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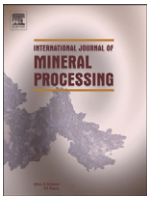

An overview of the beneficiation of iron ores via reverse cationic flotation

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ABSTRACT

Flotation is the most effective solution, both technologically and economically, when upgrading iron concentrates. Research regarding iron ore flotation began in 1931, demonstrating that reverse cationic flotation is a very efficient method for beneficiating oxidised iron ores. This method can also be applied to reduce the silica content in magnetite concentrates obtained using wet low-intensity magnetic separation. Several studies describing the processing of iron ores via reverse cationic flotation are reviewed. The predominate role of the pulp mineralogy, as well as the type and molecular structures of the collectors and depressants, on flotation is discussed critically. The results concerning the role of the silicate mineralogy on the choice of reagents and flotation processes are also discussed. Further development of the reverse cationic flotation of iron ores requires a more detailed consideration of the nature of iron-bearing gangue minerals and the application of original approaches for the selective removal of these species.

Contents

1. Introduction

Iron is one of the most common elements in Earth's crust. The primary industrial types of iron-bearing minerals include oxides and hydroxides and, to a lesser extent, carbonates: magnetite [Fe_3O_4], hematite [Fe_2O_3], goethite [FeO(OH)], limonite [$FeO(OH) \times nH_2O$] and siderite [$FeCO_3$]. The genesis of iron ore deposits is variable, similar to numerous other ore types. However, the major iron ore resources are composed of metamorphosed iron formations called banded iron formations (BIFs). Most of these formations are from the Early Proterozoic and Archean. Smaller portions of the deposits are from the Late Proterozoic and Early Paleozoic. Banded iron formations form extensive iron ore basins (kilometres across and hundreds of metres in thickness) with a typical layered structure composed of ore bodies. BIF areas are also associated with weathering crusts (also called as bedded iron deposits) formed by natural processes (hypogene and supergene Fe-enrichment). Bedded iron deposits (BIDs) contain iron-rich hematite, goethite– and siderite–magnetite, as well as martite (pseudomorph after magnetite)–goethite and microplaty-hematite ores. The Kursk Magnetic Anomaly in Russia, the Hamersley iron province in Australia, the Quadrilátero Ferrífero region in Brazil, the Anshan area in China, the province of Labrador in Canada, the Krivoy Rog basin in Ukraine, the Lake Superior district in the USA and the Singhbhum-North Orissa region in India are among the largest of these types of rock formations. The share of these types of ores compared to the overall commercial ore production exceeds 74%. Worldwide estimates of the iron reserves and mining are presented in Table 1. Major iron ore storage locations are in Australia, Brazil, and Russia. Nevertheless, most of the total iron ore production occurs in China.

In general, magnetic separation is the most commonly used beneficiation process for iron ores because the dominant iron minerals are

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Table 1
World iron ore production and reserves (million metric tons).[a]

Country	Mine production		Reserves
	2010	2011[b]	
United States	50	54	6900
Australia	433	480	35,000
Brazil	370	390	29,000
Canada	37	37	6300
China	1070	1200	23,000
India	230	240	7000
Iran	28	30	2500
Kazakhstan	24	24	3000
Russia	101	100	25,000
South Africa	59	55	1000
Sweden	25	25	3500
Ukraine	78	80	6000
Others	87	91	17,800
Total (rounded)	2590	2800	170,000

[a] Source: USGS, Mineral Commodity Summaries, January 24, 2012.
[b] Estimated E Net exporter.

ferro- and paramagnetic. However, iron ores should be processed according to its mineral composition, physical properties, character and degree of liberation of the iron-bearing minerals from the gangue. The gangue minerals in BIF typically include quartz, several iron-bearing silicates as amphiboles, micas and pyroxenes, carbonates, feldspars, and clays.

Wet and dry low-intensity magnetic separation (LIMS) techniques are used to process ores that contain minerals with strong magnetic properties, such as magnetite and titanomagnetite. For example, LIMS separators are installed at the Kiruna plant KA1 in Sweden to process a low phosphorus magnetite ore containing over 60% Fe (Söderman et al., 1996). LIMS is also utilised in Section 2 of the Qidashan mineral processing plant in China to extract magnetite from hematite– or limonite–magnetite ores (Zeng and Dahe, 2003). Various applications of LIMS can be found during processing for the iron ores from Mesabi and Marquette Iron Ranges in the USA, in addition to the Savage River and OneSteel's Project Magnet operations in Australia (David et al., 2011). Wet high-gradient magnetic separation or wet high-intensity magnetic separation (WHGMS/WHIMS) is used to separate the iron-bearing minerals with weak magnetic properties as hematite, goethite and limonite from gangue minerals (Svoboda, 1987, 2001). Concurrently, Xiong et al. (1998) explained that the biggest problems facing conventional WHGMS/WHIMS separators are matrix dogging and the mechanical entrainment of non-magnetic particles when WHGMS/WHIMS was applied to treat metallic ores, including hematite ores, because these ores contain large portions of weakly magnetic minerals and relatively coarse particles. These characteristics weaken the magnetic forces and reduce the quality of the magnetic product. To solve these problems, pulse high-gradient magnetic separation (PHGMS) has been in development since 1981 (Xiong et al., 1989; Liu et al., 1991; Yang et al., 1993). Several models of the SLon vertical ring and pulsating high gradient magnetic separators have been designed since 1986. These devices are successfully operated at 12 processing facilities for extracting hematite, limonite, siderite and other low-magnetic minerals.

Tests over a 6-month period that were used to compare WHIMS-2000 and SLon-2000 separators for a low-grade oxidised iron ore at the Gong Changling mineral processing plant have demonstrated the high efficiency of SLon separators. These separators provided high-grade magnetic products with an improved iron recovery and a low mass yield. Xiong et al. (1998) explained the increased grade and recovery of the iron using pulsating effects. Pulsations in the slurry increase the rate of collisions between the magnetic particles and the matrix, favouring the recovery of magnetic particles. However, the pulsations increase the competitive forces acting on the non-magnetic particles. This scenario is favourable for eliminating the mechanical trap for the non-magnetic particles. For example, the Gushan iron mine completely stopped using gravity-based separation techniques (spirals and centrifuges) to use magnetic separation for its hematite processing flowsheet. The flowsheet incorporates WHIMS and SLon separators at the scavenger stage. The change from gravity-based to magnetic separation improved the iron grade and recovery by 2.95% and 13.80%, respectively.

Prasad et al. (1988) have studied iron ore slimes processed by magnetic separation at the Kiriburu mines in India. A concentrate containing 63% Fe and 3.3% Al_2O_3 with an iron recovery of 56% was obtained when using WHIMS with slimes composed of hematite, goethite, and kaolinite after the classification via cyclone. Concurrently, Pradip (1994) found that multigravity separation is the most effective method for processing the slimes from the Indian ore to decrease Al_2O_3 content. However, Roy and Das (2008) reported that this method is not very commercially successful due to its low capacity. In some cases, the best results for separating low-magnetic iron fines can be achieved when the magnetic separation in a medium-intensity field (MIMS) is combined with hydrophobic selective flocculation instead of WHGMS or WHIMS. Song et al. (2002) have named this process floc magnetic separation (FMS).

The industrial production of iron ore pellets and other high-quality metallurgical raw materials, such as fluxed pellets and direct-reduced iron (DRI), requires pellet feed fines with limited contents of silica, aluminium oxide and other impurities. These requirements have led to the increased use of flotation (unlike gravity and magnetic separation) to reduce the content of harmful impurities and produce iron "superconcentrates". The high potential of flotation for the beneficiation of low-grade oxidised iron ores was emphasised by Iwasaki (1983). According to Peres and Mapa (2008), reverse cationic flotation is critical for producing pellet feed fines at all processing plants in Brazil.

2. Flotation routes for iron ores

Studies on iron ore flotation began in 1931 and revealed the following flotation routes: the direct anionic flotation of iron oxides and the reverse anionic or cationic flotation of quartz. The direct flotation of iron oxides by anionic collectors such as petroleum sulphonates, fatty acids and hydroxamates was the first to be tested and commissioned in 1950 at several processing plants, including the Humboldt mine and the Republic mine in the USA, as well as the Anshan Iron & Steel Corporation in China (Iwasaki, 1983; Ma, 2012a).

In the early 1960s, the reverse flotation of silicates using anionic collectors that were primarily fatty acids has been developed. Reagent regimes for the reverse anionic flotation of oxidised taconites from the Lake Superior deposits have been designed at the Hanna Mining and the U.S. Bureau of Mines laboratories (Bunge et al., 1977). Taconites containing approximately 39% Fe, were ground to 60–100% of -44 μm and were floated without desliming. Calcium chloride (765 g/t) was used to activate the quartz, while dextrin (Gum 9072) (1.1 kg/t) was added to depress the flotation of the iron oxides. Acintol FA2 containing 97.8% tall oil (50% of oleic and 44% of linoleic acids) was used as an anionic collector. The total collector dose was 720 g/t at pH 11.5; this pH was attained with NaOH (1.6 kg/t). The flotation concentrate contained 60.3% Fe and 6.0% SiO_2 to obtain a 90.5% Fe recovery. Finally, despite the successful flotation results, this route was not implemented commercially due to the high cost of the reagents.

The flotation of apatite used to lower the levels of phosphorus from 0.1 to 0.025% of P_2O_5 in the LIMS magnetite concentrate is applied as a pellet feed with a fatty-acid-type collector called Atrac 1563 (mixture of 95–98% of ethoxylated tall oil ester of maleic acid and 2–5% of maleic anhydride) at 30–70 g/t at the Kiruna (KA2) and Malmberget plants in Sweden. Sodium silicate (300–500 g/t) is added to disperse the fine particles and to discourage magnetite flotation. However, the studies by Forsmo et al. (2008) and Potapova et al. (2010) of the flotation concentrates obtained in these facilities indicated that the adsorption of Atrac on the magnetite surfaces seriously damaged the quality of the green pellets; an increasing amount of air bubbles became so strongly attached to particle surfaces that they could not be removed during