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# Effect of sodium silicate on the reverse anionic flotation of a siliceous–phosphorus iron ore

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ABSTRACT

In the flotation system of Chador Malu iron processing plant (Iran), the apatite is floated with fatty acid based collectors. Sodium silicate is also used as iron oxides depressant. While the phosphorous content of the iron concentrate is reduced at an acceptable level (0.047% P), the silica content (3.5% $SiO_2$) is still higher than the required level.

This study aimed to find an effective reagent combination to reduce the silica and phosphorous contents of iron concentrate. Batch flotation tests were carried out to investigate the influence of sodium silicate dosage, modulus and addition of $Ca^{++}$ ions, on the separation selectivity of phosphorous and siliceous gangue minerals from iron oxides. The feed sample, with 57.20% Fe, 6.42% $SiO_2$ and 0.748% P was mainly composed of haematite and magnetite and the main gangue minerals were apatite and quartz.

The results of flotation tests showed that sodium silicate performed better as depressant of iron oxide, but had little effect on silica flotation in the apatite–iron oxide–silica flotation system. It was also found that by using sodium silicate of modulus of 2.5 at a concentration of 800 g/t, pH value of 10, and conditioning time of 10 min, an effective separation of apatite from iron oxides could be achieved, while the silica removal (<35%) was still poor. Addition of hydrous calcium chloride ($CaCl_2{\cdot}2H_2O$), as a source for $Ca^{++}$ ions, to the sodium silicate solution enhanced the separation selectivity of quartz and apatite from the iron oxides. Applying a silicate–$CaCl_2{\cdot}2H_2O$ mixture with Me/Si ratio of 0.4, resulted in a concentration with acceptable grades of Fe (67%), $SiO_2$ (1.5%), and P (0.034%). In this case, 93.6% of Fe was recovered while 75% of $SiO_2$ and 93.9% of P were also removed.



## 1. Introduction

Flotation is usually employed to remove silicate as the main impurities from many ore types, especially iron ores. Iron oxides can be concentrated either by direct flotation, using anionic collectors, or reverse flotation of siliceous gangue with both cationic and anionic collectors [2,1]. Studies showed that the flotation recovery and selectivity was significantly higher in reverse anionic flotation [2,10,9].

Depressants including; sodium silicate, starch, dextrin, guar gum and humic acids play an important role in the reverse flotation of iron ore [16,20]. The application of sodium silicate as depressant and dispersant agent in the flotation of apatite from iron bearing minerals has been studied [15,14,3,5,12].

Sodium silicates have three major species in aqueous solution; including monomeric, polymeric and colloidal species. These are the products of hydrolysis, depending on the pH, concentration and modulus of sodium silicate, and presence of ionic species dissolved in flotation pulp. Research showed that the polymeric sodium silicate has more effect on depression of iron bearing minerals [1,3,14].

Previous studies often have investigated the depression effect of sodium silicate on phosphate ores (with impurities such as iron oxides and siliceous–calcareous gangue) and iron ores (with apatite or silicate gangue). Few studies have reported the effect of sodium silicate on the flotation behavior of iron ores with both phosphate and silica gangues [1,5,12,13,4].

In this study, attempts were made to enhance the selective separation of silica and apatite from Chador Malu iron ore. The silica content of the feed to flotation circuit of Chador Malu plant has recently increased. The current reverse anionic flotation process of apatite is not capable of reducing the silica content of the iron concentrate to an acceptable level. Several experiments were performed using different types of iron depressants. The influence of sodium silicate (concentration, modulus, conditioning time and pH) on the selectivity of apatite–iron oxides–silica flotation system, was investigates. The addition of cations to sodium silicate solution was also considered to enhance the separation efficiency of silica.

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## 2. Materials and methods

### 2.1. Feed samples

The samples were taken from the feed materials of Chador Malu flotation circuit. Chador Malu mine is the second largest iron concentrate producer, located in the central part of Iran. The ore is processed by magnetic and flotation methods. Chador Malu plant processes 3000 tph of feed, through 5 processing lines. The iron ore is ground and fed to the Medium Intensity Magnetic Separators (MIMS). The tailings of this stage is sent to the High Gradient Magnetic Separators (HGMS). The concentrate of HGMS is reground in a ball mill and fed to the flotation circuit to reduce the phosphorous content.

The flotation feed is mainly the concentrate of HGMS. Although, due to the high phosphorus content of the magnetic concentrate (MIMS) of the plant, recently a part of this concentrate is also added to the flotation feed.

The size and chemical analysis of the feed samples are shown in Table 1. The assay of Fe, P and $SiO_2$ of the feed were 57.20%, 0.748% and 6.42%, respectively. The data show that about 80% of the sample is in the −39 μm class. Also the chemical analysis indicates that the −25 μm size fraction contains 56.71% of Fe with high phosphorus and silica contents.

The results of polish section studies showed that magnetite, hematite and goethite were the main iron minerals and the gangue minerals were mostly silicates (quartz) and apatite. The liberation size for apatite and quartz was around 45 μm.

### 2.2. Flotation tests

In the flotation circuit of Chador Malu plant, the phosphorous content of the iron concentrate is removed by conventional reverse flotation method. In this circuit, Alke (fatty acid based) + Dirol (a collector/frother reagent from a local producer) are used as collector, a mixture of NaOH:$Na_2CO_3$ as pH modifier and sodium silicate as the iron oxides depressant.

Flotation tests on the feed samples of Chador Malu plant, using a Denver flotation machine, were conducted. The solid percentage of the feed was set as 30% and the agitation rate at 1200 rpm. A 50:50 mixture of Alke 742 FL and Dirole was used as collector. The pulp with a pH of around 9.5, was conditioned with depressants for 3 min then collector was added in four stages, at the rates of 300, 200, 100, and 100 g/t, and conditioned for 3 min.

In the following section first, the influence of common depressants of iron minerals were compared; then the effects of sodium silicate and its relevant parameters were discussed.

## 3. Results and discussion

### 3.1. The effects of depressant type

Among the common depressants, starch, dextrin and sodium silicate are more effective on iron oxides [20]. The effect of sodium silicate on the reverse anionic flotation of Chador Malu feed samples were compared with starch, dextrin and a mixture of starch and dextrin.

The results of these tests (Table 2) showed that increasing the dosage of starch, dextrin and their mixture improved the Fe grade of the flotation concentrate (though reduced the recovery), but the phosphorous and silica contents of the iron concentrate were still higher than the levels required ($P < 0.06\%$ and $SiO_2 < 2\%$). Previous studies showed that the presence of ions in solution or on mineral surfaces influences the adsorption of starch and dextrin significantly. The adsorption of starch on iron oxides was shown to be strongly dependent on the presence of calcium ion.

However by increasing the sodium silicate dosage, the concentrate grade was decreased. It can also be seen that sodium silicate could improve the selectivity between apatite and iron oxides, but not between silica and iron oxides.

It is believed that starch is not absorbed on the surface of quartz at alkaline pH of the pulp [9]. Besides as surface charge of quartz is negative at alkaline pH, it cannot be floated in the anionic flotation system.

As sodium silicate provides better results on the Chador Malu samples, in the following section, the influence of relevant parameters including: modulus, dosage, conditioning time and the pH of pulp are studied.

### 3.2. Effects of sodium silicate

#### 3.2.1. Sodium silicate dosage

The depressant dosage is an important factor in the reverse flotation of iron oxides, which affects the iron recovery [7]. Fig. 1 shows the effect of sodium silicate dosages on the floatability (recovery) and grade of iron, silica and phosphorus of Chador Malu samples (at pH 9.5).

At the levels of sodium silicate dosage tested, more than 55% of the silica remained in the iron concentrate. A sodium silicate dosage of 700 g/t lead to a high loss of iron (13.5%) in the tail (floated part), but increasing the dosage to 800 g/t, increased the iron recovery to 96% in concentrate. A further increase in sodium silicate dosage (900 g/t) increased the silica and phosphorus contents of the iron concentrate. The silicate dosage of 900 g/t reduced the iron loss in the tails, but increased the $SiO_2$ content (around 8%) of the concentrate.

It is postulated that, at the low dosage of sodium silicate, $Ca^{++}$ ions (resulted from apatite dissolution) promoted the unwanted activation of quartz, partially by forming calcium bearing precipitates [20,8,6]. Addition of sodium silicate reduced the effect of

**Table 1**
Size and chemical analysis of the Chador Malu feed sample.

| Size fraction (μm) | Weight (%) | Fe (%) | P (%) | $SiO_2$ (%) |
|---|---|---|---|---|
| −90 + 75 | 1.01 | 44.1 | 1.093 | 20.416 |
| −75 + 53 | 5.91 | 53.81 | 0.954 | 8.959 |
| −53 + 38 | 13.13 | 57.97 | 0.791 | 6.282 |
| −38 + 25 | 15.75 | 60.67 | 0.625 | 4.013 |
| −25 | 64.2 | 56.71 | 0.745 | 6.59 |
| Head sample | 100 | 57.20 | 0.748 | 6.42 |

**Table 2**
Comparison of sodium silicate, starch and dextrin, and their mixture on the Chador Malu samples.

| Depressant type | Depressant dosage (g/t) | Grade (%) | | | Iron recovery (%) |
|---|---|---|---|---|---|
| | | Fe (%) | P (%) | $SiO_2$ (%) | |
| Starch | 300 | 62.97 | 0.11 | 5.18 | 96.53 |
| | 400 | 63.31 | 0.095 | 4.63 | 94.65 |
| | 500 | 64.01 | 0.091 | 4.41 | 93 |
| Dextrin | 300 | 63 | 0.1 | 4.81 | 95.12 |
| | 400 | 63.53 | 0.097 | 4.89 | 93.09 |
| | 500 | 64.31 | 0.089 | 4.55 | 92.83 |
| Starch + Dextrin | 300 | 63.27 | 0.099 | 5.11 | 98.65 |
| | 400 | 63.74 | 0.112 | 5.22 | 97.12 |
| | 500 | 64.18 | 0.092 | 4.87 | 95.43 |
| Sodium silicate | 750 | 65.63 | 0.06 | 3.98 | 90.9 |
| | 800 | 65.83 | 0.054 | 4.315 | 94.43 |
| | 850 | 64.61 | 0.059 | 4.419 | 96.33 |