*Physicochem. Probl. Miner. Process. 46(2011) 173-190*

journal homepage
www.minproc.pwr.wroc.pl/journal/

Physicochemical Problems
of Mineral Processing

Index No. 32213X ISSN 1643-1049

---

Vahid SOLTANMOHAMMADI*, Mohammad NOAPARAST**, Amir Hossein KOHSARI**, Farshid ZAMANI***

# INFLUENCE OF FLOTATION PARAMETERS ON DECREASING SULFUR AND PHOSPHORUS CONTENT IN THE GOL-e-GOHAR IRON ORE CONCENTRATE

*Received April 30, 2010; reviewed; accepted July 21, 2010*

Gol-e-Gohar iron complex, one the largest iron concentrate producer, is located in the Kerman Province in Iran. The ore suffers from elevated S and P content equal to 0.5% S and 0.08% P, respectively, while the steel industrial permitted limit is 0.1% S and 0.05% P. The main source of S and P are pyrite and apatite. In this work it was attempted to decrease the S and P content in concentrate using reversed flotation with xanthates, in which pyrite floated while fine apatite particles were entrained with water. The liberation degree for pyrite in the -75+53 µm size fraction was 65%. The influecnce of such parameters as type and doze of collector, frother and depressant, solid content, pH, impeller speed, frothing time, conditioning time and desliming, on S and P removal were investigated. The best results were achieved with desliming. The collector, frother and dispersant doses were 50g/Mg of KAX, 60g/Mg of MIBC and 200g/Mg of sodium silicate at pulp pH=8 and 6 minutes of conditioning time. Under best conditions, with desliming, a concentrate with acceptable grades of Fe (70.24%), S (0.041%), and P (0.043%) were obtained. The recovery of Fe was 95.11% while sulfur removal 92.24%. The effect of different size fractions and two-stage flotation were also studied. The result showed that in +45 µm and also -38 µm size fractions, S and P contents were bellow or near the permitted limit. It was postulated that +45 µm size fraction was the most convenient for flotation while -38 µm was the best for removal with water flow. With 100 g/Mg of KAX and one-stage flotation, S content was 0.191% while in two-stage flotation it was reduced to 0.097%.

*keywords: iron ore, Gol-e-Gohar concentrator, sulfur removal, phosphorus removal*

---

* Mining Engineering Department, Yazd University, Yazd, Iran
** School of Mining Engineering, Un. College of Eng., University of Tehran, noparast@ut.ac.ir.
*** Head of R&D Division, Gol-E-Gohar iron ore concentrator, Sirjan

## 1. INTRODUCTION

Gol-e-Gohar iron ore complex (Kerman Province, Iran) is one the largest iron concentrate producers and is located 50 km southwest of the Sirjan City. The complex with about 1200 Tg (teragrams) reserves of iron ores provides production of 5 Tg/year of concentrates. The Gol-e-Gohar iron ore concentrate suffers from high content of S (0.5%) and to some extent P (0.08%), which are higher than permitted limit of 0.1% S and 0.05% P (Svoboda, 2004). Therefore, it is very important to remove and/or decrease the sulfur and phosphorus contents from the Gol-e-Gohar concentrate. In this work concentrate samples from this plant were processed to find out the optimum conditions for eliminating S and P.

Pyrite is the main source of sulfur. There are usually three types of pyrites: a) separated from magnetite, b) associated with magnetite, and c) inclusion in magnetite. Phosphorus is normally observed as apatite in fractions finer than 20 μm (Jafarzadeh et al., 1995). Floatability of pyrite is fair and micro-particles of apatite follow water flow. Therefore, to decrease S and P content in the Gol-e-Gohar concentrate a reverse flotation was implemented.

In this work different experiments were performed to achieve optimum values of various parameters involved in flotation including consumption of collector, frother and depressant, pulp solids content, pH, conditioning and flotation times. The role of desliming in sulfur and phosphorus removal was also studied.

## 2. MINERALOGICAL STUDIES

Mineralogical studies were carried out prior to processing. To do this X-ray diffraction (XRD) analysis and polished and thin sections were employed. Elemental studies indicated the presence of Fe, S, P and iron oxides. Contents of iron and iron oxides were analyzed by titration and the X-ray fluorescence (XRF) analysis. The results obtained from XRD showed that magnetite is the main phase and hematite as well as goethite were present also in the sample, but not as much as magnetite. Calcite, pyrite and chlorite were the other minerals. Thin and polished sections studies showed that the main minerals were magnetite and hematite with small amounts of goethite, chlorite, pyrite, calcite, quartz and apatite, chalcopyrite and pyrrhotite.

Pyrite was observed as separated from magnetite, associated with magnetite, and inclusions in magnetite. In some cases, because of alteration, pyrite was converted to goethite. Chalcopyrite and pyrrhotite contents were very low and they occurred as inclusion in magnetite. Figure 1 shows contacts between pyrite and magnetite while Fig. 2 illustrates inclusion of pyrrhotite in magnetite. To determine minerals liberation size and comminution size (grinding limit), the liberation degree of minerals were measured in size fractions of -150+75 and -75+53 μm (Table 1). There can be seen that in the size fraction of -75+53 μm 65% of pyrite was liberated. Therefore, this size (av. 68 micrometers) was considered as the grinding limit ($d_{80}$ of grinding product). Although in size fraction of -53+45 μm, about 80% of magnetite was liberated, but this size was too fine to be considered as grinding size and would produce significant amount of slimes.

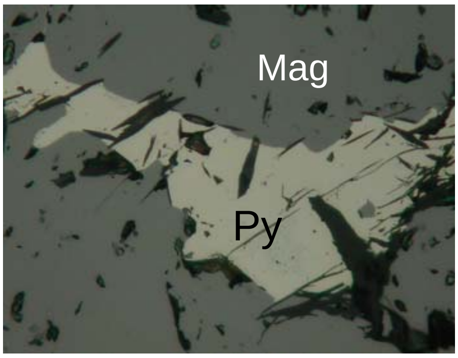

Fig. 1. Pyrite (Py) and magnetite (Mag) contact

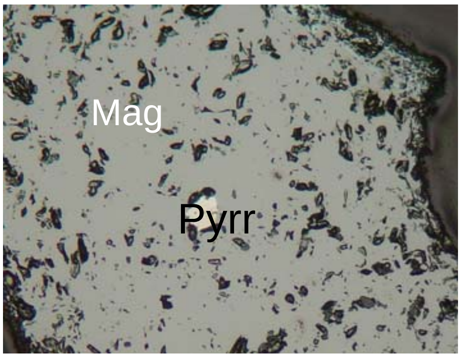

Fig. 2. Pyrrhotite (Pyrr) inclusions in magnetite (Mag)

Table 1. Liberation studies results

| Minerals | -150+75 μm | -75+53 μm |
|---|---|---|
| Magnetite-hematite-goethite | 80.5% | - |
| Pyrite | 38.8% | 65% |
| Calcite | 40.0% | 63% |

## 3. ELEMENTAL ANALYSIS

Elemental analyses were applied on two samples: i) to have the feed contents, and ii) size fractions distribution. Results obtained for the feed content showed 67.75% Fe, 17.8% FeO, 0.5% S, and 0.08% P. The contents of S and P were higher than acceptable values of 0.1% S and 0.05% P. For elemental analysis in various size fractions about 250 g samples were screened from -150+106 down to -38 μm, and then mass retained in each size fraction was analyzed for Fe, S, and P. Figures 3-5 present changes of Fe, S and P contents in different size fractions.

According to Fig. 3, the lowest Fe content, referred to ranges finer than 38 μm, and the higher ones were those of size ranges of 53 to 90 μm. In addition, the lowest content of S is for the size range over 106 μm (Fig. 4). It should be noted that the content of S was increasing with the decreasing size. According to Fig. 5, the maximum content of P was in size fractions finer than 38 μm and the lowest in -90+75 μm.

## 4. SAMPLE PREPARATION

The weight of initial sample of the Gol-e-Gohar concentrate was about 60 kg. Then, 57 of one-kilogram samples were prepared by sequential rifling approach. One of the representative samples was divided into halves. One of these 500 g samples was then screened. Figure 6 shows the size distribution of a sample which $d_{80}$ was less than 400 μm, and 60% of particles were finer than 200 μm. It can be observed that 30% of sample was finer than 90 μm.

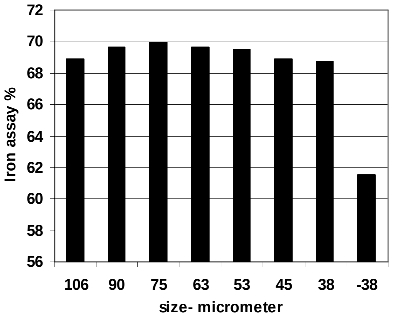

Fig. 3. Variation of Fe content versus size

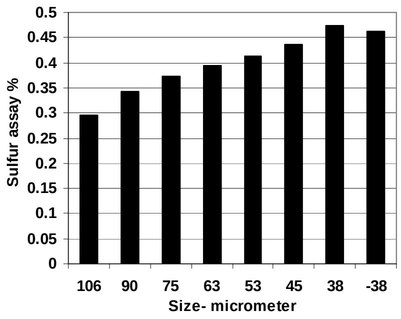

Fig. 4. Variation of S content versus size

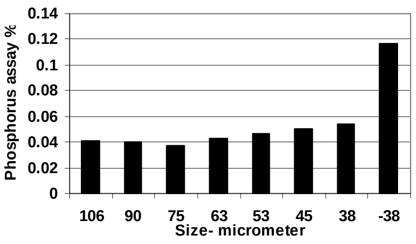

Fig. 5. Variation of P content versus size

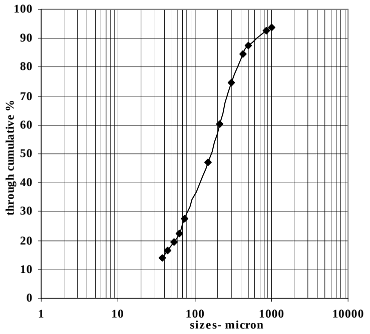

Fig. 6. Size distribution of head sample

## 5. SIZE REDUCTION PROCESS

The target of size reduction was firstly to liberate valuable minerals from the gangue, and then determination of the best size distribution for concentration. Therefore, four tests were performed in a wet rod milling. Table 2 presents the specification of used rod mill, in which the grinding times were 5, 10, 15, and 20 minutes. The results of these tests are illustrated in Fig. 7. Wet rod milling was applied for two reasons: i) lower slime production, ii) wet character of flotation.

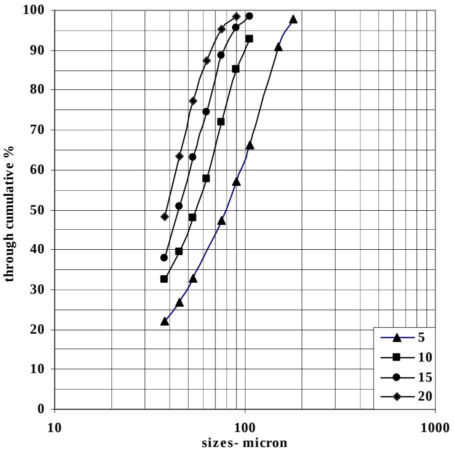

Fig. 7. Size distribution of grinding products

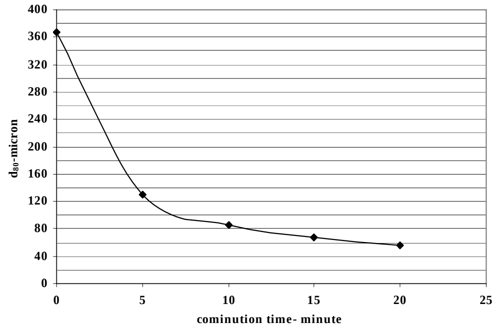

Fig. 8. $d_{80}$ values of grinding products

As it is observed in Fig. 7, after 5, 10, 15, and 20 minutes of grinding, the $d_{80}$ values of products were 130, 86, 68 and 56 μm, respectively. Figure 8 shows a diagram with $d_{80}$ values of the products versus different grinding times.

Thus, the pyrite liberation size is -75+53 μm (av. 68 μm) and 15 min was selected as the optimum grinding time while the pulp solid percent in grinding 50%.

Table 2. The specification of used rod mill

| Mill | | Rods | | |
|---|---|---|---|---|
| D-L, mm | rpm (65% of Cs) | Rod No. | D-L ,mm | W, g |
| 200-250 | 61 | 18 | 24-245 | 15710 |

## 6. FLOTATION EXPERIMENTS

Pyrite is the main source of sulfur in the magnetic concentrate of Gol-e-Gohar iron ores. In the presence of oxygen, xanthates combine with pyrite and forms dixanthogen making pyrite floatable (Rao, 2003). Due to this fact and low content of pyrite in comparison with oxide iron minerals, the reverse flotation approach was implemented for pyrite, to decrease the sulfur contents in the Gol-e-Gohar concentrate. Because of the presence of apatite in fine sizes, reverse flotation of pyrite could decrease P content as well. In this paper selection of optimum flotation conditions were based on concentrate quality and sulfur removal. In some cases, obtained contents and recoveries did not yield desired values, therefore a separation efficiency index was implemented (Wills and Napier-Munn, 2006).

## 7. REAGENTS SELECTION

In reverse flotation of pyrite, various reagents such as collector, frother and depressant can be used. Among sulphydryl anionic collectors, which are common in beneficiation of sulfides (Wills and Napier-Munn, 2006), xanthates are most suitable for pyrite flotation because of their collecting power, wide range of flotaion pH and low cost (Vijayendra, 1995). In the experiments three xanthates: potassium amyl (KAX), sodium ethyl (NaEX) and sodium isopropyl ($Z_{11}$) xanthates were utilized. In addition, two different frothers: pine oil and methyl isobouthyl carbinol (MIBC) were considered and the latter was selected for experiments due to its higher solubility, greater stability, better purity and economics (Vijayendra, 1995). Sodium silicate was used as a depressant of oxide minerals and slimes (Parekh and Miller, 1999; Bulatovic, 2007). The initial conditions of reverse flotation are presented in Table 3.

Table 3. Initial conditions of reverse flotation

| | |
|---|---|
| Comminution time, min | 15 |
| Collector doze, g/Mg | 200 |
| MIBC, g/Mg | 200 |
| $Na_2SiO_3$, g/Mg | 500 |
| Conditioning time, minute | 6 |
| Frothing time, minute | 3 |
| pH | 7 |
| Solid content, % | 20 |
| Speed, rpm | 1500 |

## 8. TYPE AND DOZE OF COLLECTOR

To investigate the effect of type and doze of collector in decreasing of S content, KAX, NaEX, and $Z_{11}$ collectors were used in the doze of 50, 100, 150, 200 and 250 g/Mg. The obtained results are presented in Table 4. They indicate that the iron content is in the range of 68-69% with 99% of recovery. The content of S was 0.15%. Under best conditions with 50g/Mg of KAX, 70% of S rejection was achieved. The content of S was higher than the permitted limit of 0.1%, and therefore, to reach this level, other conditions had to be adjusted.

In all the tests the content of P was higher than permitted limit of 0.05%. In comparison with other xanthates, influence of KAX on decreasing P content was more distinctive. Due to a high sulfur removal 50 g/Mg of KAX was selected as the best dose. Figures 9-10 illustrate S content and removal vs. collector consumption.

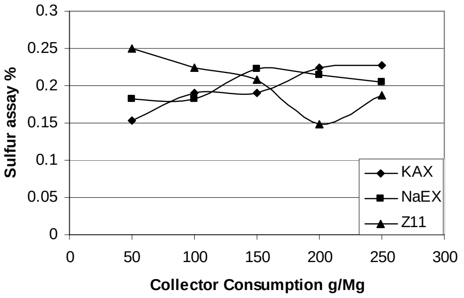

Fig. 9. Effect of collector doze on S content

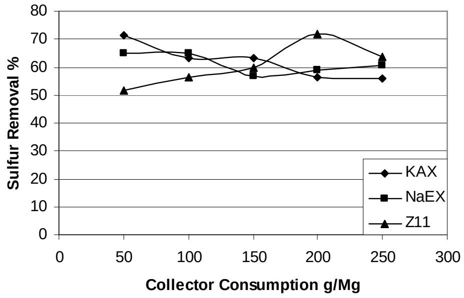

Fig. 10. Effect of collector doze on S removal

Table 4. Results of flotation tests with KAX, NaEX and $Z_{11}$

| Collector | Consumption, g/Mg | Concentrate content, % | | | Iron recovery, % | Sulfur removal, % |
|---|---|---|---|---|---|---|
| | | Fe | S | P | | |
| KAX | 50 | 68.24 | 0.153 | 0.070 | 99.5 | 70.4 |
| | 100 | 68.03 | 0.191 | 0.070 | 99.7 | 63.1 |
| | 150 | 68.65 | 0.190 | 0.065 | 99.1 | 63.4 |
| | 200 | 68.97 | 0.225 | 0.070 | 99.0 | 56.3 |
| | 250 | 68.94 | 0.227 | 0.070 | 98.9 | 55.8 |
| NaEX | 50 | 68.35 | 0.183 | 0.070 | 99.4 | 64.8 |
| | 100 | 68.05 | 0.182 | 0.068 | 99.6 | 65.0 |
| | 150 | 67.85 | 0.223 | 0.075 | 99.9 | 56.7 |
| | 200 | 68.78 | 0.214 | 0.073 | 99.2 | 58.7 |
| | 250 | 68.45 | 0.205 | 0.073 | 99.4 | 60.8 |
| $Z_{11}$ | 50 | 68.72 | 0.250 | 0.073 | 99.0 | 51.8 |
| | 100 | 68.12 | 0.225 | 0.071 | 99.7 | 56.5 |
| | 150 | 68.48 | 0.208 | 0.073 | 99.5 | 59.6 |
| | 200 | 68.55 | 0.149 | 0.071 | 98.8 | 71.9 |
| | 250 | 68.57 | 0.187 | 0.072 | 99.3 | 63.7 |

## 9. EFFECT OF FROTHER

To consider the effect of frother consumption, 20, 60, 100, 140 and 200 g/Mg of MIBC, and KAX (50 g/Mg) were tested. The results are presented in Table 5. The content of Fe and its recovery are around 68% and 99%. However, in all the tests, S content was higher than permitted limit of 0.1%, and under the best condition was with the consumption of 60 g/Mg of MIBC. In latter test, the S content and its removal was obtained as 0.157% and 69.7%, respectively. In addition, P content decreased to 0.06% which was just 0.01% higher than the permitted limit of 0.05%. Figures 11-12 illustrate S content and removal vs. MIBC consumption. The diagram shows that with increasing MIBC consumption S content increases and its removal decreases.

Table 5. Results of flotation tests with MIBC

| Consumption g/Mg | Concentrate content, % | | | Iron recovery, % | Sulfur removal, % |
|---|---|---|---|---|---|
| 20 | 68.54 | 0.184 | 0.059 | 99.2 | 64.4 |
| 60 | 68.07 | 0.157 | 0.059 | 99.7 | 69.7 |
| 100 | 68.37 | 0.204 | 0.061 | 99.4 | 60.5 |
| 140 | 68.50 | 0.184 | 0.058 | 99.1 | 64.6 |
| 200 | 68.78 | 0.214 | 0.073 | 99.2 | 58.7 |

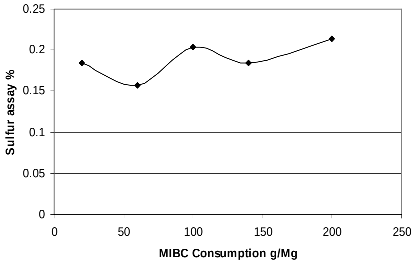

Fig. 11. Effect of frother dose on S content

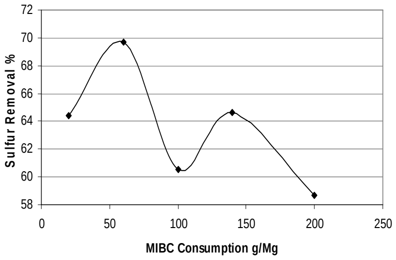

Fig. 12. Effect of frother dose on S removal

## 10. EFFECT OF DEPRESSANT

In different flotation tests $Na_2SiO_3$ was used as: i) depressant of silicate and oxide minerals (Parekh and Miller, 1999; Bulatovic, 2007), ii) dispersant of slimes. The influence of various amounts of $Na_2SiO_3$ was investigated on S decreasing using 0, 200, 300, 400 and 500 g/Mg. The obtained results are presented in Table 6.

Table 6. Results of flotation tests with $Na_2SiO_3$

| Consumption g/Mg | Concentrate content, % | | | Iron recovery, % | Sulfur removal, % |
|---|---|---|---|---|---|
| | Fe | S | P | | |
| 0 | 69.55 | 0.248 | 0.058 | 97.8 | 54.0 |
| 200 | 68.41 | 0.200 | 0.060 | 99.3 | 61.8 |
| 300 | 68.25 | 0.203 | 0.058 | 99.5 | 61.2 |
| 400 | 68.40 | 0.248 | 0.058 | 99.3 | 52.9 |
| 500 | 68.37 | 0.252 | 0.059 | 99.3 | 51.6 |

In the absence of $Na_2SiO_3$, the content of iron was 69.55% and the recovery 97.8%. The results in Table 8 indicate that the presence and/or absence of sodium silicate does not have any remarkable effects on sulfur removal. However, it was observed that the best values were achieved using 200 g/Mg of $Na_2SiO_3$. Figures 13-14 illustrate S content and its removal vs. $Na_2SiO_3$ consumption. Figure 13 shows that increasing with $Na_2SiO_3$, S content decreased at first and then increased to nearly constant amount. Figure 14 shows that also S removal increased at first, and then reached a constant level.

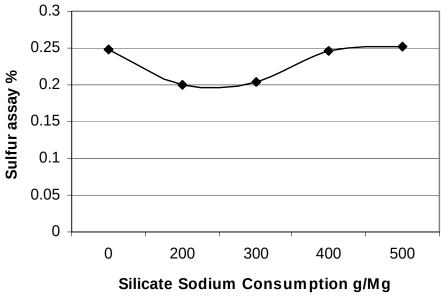

Fig. 13. Effect of $Na_2SiO_3$ dose on S content

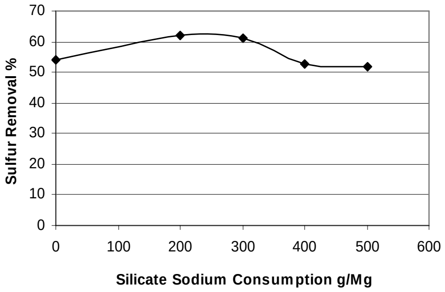

Fig. 14. Effect of $Na_2SiO_3$ dose on S removal

## 11. IMPELLER SPEED

Increasing impeller speed caused fine bubbles production. Thus, the possibility of particles contacts with bubbles was increased leading to increased recovery. It should be noted that very high impeller speed causes the bubbles to be blown, and therefore the recovery drops accordingly. The role of impeller speed was studied at 1350, 1500 and 1650 rpm. The results of these tests were presented in Table 7. They indicate that the Fe contents and recoveries are around 68% and 99%, respectively. The most unsuitable test to decrease S content was at 1350 rpm. It was observed that at 1500, and 1650 rpm, the removal of sulfur was increased. To select the best impeller speed, the Schulz separation efficiency index (SE) was also employed (Wills and Napier-Munn, 2006). The results of these tests and separation efficiency estimation showed that at 1500 rpm, the SE values were higher than those of other speeds. Therefore, 1500 rpm was selected as the most suitable value for impeller speed. It should be mentioned that the P content obtained from the test at 1500 rpm was higher than the permitted limit of 0.05% in all three experiments.

Table 7. Results of different impeller speed tests

| Speed, rpm | Concentrate content, % | | | Fe recovery, % | S removal, % | SE |
|---|---|---|---|---|---|---|
| | Fe | S | P | | | |
| 1350 | 68.1 | 0.311 | 0.057 | 99.6 | 42.4 | - |
| 1500 | 68.4 | 0.200 | 0.060 | 99.3 | 61.8 | 57.8 |
| 1650 | 68.4 | 0.211 | 0.056 | 99.1 | 62.5 | 51.8 |

## 12. FROTHING TIME

By increasing frothing time the recovery increases. The trend of this increase follows exponential function. Different experiments were carried out to consider the effect of frothing time on sulfur decrease, iron content and recovery. The frothing time was 1st, 3rd and 7th min of flotation. The results obtained from these experiments are shown in Figs 15-16. It was observed that with increasing frothing time, the content of S in concentrate decreased, and its removal accordingly increased. Therefore, the best frothing time was 7 minutes.

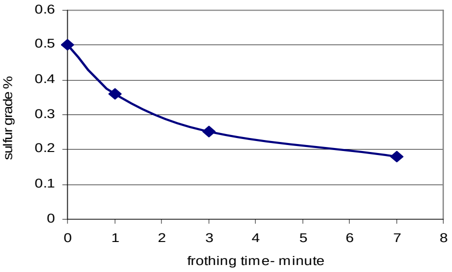

Fig. 15. Frothing time versus S content

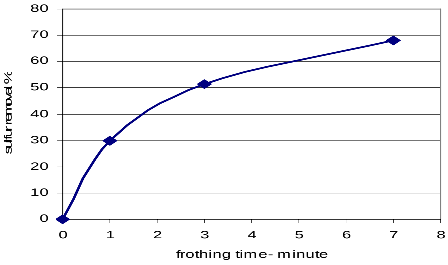

Fig. 16. Frothing time versus S removal

## 13. EFFECT OF pH

The influence of pulp pH on S removal was studied in acidic, neutral and alkaline environments, and the results are shown in Table 8. The natural pH of pulp was 8, and thus no regulator was added, but sulfuric acid was used in other tests to adjust the pH.

Table 8. Effect of pH on sulfur removal

| pH | Concentrate content, % | | | Iron recovery, % | Sulfur removal, % |
|---|---|---|---|---|---|
| | Fe | S | P | | |
| 5 | 67.85 | 0.293 | 0.058 | 99.9 | 46.0 |
| 6 | 68.00 | 0.174 | 0.057 | 99.7 | 67.7 |
| 7 | 69.40 | 0.158 | 0.058 | 99.1 | 70.7 |
| 8 | 69.00 | 0.113 | 0.057 | 99.4 | 79.2 |

According to Table 8, by increasing pH, the content of iron increased and its recovery decreased. In addition, the content of sulfur decreased and its removal increased. The optimum value for pH was achieved at natural pH=8, and the content of sulfur and its recovery were 0.113% and 79.2%, respectively. Increasing pH did not have any significant effects on decreasing P content and under the best condition its amount was decreased to 0.057%, which is higher than the permitted limit. Figures 17 and 18 illustrate S content and removal versus pH, respectively. Trend of the diagram shows that by increasing pH, S content decreases and its removal increases.

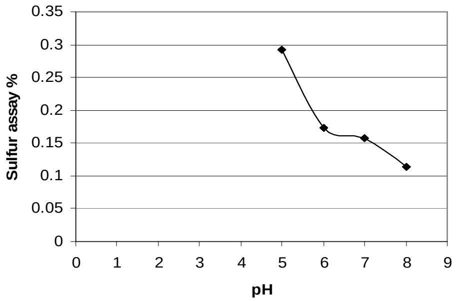

Fig. 17. Effect of pH on S content

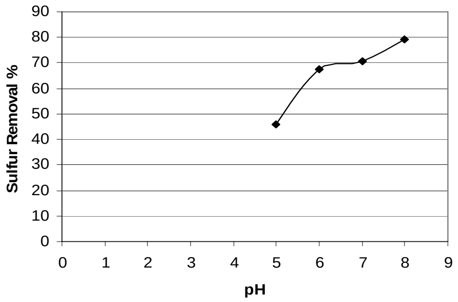

Fig. 18. Effect of pH on S removal

## 13. EFFECT OF SOLID CONTENT

Solids content in any pulp shows a direct relation with ore density. The amount of the weight solid content could be from 10 to 15% for light minerals such as coal, and higher than 35% for heavy minerals such as galena and sphalerite (Vijayendra, 1995). In order to obtain optimum flotation results, the solids content has to be in a certain range. Economically it is 30-35% (Vijayendra,1995; Parekh and Miller, 1999).

In this project, the weight of solids was tested between 20 and 36%, and the results are presented in Table 9. According to this Table, the content of iron in different experiments and for various solids content was approximately nearly the same and showed very small variation from 68.6 to 69.0%. By increasing the solids content, S content increased and then decreased, so at the solids content of 36% the S content decreased to 0.08% and its removal recovery increased to 85.5%. Since the content of sulfur at the solids content of 36% was less than permitted level, this value was selected as the optimum for the solids. The P content was approximately similar in all tests, and at the solids content of 36% reached 0.052%, which is very near to the permitted level.

Figures 19-20 illustrate S content and its removal vs. solid content, respectively. Figure 19 shows that by increasing solids content, S content increased at first and then decreased. Also Fig. 20 indicates that S removal decreased at first and then increased.

Table 9. Results of solid content tests

| Solid content, % | Concentrate content % | | | Iron recovery, % | Sulfur removal ,% |
|---|---|---|---|---|---|
| | Fe | S | P | | |
| 20 | 69.0 | 0.113 | 0.057 | 98.4 | 79.2 |
| 25 | 68.6 | 0.134 | 0.055 | 99.0 | 75.0 |
| 31 | 68.9 | 0.115 | 0.056 | 97.8 | 78.29 |
| 36 | 68.8 | 0.080 | 0.052 | 98.4 | 85.5 |

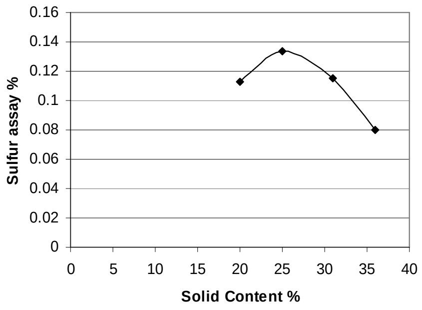

Fig. 19. Effect of solid content on S content

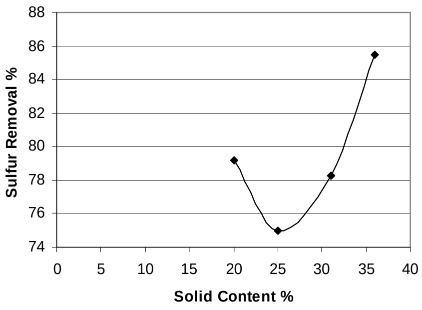

Fig. 20. Effect of solid content on S removal

## 14. CONDITIONING TIME

To verify the effect of conditioning time on flotation, it was reduced to 25% (25% less than initial time, Table 3), for each reagent. Then, the content of S and its removal were studied. The results obtained for 4.5 and 6 min as the conditioning time are shown in Table 10. The content of sulfur increased from 0.08% to 0.113%, which was 0.013% (small discrepancy) higher than the permitted limit (0.1%). The content of P also increased. Thus, 6 minutes was the best time for conditioning.

Table 10. Results of two conditioning time tests

| Time, min | Concentrate content % | | | Iron recovery % | Sulfur removal % |
|---|---|---|---|---|---|
| | Fe | S | P | | |
| 4.5 | 68.5 | 0.113 | 0.056 | 98.8 | 79.5 |
| 6 | 68.8 | 0.080 | 0.052 | 98.4 | 85.5 |

## 15. EFFECT OF DESLIMING

The aim of desliming was to study: i) direct influence on decreasing S and P contents, and ii) effect on flotation. We attempted to separate particles finer than 10 µm using hydrocyclone and then flotation experiments were preformed on deslimed samples. In the first test, the sample was ground for 15 minutes in a rod mill. The product of mill was then deslimed with a hydrocyclone to remove particles finer than 10 µm. The samples of feed, overflow and underflow of hydrocyclone were analyzed for Fe, S, and P content. The results are presented in Table 11.

It is observed that desliming did not have any significant effect on decreasing S content, but P content decreased to 0.05%, which is in the acceptable range. It can be concluded that the main part of apatite existed in the undersize size fractions and the weight of slimes (-10 μm) is 7% of the initial sample weight. Next, the deslimed sample was floated to verify the influence of flotation on the deslimed sample. The conditions of this test are shown in Table 12, and the results in Table 13. The recovery of Fe was 98.5% with 69.5% Fe in the concentrate. The content of S reached 0.088%, which was less than the limit, and with 80.6% of S removal. The content of P decreased to an acceptable limit of 0.049%. Frothing time was reduced to 3 minutes.

Table 11. Results of desliming test (first test)

| Products | Fe, % | S, % | P, % | Weight, % |
|---|---|---|---|---|
| Feed | 67.75 | 0.500 | 0.080 | 100 |
| Underflow | 67.91 | 0.440 | 0.052 | 89.9 |
| Overflow | 48.95 | 0.564 | 0.107 | 7.35 |
| Lost | - | - | - | 2.75 |

Table 12. Conditions of flotation test (first test)

| | |
|---|---|
| Collector (g/Mg) | KAX 50 |
| Frother (g/Mg) | MIBC 60 |
| Depressant (g/Mg) | Sodium silicate 500 |
| Solid content % | 20 |
| Pulp pH | 7 |
| Conditioning time (minute) | 6 |
| Frothing time (minute) | 3 |
| Impeller speed (rpm) | 1500 |

Table 13. Results of deslimed sample flotation (first test)

| Products | Fe% | S% | P% | Iron recovery % | Sulfur removal % |
|---|---|---|---|---|---|
| Feed | 67.91 | 0.440 | 0.052 | 98.50 | 80.57 |
| Concentrate | 69.45 | 0.088 | 0.049 | | |
| Tail | 27.21 | 12.236 | 0.077 | | |

Table 14. Results of desliming (second test)

| Products | Fe, % | S, % | P, % | Weight, % |
|---|---|---|---|---|
| Feed | 67.75 | 0.500 | 0.080 | 100 |
| Underflow | 68.00 | 0.454 | 0.051 | 89.4 |
| Overflow | 50.00 | 0.548 | 0.103 | 7.4 |
| Lost | - | - | - | 3.2 |

Table 15. Results of deslimed sample flotation (second test)

| Products | Fe, % | S, % | P, % | Iron recovery % | Sulfur removal, % |
|---|---|---|---|---|---|
| Feed | 68.00 | 0.454 | 0.051 | 95.11 | 92.24 |
| Concentrate | 70.24 | 0.041 | 0.043 | | |
| Tail | 41.66 | 8.54 | 0.104 | | |

The procedure of the second test was identical with the first one: 15 minutes of rod milling, and then a hydrocyclone was used to deslime the ground sample to remove particles finer than 10 μm. The results of desliming are presented in Table 14, which indicates that desliming did not have any direct effect on the S while P content decreased to 0.05%. In the next step, the deslimed sample was floated, but some parameters were different from the those of the first test. In this experiment, the solids content in the pulp was 44% (in first test 20%), and pH was 8 (in first test 7). Moreover, the consumption of sodium silicate decreased from 500 to 200 g/Mg and the other parameters were identical with the first test (Table 12). The results achieved in this test are presented in Table 15. It was observed that flotation of deslimed sample decreased the S content to 0.041%, which was remarkably less than permitted limit of 0.1% with sulfur removal of 92.24%. The content of Fe was 70.24% with 95.11% of recovery. The content of phosphorus reached 0.043% (less than permitted level 0.05%). It was found that increasing solids content, pulp pH, and decreasing $Na_2SiO_3$ consumption, yielded very significant results, particularly S elimination.

In this work effect of size fraction and two-stage flotation (rougher+cleaner) on S and P content reduction were also studied which are presented in following section.

## 16. EFFECT OF FLOTATION ON S AND P REDUCTION IN SIZE FRACTIONS

Prior to running flotation experiments, contents of S and P in the head sample, S content in all size fractions, and P content in the -38 μm fraction were higher than their permitted limits. The flotation test yielded a considerable decrease of the S and P content in all size fractions. The greatest decrease occurred in -38 μm and the least in -45+38 μm size fractions, respectively. Figures 21 and 22 present the results of the flotation experiments. The lowest contents of S are obtained in the -63+53 μm and the highest in the -45+38 μm size fractions. It should be noted that except of -45+38 μm fraction, the S and P contents are near to or below of the desired limits in other fractions. It could be postulated that the decrease of the S and P content in the -38 size fraction is due to the fineness of particles in this size class which causes their easily removal by water flow. It seems that +45 μm particles have enough capability to float while -45+35 fraction is not too fine to be removed by water flow (as -38 μm particles). These facts are presented in Fig. 22. They indicate that the P content is around 0.05% before flotation in all size fractions coarser than 45 μm, and it is around 0.05% for the -45+38 μm fraction, but it is high for the -38 μm size fraction (about 0.12%).

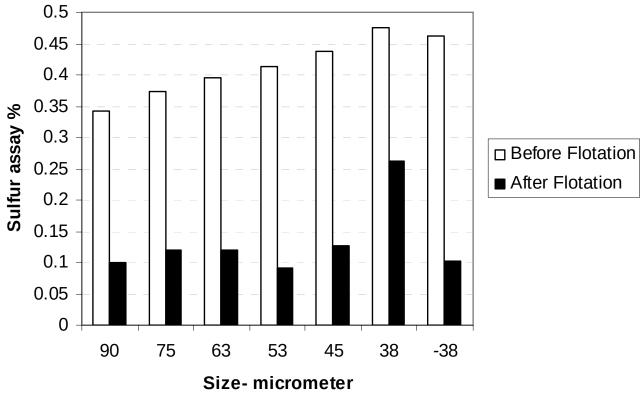

Fig. 21. Effect of flotation on S content in different fractions

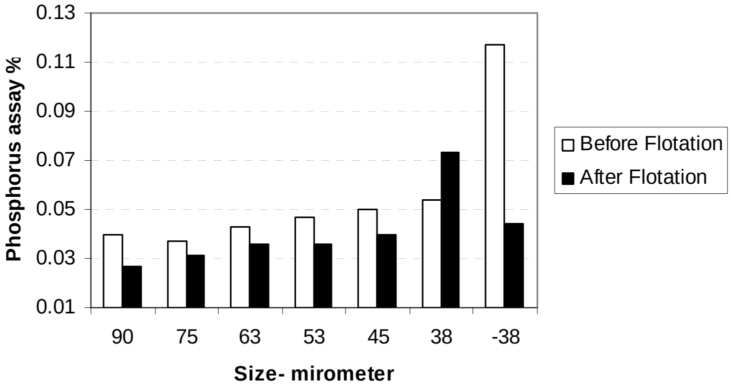

Fig. 22. Effect of flotation on P content in different fractions

## 17. EFFECT OF TWO STAGE FLOTATION

Table 4 presents results of a flotation test using 100g/Mg of KAX. In this test the content of S reached 0.191% which is more than the accepted limit. In a next step, it was considered to perform the flotation tests in two stages. In each test 50g/Mg of KAX was used, and concentrate of the first test was used as the feed of the second test (cleaner). In this cleaner test 50g/Mg KAX, 40g/Mg MIBC, 500g/Mg sodium silicate, 20% solids content of the were used in a 2 $dm^3$ Denver flotation cell with 1500 rpm at pH=7. The new approach yielded better results than the one-stage flotation test. Table 4 shows that by using 100 g/Mg KAX, S content was 0.191% with 63.1% recovery, while using twice 50 g/Mg of KAX in two tests, the S content reached 0.097% with 81.88% recovery, and P content nearly reached the desired limit.

Table 16. Results of two-stage flotation tests

| Stage | Material | content % | | | Iron recovery % | | Sulfur removal % | |
|---|---|---|---|---|---|---|---|---|
| | | Fe% | S | P | initial | overall | initial | overall |
| 1 | Feed | 67.75 | 0.5 | 0.080 | 99.49 | - | 70.45 | - |
| | Product | 68.24 | 0.153 | 0.070 | | | | |
| | Tail | 27.5 | 8.241 | 0.114 | | | | |
| 2 | Feed | 68.24 | 0.153 | 0.070 | 98.99 | 98.49 | 38.67 | 81.88 |
| | Product | 68.66 | 0.097 | 0.056 | | | | |
| | Tail | 43.48 | 1.81 | 0.159 | | | | |

## 18. CONCLUSION

The iron ore concentrate of the Gol-e-Gohar complex contains high amount of sulfur and phosphorus. Their contents were 0.5% S and 0.08% P, respectively, which were higher than the steel industrial permitted limit of 0.1% S and 0.05% P. The major sources of S and P are pyrite and apatite. To decrease the sulfur and phosphorus content in the concentrate, reverse flotation of pyrite in the presence of xanthates was used. In reverse flotation, pyrite was floated and apatite particles were entrained with the froth product water. Prior to the flotation tests, mineralogical and size reduction studies were carried out. Results indicated that pyrite liberation (65%) was achieved in the size fraction of -75+53 μm. Therefore, the average size of 68 μm was considered as the target size for grinding. In order to achieve this size, 15 minutes of rod milling was needed.To yield the optimum condition, role of various parameters such as type and doze of collector, frother and depressant, solid content, pH, impeller speed, frothing time, conditioning time and desliming were investigated. The results obtained in two procedures, with and without desliming, are given in Table 17. The best results were obtained appying 50 g/Mg of KAX, 60 g/Mg of MIBC and 200 g/Mg of sodium silicate, pulp pH=8, and conditioning time 6 minutes. Other conditions are presented in Table 17, which shows that desliming produced better results than without desliming, leading to a decrease of sulfur and phosphorus contents in the concentrate.

In addition, some experiments were performed to investigate the influence of particles size and two-stage flotation, which showed that in the +45 and -38 μm fractions, sulfur and phosphorus content are near to the permitted limits, but in the -45+38 μm fraction those were too high. It was postulated that for convenient flotation, +45 μm particles, and -38 μm fraction removal with water flow should be used. Results indicated that consumption of 100 g/Mg of KAX in two-stage (50+50) flotation, S and P contents could be reduced to 0.097% and 0.056% (near the permitted limit), while the same collector dose in one-stage flotation, the content were 0.191% and 0.070%, respectively.

Table 17. Optimum flotation results

| State | | Without desliming | With desliming |
|---|---|---|---|
| Solid content, % | | 36 | 44 |
| Frothing time, min | | 7 | 3 |
| Elemental contents of product, % | Fe | 68.80 | 70.24 |
| | S | 0.080 | 0.041 |
| | P | 0.052 | 0.043 |
| Iron recovery, % | | 98.43 | 95.11 |
| Sulfur removal, % | | 85.50 | 92.24 |

## REFERENCES

BULATOVIC, S.M., 2007, *Handbook of Flotation Reagents: Chemistry, Theory and Practice: Flotation of Sulfides Ores*, Vol. 1, Elsevier, Amsterdam.

JAFARZADEH, A., QURBANI, M., PEZESHKPOR, M., 1995, *Iran Geology-Iron Ores*, Iran Geology Organization, Tehran, Iran.

PAREKH, B.K., MILLER, J.D., 1999, *Advances in Flotation Technology*, SME Publishers, New York.

RAO, S.R., 2003, *Surface Chemistry of Froth Flotation* 2nd Edition (1st Edition by Leja, J.), Marcel Dekker.

SVOBODA, J., 2004, *Magnetic Techniques for the treatment of minerals*, Kluwer Academic Publishers, Boston.

VIJAYENDRA, H.G., 1995, *Handbook on Mineral Dressing*, Vikas Publisheing House PVT Ltd., New Delhi.

WILLS, B.A., NAPIER-MUNN, T., 2006, *Wills' Mineral Processing Technology*, 7th Edition, Butterworth Heinemann, Boston.

**Soltanmohammadi, V., Noaparast, M., Kohsari, A.H., Zamani, F.,** *Wpływ parametrów flotacji na zmniejszanie zawartości siarki i fosforu w koncentratach żelaza z Gol-e-Gohar*, Physicochem. Probl. Miner. Process., 46 (2011) 173-190, (w jęz. ang), http://www.minproc.pwr.wroc.pl/journal

Kombinat Gol-E-Gohar znajdujący się w Iranie w prowincji Kerman jest jednym z największych producentów koncentratów żelaza. Wykorzystywana ruda ma nadmierną zawartość siarki (0.5%) oraz fosforu (0.08%) gdyż dozwolona ich ilość wynosi 0.1% S oraz 0.05% P. Głównym źródłem siarki i fosforu w rudzie są piryt oraz apatyt. W tej pracy podjęto próbę zmniejszenia zawartości S i P stosując flotację. Podczas flotacji ksantogenianami flotuje piryt, podczas gdy drobne ziarna apatytu są wynoszone mechanicznie z wodą piany. Stopień uwolnienia pirytu w klasie -75+53 μm wynosił 65%. Badano wpływ takich parametrów jak typ i dodatek kolektora, spieniacza, depresantu, zawartości części stałych, pH, prędkości mieszania, czasu pienienia, czasu kondycjonowania oraz odszlamiania na usuwanie S oraz P. Najlepsze wyniki osiągnięto przez odszlamianie. Ilości kolektora, spieniacza oraz dyspresantu wynosiły 50 g/Mg KAX, 60 g/Mg MIBC oraz 200 g/Mg krzemianu sodu. pH pulpy było 8, a czas kondycjonowania wynosił 6 minut. W tych warunkach, z odszlamianiem, otrzymano koncentrat zawierający kwalifikowane zawartości składników: 70.24% Fe, 0.041% S oraz 0.043% P. Uzysk Fe wynosił 95.11%, a uzysk siarki w odpadzie osiągnął 92.24%. Badano także wpływ różnych klas ziarnowych oraz dwustopniowej flotacji na obniżenie zawartości S oraz P. Wyniki wskazywały, że dla frakcji większych niż 45 mikrometrów oraz mniejszych niż 38 μm zawartości S oraz P były poniżej lub blisko dozwolonych ilości. Postuluje się, że frakcja +45 μm jest najbardziej odpowiednia do flotacji, a frakcja -38 μm do usuwania z wodą.

*słowa kluczowe: Gol-e-gohar, usuwanie siarki, usuwanie fosforu*