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Effects of magnetite on magnetic coating behavior in pentlandite and serpentine system

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ABSTRACT

The effects of magnetite as the magnetic seed on magnetic coating behavior in pentlandite and serpentine system were investigated through magnetic separation tests, X-ray diffraction analysis, zeta potential measurements, and calculations of DLVO (Derjaguin–Landau–Verwey–Overbeek) theory. The results show that, the pentlandite recovery increased with the increment of magnetite while the recovery of serpentine remained low. Results obtained from XRD indicate that magnetite adhered predominately to the surface of pentlandite but only marginally to serpentine. Zeta potential measurements demonstrate that at pH values above 4.0, surfaces of serpentine, magnetite and pentlandite were all negatively charged with the sodium hexametaphosphate (SHMP) addition, and the serpentine with a higher negative potential surface following by magnetite and pentlandite. Thus, the repulsive force between pentlandite and serpentine was stronger, which weakens the hetero-aggregation between them. Calculations of DLVO theory indicate that the interaction energy between magnetite and pentlandite particles was higher than that between magnetite and serpentine. Consequently, it was easier for fine magnetite fractions to adhere to the surface of pentlandite particles and enhances its magnetism to allow for the magnetic separation of pentlandite from serpentine.

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1. Introduction

As a transition metal, nickel is located in the fourth period and the eighth subgroup in the periodic table of elements. It is a silver-white ductile malleable metal with the advantages of good plasticity and mechanical strength, corrosion resistance, oxidation resistance, and difficult to dissolve. Nickel is widely used to produce various types of steel and alloys, whose properties such as corrosion-resistant, heat-resisting, and magnetic properties make it broadly use in many fields (He and Cai, 2004). At present, pentlandite, $(Fe, Ni)_9S_8$, is the main source of nickel worldwide and is typically concentrated by flotation. In nickel sulfide flotation, magnesium silicate (MgO) gangue minerals, such as serpentine $(Mg_3(OH)_4(Si_3O_5))$, chlorite $((Fe, Mg, Al)_6(Si, Al)_4O_{10}(OH)_8)$, and talc $(Mg_3Si_4O_{10}(OH)_2)$, are known to cause problems by adhering to the valuable mineral particles as "hetero-aggregation or slime coating" due to their low hardness and their tendency to float with concentrate, which reduces copper and nickel grades and causes downstream processing problems as well as increases smelting costs. (Bremmell et al., 2005; Fornasiero and Ralston, 2005; Lu et al., 2009; Chen et al., 1999). It has been deduced from flotation studies that the formation of slime coating is directly related to the surface potentials of pentlandite and MgO gangue particles (Edwards et al., 1980). Therefore, in the processing of copper and nickel sulfide ores, reducing the content of MgO in the concentrate and improving grade and recovery of Ni and Cu have been the focus of a great deal of research.

Researchers have dealt with the problem of pentlandite ore from flotation processes, flotation reagents, and flotation equipments. A unique process, the split flotation, was implemented at Mt. Keith to optimize pentlandite flotation. By comparison with the original circuit the key changes included separation of the deslime circuit underflows, flotation of the first stage underflow ($-160\,\mu m$) in one rougher–scavenger module, flotation of the second stage underflow ($-25\,\mu m$) in the other rougher–scavenger module, and the installation of an acid storage and delivery system. Implementation of these changes had raised nickel recovery by 10% and nickel production had increased by over 6000 t.p.a. (Senior and Thomas, 2005). Pietrobon et al. (1997) in their laboratory study demonstrated the use of soda ash and carboxymethylcellulsoe (CMC) to disperse serpentine coating from pentlandite surfaces and improved pentlandite flotation rate and recovery. However, soda ash and CMC were only used in Mt. Keith's slime

and fine flotation circuits and not used to improve the overall pentlandite flotation through improving the poor, bore water quality in the plant. Peng and Seaman (2011) investigated the use of CMC as a dispersant to improve pentlandite flotation in both deionised and bore water and pointed out that the degree of substitute (DS) of CMC was an important parameter, which is linked with the charge density of CMC. As a result, in deionised water, the higher the DS of CMC with the higher charge density, the better the pentlandite flotation, while in bore water, the lower the DS of CMC with the lower charge density, the better the pentlandite flotation. Ma (2009) used the cyclonic static mirco-bubble flotation column to process the Jinchuan nickel ores and consequently, the Ni concentrate grade and recovery were increased by 1.24% and 1.86%; meanwhile, the MgO content in the concentrate was reduced by 2.03%.

In view of such problems in separation of copper–nickel sulfide ores, the "magnetic coating" method was investigated to treat copper–nickel sulfide ores and was the focus of this paper. At present, "magnetic coating" method has been widely used in effluent treatment and medical field. In mineral processing engineering, this technology is mainly used in purification of nonmetals, such as the removal of TiO_2 from clay or kaolin and separation of metal oxidized ore, like hematite (Nott and Price, 1978; Prakash et al., 1999). The process of magnetic coating is as follows: dispersant is firstly added in the pulp, which is conditioned at a high concentration and velocity mixing, then magnetic seed (mainly using magnetite fines) is added, a flocculant could be added, magnetic seed selectively coats the target mineral and then the slurry is magnetic separated (Xing, 1994). Karapinar (2003) studied magnetic separation of ferrihydrite from wastewater by magnetic seeding (13 μm) and showed that maximum seeding was obtained at a pH 7.9–8.2 (the point of zero charge of ferrihydrite) to form ideal flocculants, the magnetization of which were determined by iron-to-magnetite ratio, the lower the ratio, the better the magnetization of precipitate. Anastassakis (2002) adopted the selective magnetic coating to separate quartz from magnesite fines in an artificial mixture with the extremely fine magnetite of −5 μm, which results showed that the attachment of fine magnetite on quartz was possible in the presence of dodecylamine and kerosene in the pH range 6–11 and only partly coated the surface of magnesite particles. Moreover, there has been very little published literature investigating this technique in the separation of sulfide ores. Thus, this paper has investigated the influence of magnetite on magnetic coating behavior based on the results of magnetic separation tests; the change to a mineral surficial property before and after coating and the generation mechanism of "magnetic coating" were then analyzed with the use of XRD, Zeta potential measurements, and DLVO theory. This work will demonstrate the possibility of separating copper–nickel sulfide ores using "magnetic coating" method.

2. Experimental

2.1. Samples and reagents

The pentlandite, serpentine and magnetite minerals used in this study were obtained from Jinchuan (Gansu Province, China), Xiuyan (Liaoning Province, China), and Nanfen (Liaoning Province, China), respectively. Each lump ore sample was handpicked to select pure minerals. The pentlandite sample was crushed with a hammer to −2 mm before being further separated to remove further gangue. The −2 mm sample was then ground in a ceramic ball mill for 8 min to −75 μm before being concentrated on a Wilfrey shaking table. The concentrate was weakly magnetically separated to remove the strongly magnetic minerals before being further enriched on the shaking table to make the pentlandite sample.

The serpentine sample was hammer crushed to −2 mm before being ground in a ceramic ball mill for 5 min before being deslimes to produce the serpentine sample of 75–20 μm. The magnetite sample was first hammer crushed to −2 mm before being ground in a stirred mill for 45 min to −20 μm before being concentrated on a shaking table and the concentrate weakly magnetically separated to produce the magnetite sample. The XRD analyses and chemical multi-element analyses of each mineral are listed in Figs. 1–3 and Tables 1–3.

Freshly prepared 1% $(NaPO_3)_6$ (sodium hexametaphosphate (SHMP), Tianjin Kermil Inc., AR) solution was used as dispersant. Oleic acid (Tianjin Kermil Inc., AR) and kerosene (from Jinchuan dressing plant, China, industrial pure) were used as adhesion reagents. Prepared 2% HCl and 2% NaOH (Tianjin Kermil Inc., AR) were as pH modifiers. Deionized water was used for preparation of solutions used throughout this study.

2.2. Test methods

2.2.1. Magnetic coating tests

Magnetic coating tests were carried out in a 200 mL XFGC batch flotation cell used for its ideal mixing. The mineral suspension was prepared by adding 10.0 g pentlandite minerals and the desired amount of serpentine to 100 mL deionized water. The pH of the suspension was adjusted to desired values by adding HCl or NaOH solution. The prepared sodium hexametaphosphate (SHMP, 100 g t^{-1}), oleic acid (4.5 L t^{-1}), kerosene (4.5 L t^{-1}) and fine magnetite fractions were added at each desired concentration and conditioned for 3 min after which the fine magnetite fractions was added and conditioned for a further 5 min at a stirring speed of 2400 r min^{-1}.

2.2.2. Magnetic separation tests

The suspension coated by magnetite fractions was separated using a XCSQ-50 × 70 wet high intensity magnetic separator (WHIMS). The magnetic and non-magnetic products collected were filtered and dried. The magnetic separation recovery was calculated based on the solid mass distributions between the magnetic and non-magnetic products. The magnetic field intensity was determined by the amount of additional magnetite.

2.2.3. Zeta potential measurements

Small amounts of pure mineral of pentlandite, serpentine and magnetite was added to desired amount of 100 mL deionized water and ultrasonicated for 3 min, mechanical stirred for 8 min while the pH was adjusted using HCl or NaOH. Then reagents of tests required were added and left to condition for further 8 min.
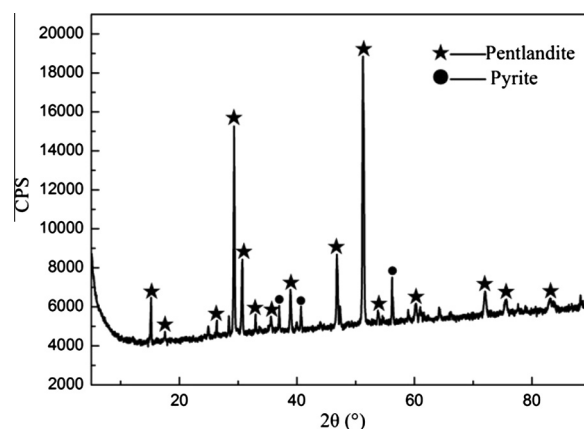

Fig. 1. XRD pattern of pentlandite sample.