Full Length Research Paper

The Effect of Acid Concentration on the Chemical Leaching of El-Gedida High-Ba Iron Ore, El-Bahariya Oasis, Western Desert, Egypt

Galal El-Habaak¹, Mohamed Askalany², Mohamed Farghaly³, Mahmoud Abdel-Hakeem²*

¹Deaprtment of Geology, Faculty of Science, Assiut University, Egypt
²Department of Geology, Faculty of Science, South Valley University, Egypt
³Department of Mining and Petroleum Engineering, Faculty of Engineering, Al-Azhar University, Egypt
*Corresponding Author: mahmoud.sabry@sci.svu.edu.eg

Received 01 December 2016; Accepted 24 February 2017

Abstract. El-Gedida high-Ba iron ore was subjected to microscopic, mineralogical and chemical characterizations followed by chemical leaching using HCl. The microscopic investigations revealed that the textural relationships between barite and iron minerals are complicated, resulting in a difficult liberation during the comminution process. XRD analysis of the studied ore indicated the presence of hematite and goethite as the dominant iron minerals and barite, quartz and halite as gangue minerals. Chemical assays using XRF showed that the investigated ore contains 42.29% Fe₂O₃ (29.58% Fe total), 36.99% BaO and 16.95% SO₃. The pre-treatment operations involved crushing and milling up to -150µm particle size. The processing operation included chemical leaching of 15 gm representative sample of the ground ore using acidic medium of HCl at fixed agitation speed 900 r/m. The leaching was followed by filtration, solvent extraction and precipitation processes. The resultant dual concentrate is divided into iron fraction containing 66.11% Fe with 99.84% iron recovery and barite concentrate containing 66.85% BaO (99.47% recovery). The resultant iron fraction is accepted as a blast furnace feed charge for the Egyptian Iron & Steel Company, while barite fraction can be used for the oil industry and glassmaking.

Key words: chemical leaching; dual concentrate; El-Gedida mine; high-Ba iron ore.

1. INTRODUCTION

El-Gedida mining area is located at the northeastern part of El-Bahariya Oasis, Western Desert, Egypt (El Aref et al., 2001). This mining area is endowed with 126.7 million metric tons of iron ores, which are the only oolitic iron ores of a great economic importance in the northern Africa and southern Europe (Salama et al., 2012). These iron ores are considered the main supply of the iron and steel industry in Egypt. There is one million metric ton of such ores contains high concentrations of BaO reported up to 34 wt% (Farghaly, 2002). The high percentage of BaO present in the iron ore is considered one of the production problems of pig iron in the blast furnace at the Egyptian Iron and Steel Company, Cairo. For instance, the high content of BaO leads to increase the amount of coke consumed for the reduction of BaO to BaS, results in decreasing the sintering temperature and lowering the FeO content in the sinter product (Hessien et al., 2008). Also, barite mineral containing BaO is well known for its thermal stability at temperatures above 900 °C, and hence the sintering process will be more energy intensive (Jablonska et al., 2001).

Several decades ago various attempts have been carried out to upgrade El-Bahariya iron ores using gravity separation, flotation, shaking table and magnetic separation (Emara and Wasel, 1978; Abdel Monen and Kamel, 1993; Abd El-Rahim and Arafa, 1999). Recently, Faraghy (2002) used the dry high intensity magnetic separation and reduction roasting followed by wet low intensity magnetic separation for upgrading El-Gedida high-Ba iron ore. He obtained final product assaying 56.78% Fe and 1.61% BaO at recovery of 82.76% from a head sample containing 23.5% Fe and 34% BaO. Al-Wakeel and Abd El-Rahman (2006) beneficilated the high-silica iron ore of Ghorbani mine located at the northeastern part of El-Bahariya Oasis. They studied head sample containing 44.10% Fe₂O₃ and 36.8% SiO₂ and subjected it to size reduction, screening, attrition scrubbing, dry low intensity magnetic separation and hydrocyclone classification. The overall result was high-grade concentrate assaying 53.22% Fe with recovery of 83%.
Although efforts were made for upgrading El-Bahariya iron ores located at El-Gedida and Ghorabi mines, the literature showed little about the chemical treatment of such iron ores. The main aim of the present study is to obtain a dual concentrate from this problematic iron ore using a combination of chemical leaching and solvent extraction processes.

2. MATERIALS AND METHODS

2.1. Sample preparation

The used sample in the present study is a high-Ba iron ore obtained from the high central area of El-Gedida iron mine, El-Bahariya Oasis in the Western Desert of Egypt. The head sample was prepared for the chemical leaching by a combination of size reduction and screening processes. About 250 kg representative sample was fed into a laboratory jaw crushe rset at 2mm outlet. The crushed sample was screened on 2mm sieve, and the retained fraction was recharged into the crushe r until the whole size fraction became 2mm in diameter. The jaw crushe r product was then ground in a closed circuit using hammer mill to attain the desirable size fraction (-150µm) of mineral particles. After comminution, the ground ore was sampled using mechanical splitter (Taylor and Brunton Splitter). The splitted sample was used for mineralogical and chemical analyses and chemical leaching.

2.2. Characterization and analytical methods

First of all, the nature of grain boundaries between iron minerals (valuable) and barite (gangue) was investigated by preparing polished sections that in turn were examined under the ore microscope (Leica DM750P). The bulk mineralogy of the studied ore was identified using XRD (X’Pert PRO-PAN, CuKα, 40 kV, 25 mA), while the bulk chemistry was determined using XRF hosted at the Egyptian Geological Survey.

2.3. Chemical leaching

About 15 gm representative sample of -150µm size fraction was put into 200 mL glass flask provided with a condenser to minimize the evaporation of solution during the experiment, and then 100 mL of HCl solution was added into the flask with heating and stirring. The leaching process was conducted at fixed agitation speed 900 r/min. The efficiency of leaching was studied at different acid concentrations (2, 4, 6 and 8 M) and fixed leaching temperature 80 °C and constant leaching time 80 min. Afterwards, the liquor was filtered from the residue. The filtration process was followed by washing the barite residue by distilled water for three times in a centrifuge set at 3000 RPM for 15 minutes. The specific gravity of barite fraction was measured by the weight ratio of a substance in air and that of an equal volume of water (Rafferty, 2012). The barite residue was then subjected to mineralogical and chemical characterizations. The final liquor was undergone solvent extraction process as the following steps:

1. Pouring around 600 mL iron salt-bearing solution in 1 liter separatory funnel, and then adding 120 ml diethylether into the solution.
2. Placing the plastic stopper in the neck of the funnel and shaking the funnel for 30 minutes. During the shaking, the pressure should be released by opening the stopcock.
3. After shaking and standing, two layers can be observed inside the funnel. The upper layer (A) is composed of iron salts and diethylether, while the lower one (B) consists of acid and water with some amount of iron salts.
4. Draining the acid-water layer (B) in 600 ml beaker and then return it to the separatory funnel with adding of 120 ml diethyl ether and shaking.
5. Two layers are also observed, one is iron salts bearing ether layer (C) and the other is acid-water layer (D).
6. The two ether layers (A&C) are combined with each other in 600ml beaker.
7. To separate the iron salts from ether, distilled water is added to the mixed layers. The iron salts will leave the ether layer and mix with water that is in turn separated from the ether part.
8. By adding ammonia solution (1:1), drop by drop, to the final solution of iron salts, ferric hydroxide \{Fe (OH)₃\} will precipitate. To obtain ferric oxide (Fe₂O₃), the precipitate is fired at 750º C for one hour.
9. The obtained ferric oxide is weighed and subjected to mineralogical and chemical characterizations.

3. RESULTS AND DISCUSSIONS

3.1. Microscopic characterization

Hematite is the predominant iron mineral in the studied samples and occurs as irregular patches and pellets which are cemented by barite matrix (Fig.1a). Goethite is less common than hematite and characterized by internal reflection of yellow to yellowish brown. It occurs as irregular patches varying in size from 0.5 to 5mm engulfed in barite matrix and as alteration product after hematite (Fig.1b).

Barite is the main gangue mineral in the studied iron ore and characterized by milky and multicolored
internal reflection. Barite occurs as individual irregular grains (0.25 to 1.1mm in size) and subhedral to euhedral crystals (3.75mm-2cm) cemented and corroded, especially along the outer margin, by hematite or goethite (Fig.1c). It occurs also as traversing vienlets within hematite and goethite grains (Fig.1d).

Generally, microscopic investigations indicate the occurrence of two intergrowth types between iron minerals and barite namely, inclusion and intergranular locking. These interlocking types will lead to a difficult liberation of iron minerals from barite during the comminution process (Amstutz and Giger, 1972; Petruk, 2000). Thus, a physical treatment of this problematic iron ore may result in consumption of more energy and time; therefore, chemical leaching followed by solvent extraction process is considered a suitable operation for upgrading this high-Ba iron ore. At this point, it is worth mentioning that the role of microscope in prediction of the liberation degree can contribute to determination the suitable beneficiation process and save energy consumed during the ore dressing operations (Tomanec and Milovanovic, 1994).

3.2. Mineralogical characterization

Interpretation of XRD data using the X’Pert High Score Software (Fig. 2) revealed that the iron minerals are represented by hematite and goethite. Hematite is the most predominant iron mineral compared to goethite. Barite is the dominant sulfate mineral and is considered the most problematic gangue associated with iron minerals. In addition to barite, gangues also include trace amount of quartz and halite.

3.3. Chemical characterization

Chemical analyses (Table 1) show that El-Gedida high-Ba iron ore contains 42.29% Fe$_2$O$_3$ with total iron content reported at 29.58% Fe. The main gangue oxides are represented by 36.99% BaO and 16.95% SO$_3$. Moreover, the main components of slag (silica and alumina) are detected at low contents of 0.32% SiO$_2$ and 0.25% Al$_2$O$_3$. The presence of chloride (0.19%) is attributed to the occurrence of halite mineral, as illustrated by XRD pattern (Fig.2).

<table>
<thead>
<tr>
<th>SiO$_2$</th>
<th>TiO$_2$</th>
<th>Al$_2$O$_3$</th>
<th>MnO</th>
<th>Fe$_2$O$_3$</th>
<th>Fe total</th>
<th>MgO</th>
<th>CaO</th>
<th>Na$_2$O</th>
<th>K$_2$O</th>
<th>BaO</th>
<th>P$_2$O$_5$</th>
<th>SO$_3$</th>
<th>Cl</th>
<th>L.O.I</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.32</td>
<td>0.17</td>
<td>0.25</td>
<td>0.14</td>
<td>42.29</td>
<td>29.58</td>
<td>0.15</td>
<td>0.28</td>
<td>0.21</td>
<td>0.15</td>
<td>36.99</td>
<td>0.23</td>
<td>16.95</td>
<td>0.19</td>
<td>1.67</td>
</tr>
</tbody>
</table>

3.4. Chemical leaching

Due to the depletion of low Ba-iron ores at El-Gedida iron mine, the high-Ba iron ores are planned to be exploited to produce sinter for a subsequent usage in the blast furnace for pig iron production. As a result, the undesirable high BaO content will affect on the morphology and structure of the produced sinter and the reduction behavior of iron oxides (Hessein et al., 2008). Moreover, the undesirable amount of barite in
the blast furnace feed results in high viscous slag and more coke consumption in the blast furnace due to the high thermal stability (1580° C) of barite (Linchevsky et al., 1983; Ahmed et al., 2006). So, finding a suitable method for the beneficiation of El-Gedida iron ore is considered indispensable step. The chemical leaching of the high-Ba iron ore containing 29.58% Fe and 36.99% BaO yielded two products namely; iron and barite concentrates at different acid concentrations 2, 4, 6 and 8M (Table 2).

It is noticeable that the purity of iron concentrate is slightly decreased from 66.82% to 66.07% Fe with the increase of acid concentration. This is attributed to the slightly dissolution of barite in the acid medium, resulting in the liberation of little amounts of BaO and SO₃ from the crystal structure of barite during the leaching process. The high resistance of barite to the acid attack was reported by Tunkasiri et al. (1992). Also, the resultant iron fraction is acceptable as a blast furnace feed charge at the Egyptian Iron and Steel

<table>
<thead>
<tr>
<th>Acid conc.</th>
<th>Product</th>
<th>Wt.%</th>
<th>Fe%</th>
<th>BaO%</th>
<th>Assay %</th>
<th>Recovery %</th>
<th>Assay %</th>
<th>Recovery %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2M</td>
<td>Iron fraction</td>
<td>40</td>
<td>66.82</td>
<td>90.36</td>
<td>0.15</td>
<td>0.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Barite fraction</td>
<td>60</td>
<td>4.75</td>
<td>9.64</td>
<td>61.55</td>
<td>99.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>100</td>
<td>29.85</td>
<td>100</td>
<td>37.0</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4M</td>
<td>Iron fraction</td>
<td>42.53</td>
<td>66.79</td>
<td>96.04</td>
<td>0.17</td>
<td>0.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Barite fraction</td>
<td>57.47</td>
<td>2.04</td>
<td>3.96</td>
<td>64.24</td>
<td>99.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>100</td>
<td>29.85</td>
<td>100</td>
<td>36.97</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6M</td>
<td>Iron fraction</td>
<td>43.80</td>
<td>66.72</td>
<td>98.79</td>
<td>0.21</td>
<td>0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Barite fraction</td>
<td>56.20</td>
<td>0.64</td>
<td>1.21</td>
<td>65.66</td>
<td>99.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>100</td>
<td>29.85</td>
<td>100</td>
<td>36.99</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8M</td>
<td>Iron fraction</td>
<td>44.67</td>
<td>66.07</td>
<td>99.77</td>
<td>0.33</td>
<td>0.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Barite fraction</td>
<td>55.33</td>
<td>0.13</td>
<td>0.23</td>
<td>66.59</td>
<td>99.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>100</td>
<td>29.85</td>
<td>100</td>
<td>36.98</td>
<td>100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 2: XRD pattern of a representative sample of El-Gedida high-Ba iron ore.
Company that exploits iron raw material with total iron content at least 51% Fe (Faraghaly, 2002). On the other hand, the BaO content of barite concentrate increases from 61.55% to 65.66% with increasing the acid concentration due to the high solubility of iron oxides and hydroxides in acid solutions of HCl (Tunkasiri et al., 1992; Cornell and Giovanoli, 1993; Baba et al., 2005).

Fig. 3: Flow-sheet of the chemical leaching process of El-Gedida high-Ba iron ore.
Thus, the leaching process of El-Gedida high-Ba iron ore has overcome the undesirable high content of BaO and produced iron concentrate containing average 0.21% BaO. This low content of BaO is within the tolerance limit (< 2% BaO) for a suitable blast furnace feed (Ahmed, 2006). Also, the efficiency of chemical leaching in removal the detrimental high content of BaO from El-Gedida high-Ba iron ore are better than that of physical beneficiation operations that reduced the BaO content up to 1.61% (e.g. Faraghaly, 2002).

In addition to the high content of BaO, El-Gedida high-Ba iron ore is well known by its high content of sulfur that can reach up to 16.95% SO₃. After leaching, this high content of sulfur has been reduced noticeably to 0.55% SO₃ in the obtained iron fraction. The removal of sulfur from El-Gedida high-Ba iron ore is considered a significant step due to its serious and detrimental effects on the production of pig iron in the blast furnace. Sulfur can lead to form troublesome sulfides, such as iron and magnesium sulfides, that lower the melting point and contribute to the steel brittleness via promotion of granular weakness and cracks in steel during the solidification process (Pereira et al., 2006; Reardon, 2011). Considering alkalis, the resultant iron concentrate contains 0.03% Na₂O and 0.04% K₂O. These concentrations are lower than the tolerance limit that should not exceed 0.08% (Olayebi, 2014).

Regarding barite fraction, approximately 80% of the world’s production of barite is widely and essentially used as a weighting agent in the petroleum industry (Ciullo, 1996). According to Searl (2004), there are three reasons regarding barite exploitation as a weighting agent during the process of drilling mud. The first one is the high specific gravity of such mineral (at least 4.2 g/cm³), resulting in increase the density of drilling liquid. Furthermore, barite is a soft mineral; thereby it does not cause any damaging to drilling tools, and acts as a lubricant. Eventually, barium sulfate is chemically inert material, so it does not interface or react with the mud components used in the drilling process. To be acceptable for oil industry, barite material must have a high specific gravity, at least 4.2 g/cm³, purity of 92-94% BaSO₄ (Harben and Bates, 1990; Ciullo, 1996; Searl, 2004). Moreover, barite can be exploited for the glassmaking if its purity attains 96-98% BaSO₄ with less than 0.2% Fe₂O₃ and 1.5% SiO₂ (Harben and Bates, 1990; Ciullo, 1996). The obtained barite concentrate is characterized by a high specific gravity and purity reported at 4.19 g/cm³ and 97.38% BaSO₄. Also, the contents of iron and silica are detected at 0.14 and 1.36%, respectively. Depending on all of these specifications, barite concentrate obtained from the chemical leaching of El-Gedida high-Ba iron ore is suitable for both oil industry and glassmaking.

4. CONCLUSION

Chemical leaching followed by solvent extraction of El-Gedida high-Ba iron ore has produced a dual concentrate of iron and barite fractions. The purity of iron concentrate is 66.11% Fe (99.84% iron recovery) with barium content recorded at 0.15. Thus, the obtained iron concentrate is an acceptable charge for the blast furnace feed with barium and sulfur contents lower than the tolerance limits. On the other hand, the resultant barite fraction is physically and chemically suitable for both oil industry and glassmaking.

ACKNOWLEDGEMENT

Authors are grateful and highly appreciate the collaboration of Dr. M. Mansour, the Chairman of El-Bahariya Oasis Sector, Egyptian Iron & Steel Company, and the central chemical lab at the Faculty of Mining, Geology and Petroleum Engineering-Zagreb University-Croatia.

REFERENCES


