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Role of silica and alumina content in the flotation of iron ores

Hrushikesh Sahoo, Swagat S. Rath, Danda S. Rao, Barada K. Mishra, Bisweswar Das *

CSIR-Institute of Minerals and Materials Technology, Bhubaneswar-751013, India

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ABSTRACT

Indian low grade iron ores mostly contain quartz, gibbsite, and clay as the major impurities. Depending upon the ore characteristics, in many instances froth flotation has to be used to recover the hematite and other iron oxides from the ground ores. In this context, the difference in silica and alumina content in low grade iron ores is brought to bear on the prospects of iron ore flotation. For this purpose, pure minerals like hematite, quartz, gibbsite, and clay have been used to prepare synthetic mixtures and analyzed to determine the difference in floatability. The results are compared against natural iron ores with variations in silica and alumina content. The flotation results with oleic acid and dodecylamine show better recovery of iron values in the hematite–quartz mixture as well as in the naturally occurring high silica ore compared to the hematite–clay mixture and the high alumina ore respectively. Similarly results on a variety of iron ores show that high silica content as quartz in the ore causes less hindrance in the flotation of iron ore, whereas the presence of silica as clay inhibits the flotation response of iron ore. The scanning electron microscopic (SEM) studies indicate that clay particles cover the surface of hematite, making it less selective for interaction with the collector. The surface potential studies of clay and quartz suggest that charge reversal takes place for quartz treated with dodecylamine (DDA), but for the DDA adsorption on clay, negative potential values are noted beyond a pH of 4.6.

1. Introduction

Iron ore deposits in India can be broadly classified as aluminous and siliceous. Although most of the Indian ores are highly aluminous in nature, in some mines, silica content is even higher than the alumina content. It is often seen that iron ores available in the southern part of the country are siliceous in nature, whereas the iron ores from the eastern and central parts of India contain higher amounts of clay or gibbsite and are aluminous in nature. In general, each ore deposit of India has its own unique characteristics with respect to either silica or alumina content. Therefore, based on the origin of the ore, it would require a specific beneficiation technique for efficient enrichment of iron values. The choice of beneficiation methods depends on the nature of the gangue present and its association with the ore structure. Hence, development of an efficient beneficiation method has to be essentially supported by an in depth analysis of the mineralogical association of silica or alumina with the iron minerals.

Although froth flotation has been established as an efficient method to remove impurities from iron ore elsewhere in the world, Indian iron ore mines are yet to apply this technique. The reason is that most of the steel industries in India are operated by blast furnaces to which calibrated ore and sinters are fed. To ensure quality of these feed materials, Indian beneficiation plants are now adopting the flotation technique. Therefore, the importance of the froth flotation process in addition to conventional washing, gravity, classification, or magnetic separation processes has increased. It is mainly due to the market requirements for superior grade iron concentrates and rejection of lesser iron values into tailings. It is believed that beneficiation of iron values by flotation coupled with agglomeration such as pellet making will be emphasized more in future.

Iron ores can be concentrated either by direct anionic flotation of iron oxides or reverse cationic flotation of silica. In direct flotation, oleic acid or its sodium salt is the preferred reagent. Several studies on oleate-hematite interactions suggest that the oleate adsorption on hematite mainly depends on solution pH (Paterson and Salman, 1970; Peck et al., 1966; Pope and Sutton, 1973). In reverse flotation, the removal of silica from iron ores is typically carried out by amine based collectors. Reagents such as dodecylamine, ether amines, ether monoamines, di-amines and quaternary ammonium salts are used in cationic flotation (Ma et al., 2011; Vieira and Peres, 2007). Literature shows that in all the reverse flotation studies, the depression of hematite and other iron oxides is carried out with the use of a variety of starches. The recent work carried out by Kar et al. (2013) has compared the depressing action of several starches on hematite. The flotation studies of hematite and quartz minerals indicate that soluble

* Corresponding author.
E-mail address: bdas@immt.res.in (B. Das).

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starch is the most effective starch for hematite. However, the efficiency of the flotation process depends on the impurities present and the degree of liberation of the target minerals.

1.1. Separation chemistry

Major iron minerals associated with most of the iron ores are hematite, goethite, limonite, and magnetite to a lesser extent. The silica and alumina bearing minerals present in the iron ore are quartz, kaolinite, montmorillonite, illite, gibbsite, diaspore and corundum. Out of these, it is often observed that, kaolinite and gibbsite are the two main alumina bearing minerals present in iron ore. Generally, iron bearing minerals and gibbsite have similar structure (Fe_2O_3 and Al_2O_3) associated with some water molecules. The cations are trivalent in nature and have common chelation characteristics. Besides this, the bond distance between Fe–Fe and Al–Al is very small i.e., 2.85 and 2.852 Å respectively (Ravishankar et al., 1995). Therefore, gibbsite and iron oxides have similar surface charge and almost identical complexation characteristics. Hence, the separation of gibbsite from hematite or goethite by any surface active agents is quite difficult. Moreover, since most of the gibbsitic alumina occurs in the finer size range (−20 to −10 μm size), its flotation is not feasible. As a result the bioprocessing method for hematite–corundum (Al_2O_3) or hematite–gibbsite has been carried out (Anand et al., 1996; Deo and Natarajan, 1997, 1998; Natarajan and Deo, 2001). It was reported that corundum-adapted strains and metabolites of *paenibacillus polymyxa* separate corundum efficiently from iron oxides. However, no industrial application of this method has been reported.

In order to recover the iron values from slimes, some investigations were carried out on high alumina iron ore slimes from India using a combination of hydrocyclone separation and flotation. It has been observed that, due to the fine size of the slimes coupled with complex mineralogy and the presence of locked particles, it is not possible to obtain an acceptable concentrate through the direct flotation of hematite. As most of the alumina and silica bearing minerals are associated with the finer sizes, classification of slimes with two stage hydrocycloning followed by reverse cationic flotation using amines or direct flotation with fatty acid have been carried out (Thella et al., 2012). The results of the studies indicate that a final concentrate of 64.5% Fe, 2.66% Al_2O_3, and 2.05% SiO_2 with an Fe recovery of 69.03% could be achieved from a feed containing around 54.93% Fe. Another study carried out on beneficiation of Indian iron ore slimes used direct and reverse flotation techniques using oleic acid and dodecylamine as the collector respectively (Das et al., 2005). Taking into account the physico-chemical properties of the slimes, it is concluded that the samples need to be deslimed by hydrocycloning before flotation. The results of both flotation cell and column studies carried out by the same group have shown that a feed containing 57.5% Fe could be upgraded to 65.5% Fe at 50% overall recovery. Furthermore, it has been found that a simultaneous decrease in the SiO_2 and Al_2O_3 content to 2.3% and 1.8% respectively is achievable using oleic acid as the collector. In the case of another sample, it has been established that reverse flotation of silica is a preferable technique to improve both the grade and recovery of iron. In such studies, batch flotation in a cell using dodecylamine as the collector has shown that a product grade of 63.1% Fe could be obtained at 44% recovery. In another investigation, to separate hematite from a clay mineral (kaolinite), it has been shown that ether amine, ammonium quaternary salts, dodecyl trimethyl ammonium bromide (DTAB) and tomamine Q-14-2 PG (AQ142) can be used along with corn starch as the depressant to obtain the desired selectivity (Rodrigues et al., 2013).

In the case of kaolinite and quartz, it has been found that the flotation behavior of kaolinite is opposite to that of silica. For example, ether diamine, regarded as a strong collector for quartz, does not induce any collector action for kaolinite at alkaline pH. Besides that, the presence of calcium and magnesium ions is also detrimental to kaolinite removal from iron ore. Similarly, sodium silicate, a good dispersant for silicates present in iron ore does not disperse any kaolinite (Ma et al., 2009a).

Taking into consideration all the above facts, we aimed to seek a thorough understanding of the difference in the flotation response of a quartz rich and an alumina rich ore in a comprehensive manner. Flotation studies of hematite, quartz, clay, gibbsite and their synthetic mixtures have been conducted and subjected to direct and reverse flotation processes to find out the differences. Further, the studies have been extended to four types of naturally occurring iron ores having different compositions of silica and alumina with the aid of proper characterization studies to understand the underlying reason for the difference in their floatability.

2. Materials and methods

Flotation studies were initially conducted using high quality minerals like gibbsite, clay (kaolinite), quartz, and hematite having 98–99.8% purity to evaluate the performance of direct and reverse flotation processes. The samples of quartz and hematite were obtained from different Odisha mines, while clay samples rich in kaolin and gibbsite were obtained from Jharkhand. The quartz sample was further purified by digestion in dilute hydrochloric acid and repeated washing with distilled water to remove any contaminated iron particles. All the samples were carefully prepared by crushing and subsequent wet grinding in a laboratory ball mill (6″ × 6″) made up of mild steel. Mild steel balls having 20–40 mm sizes were used as the grinding media. Particle sizes of below 100 μm were used for flotation studies.

The synthetic mixtures of hematite–gibbsite, hematite–quartz, and hematite–clay in 1:1 proportions were prepared for different flotation tests. In the flotation study, 150 g of hematite, 150 g of clay/quartz/gibbsite, and 700 ml of water were mixed and agitated at 1500 rpm in the conventional cell prior to the addition of any reagents. Direct flotation was conducted using oleic acid as the collector and sodium silicate as the dispersant. For reverse flotation, dodecylamine (DDA) was used as the collector for quartz or clay or gibbsite, while soluble starch was used as the depressant for hematite. In all the flotation experiments, 45 g/t of methyl isobutyl carbinol (MIBC) was used as the frother. The reagents were prepared afresh every time before the start of the experiments.

In the second stage of the flotation study, four low grade iron ore samples were taken from four different mines with wide variation in silica and alumina content. All the samples were crushed by a roll crusher to reduce the particle size. The samples were then ground to below 100 μm size using a laboratory ball mill (12″×12″) made up of mild

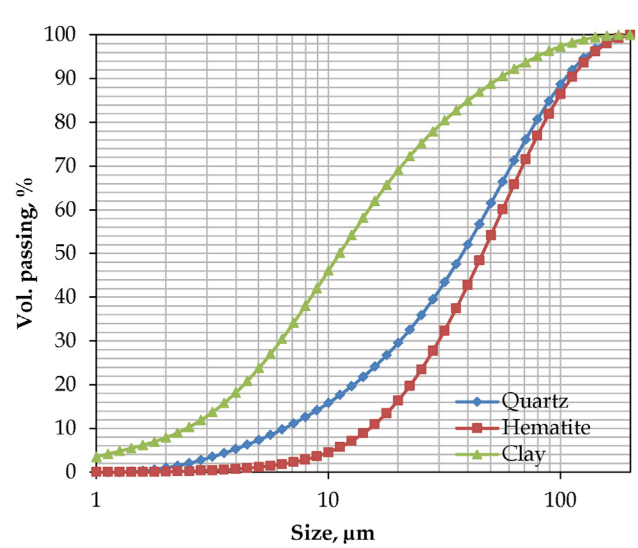

Fig. 1. Particle size distribution of hematite, quartz and clay used for flotation studies.