyscan, Belgium), with the former equipped with a 1024 × 1024 CCD detector (coupling to X-ray scintillator). The pellets were scanned at a 100 kV/98 μA power setting (source to sample distance: 203 mm) in the 0–180° interval rotation using a 0.675° scan rotation step (20 s exposure time for each projection) and images with 18.6 μm pixel size were produced.

Table 1
Mineralogical compositions of the major mineral species in the nickel laterite samples as revealed by QEMSCAN analysis.

Mineral mass%	SAP	SG	G
Quartz	11.8	36	1.6
Mg-bearing silicates	37.5	9	0.5
Nontronite	16.2	19	1.1
Goethite	16.3	26	68.4
Iron oxides (hematite, magnetite)	6.5	3	9.53
Cr-bearing minerals	5	3	0.7

2.4. Single pellet and column leaching test

In single pellet leaching tests, a single pellet was placed on a perforated plate and 44 wt.% sulphuric acid solution was uniformly dripped onto the pellet at a fixed rate of 20 L/m^2/h. The pellet stability under leaching conditions determined the total leaching time, i.e., leaching was stopped when the pellet started to disintegrate.

The column leaching test work was based on the methods reported by Agatzini-Leonardou and Dimaki [8] and Elliot et al. [9]. Leaching tests were conducted using Perspex columns, 125 mm in diameter and 2 m long. A layer of coarse (∼20 mm size) quartz chips approximately 140 mm deep was placed at the bottom of each column to prevent the agglomerates from plugging the pregnant solution outlet. A known mass (5 kg) of agglomerates was gently placed in the column to a depth of about 450 mm. This was followed by another layer of coarse silica chips, which facilitated the distribution of the sulphuric acid lixiviant over the bed of agglomerates. Sulphuric acid strength of 200 g/L was metered over ∼100 days without recycle. The irrigation rate for each column was 96 ml/h corresponding to 8.5 L/m^2 h. The height and slumping of the ore bed was recorded periodically by % slump = change in height/initial column height ∗ 100. In order to simulate the effect of hydrostatic load and hence the increasing bed height up to 3.5 m on the strength and slumping of the agglomerates during heap leaching, weights up to 30 kg were added after the columns had been irrigated for approximately 100 days and the slump recorded.

In both single pellet and column leaching tests, leachate solutions were collected from the bottom and ICP MS analysis was carried out so that the cumulative concentrations of Ni and other metals leached out over a certain time were obtained.

3. Results and discussions

3.1. Single pellet leaching behaviour

3.1.1. Effect of mineralogy

In metal leaching, the key difference between Cu oxide/sulphide and Ni laterite ores is the absence of specific Ni phases in the latter [10]. For sulphuric acid leaching of Ni laterites at atmospheric pressure, McDonald and Whittington [11] gave a detailed review on the sulphuric acid leaching characteristics of Ni laterites at atmospheric pressure, with special emphasis on the mineralogy and dissolution kinetics of the Ni-bearing phases. Ni extraction rates in many different types of Western Australian nickel laterites were also studied [10]. Depending on the crystallographic faces of goethite and ionic substitution of iron in goethite, the dissolution rate of goethite in acid varies up to ten fold [10]. Other work on Ni laterites has shown that, for a selected ore, the Ni extraction rate is in the order of chlorite/smectite > Fe oxyhydroxides > silico-ferruginous plasma (a clay-rich but poorly defined phase) > serpentine > Mn oxyhydroxides [12]. The chemical reactions of the key compounds such as goethite, hematite with sulphuric acid are reported in references [13,14].

To compare the leaching behaviour of nickel laterite pellets with different mineralogy, single pellets of the three ore types were made with 19.03 wt.% of water as a binder at a pre-set