CHAPTER 11

Floatability of Phosphate Minerals in the Presence of Soluable Glass, Salts, Slimes and Carbonate Minerals

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ABSTRACT

Based on theoretical and experimental researches of phosphate and carbonate minerals flotation in the presence of soluable glass at various pH values and sodium silicate concentrations, it has been established that the presence of soluable glass in solution leads to formation of silicate compounds on the surface of phosphate and carbonate minerals causing change in their floatability for the worse. The harmful influence of soluable salts is done by tying of collector as metallic soaps, forming precipitates on the surface of minerals to be floated and causing their depression of flotation, and breaching of the froth etc. Depressing action of slimes and products of interaction with collector depends on the ratio of values and signs of potentials of the mineral surfaces. The possibility of phosphate and gangue minerals separation can be evaluated by comparing the minimum-necessary concentrations of collector required for their flotation.

Keywords: Apatite, Calcite, Dolomite, Magnesite, Wollastonite, Sodium silicate, Soluable glass, Flotation, Modeling, Control and regulation

INTRODUCTION

Flotation of such phosphate-containing minerals as minerals from apatite group is practically the only process for producing concentrates for high quality fertilizer production. A considerable amount of study has been devoted to the physico-chemical aspects of these minerals flotation to understand the reasons of their surface hydrophobisation, to establish the regularities of their flotation and to improve the industrial processes of such minerals flotation.

The following have been established by previous researches (Abramov et al., 1998):

1. The regularities of phosphate-containing minerals (fluorapatite, carbonapatite, hydroxyapatite) and carbonate minerals (calcite, dolomite, magnesite) flotation cannot be explained by the formation of calcium salts of fatty acids on the mineral surface, since the optimal conditions of their formation and flotation of the minerals are different. Maximum floatability of the minerals is determined by chemisorbed collector species at pH values corresponding to zero charge of mineral surface ensuring optimal conditions for physical sorption of collector species;

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2. The optimal collector concentrations, necessary for the complete phosphate-containing minerals flotation at different pH values, are dependent on the regularities of changes in the ratio of potential-determining mineral ions and collector ions in the liquid phase of pulp. This ratio maintains quite definite value to secure the potential of zero charge on the mineral surface.

3. The optimal conditions for selective flotation of phosphate-containing minerals can be determined as a result of the thermodynamic analysis of the ratio of collector concentrations required for complete flotation of the minerals to be separated in the presence of necessary modifiers.

4. The main reasons for harmful influence of soluable salts in recycling waters on flotation of phosphate-containing minerals are attributed to the precipitation of collector in the pulp, activation of gangue minerals and the effect of "depression by hydrophobic slimes." Optimal conditions for recycled water should have salts concentration at such level that they will be unable to interact with collector, with the concentration being equal to the minimum-necessary one for flotation of phosphate-containing minerals at pH values used.

Sodium silicate is the most widely used modifier in non-sulphide minerals flotation. The reagent depresses silicate minerals significantly in flotation of different kinds of ores and can increase efficiency of calcium minerals separation (Bogdanov et al., 1990). However the mechanism of sodium silicate depression action is complex and it hasn't been investigated completely by now. In particular, salt-type minerals flotation is usually connected with physical adsorption of colloid silica and polymeric silicic acid (Nikiforov and Skobeev, 1968) or silicate ions (Fuerstenau et al., 1972). So the main aim of this research was to study the mechanism of sodium silicate action, and to optimize salt-type calcium minerals separation by determination of their floatability regularities using physical-chemical modeling of flotation process.

**MATERIALS AND METHODS**

The investigation was carried out with apatite, calcite, dolomite, magnesite, wollastonite as minerals, sodium oleate as collector and sodium silicate as modifier.

Flotation studies were carried out by using modernized Hallimond tube with 0.1 - liter Pyrex glass cell (Melik-Gaikazyan et al., 1990). Minerals (without the secondary phase impurities) after grinding in a ceramic ball mill were screened to obtain 100 × 325 mesh material for flotation (one gram in each test). Reagents utilized included NaOH, H2SO4, sodium oleate, phosphoric acid, sodium phosphate, sodium carbonate and soluble glass.

Physico-chemical environment in the presence of sodium silicate and mineral was estimated on the basis of solution chemical equilibria.

Modeling of processes with the application of thermodynamic analysis included modeling of reagent state in solution, mineral surface state in solution and the whole system state under the same condition.

Modeling of sodium silicate state in solution was made on the basis of reactions with due regard for the all known possible ions and molecules which can take part in this case. Their Gibbs energies taken in calculations (according to the methodology of thermodynamic analysis elaborated for flotation system (Melik-Gaikazyan et al., 1990)) are (in kcal/mol): Ca2+ - -132.18; CaOH+ - -171.55; CaOH2 - -214.22; CO32- - -126.22; Mg2+ - -108.99; MgOH+ - -150.10; HCO3- - -140.31; H2CO3 - -149.0; OH– - -37.595; H2O - -56.69; Fe2+ - -20.3; Fe(OH)+ - -65.2; Fe(OH)2 - -115.57; PO43- - -245.1; HPO42- - -261.5; H3PO4 - -271.3; H2PO4 - -274.2; Fe3(P04)2 - -642.2; Ca5(PO4)2 - -986.2; CaCO3 - -288.45; FeCO3 - -178.7; CaSiO3(aq) - -377.4; FeSiO3(aq) - -257.7; H2SiO4 - -312.57; H4SiO4 - -299.33; H2SiO32- - -283.10; H2SiO2- - -266.46; SiO32- - -249.82; H2SiO3 - -242.00; HSiO3- - -228.36; SiO2 - -212.00; MgCO3 - -246.05; CaMg(CO3)2 - -517.10; CaSiO3 - -360.37; Ca5SiO7 - -525.46; Ca3Si2O7 - -899.00; MgSiO3 - -349.42; Mg2SiO4 - -491.83.
Results and Discussion
Previous researches (Abramov and Abramov, 1996; Abramov and Magazanik, 1998) concluded that salt-type minerals flotation optimal parameters are achieved under conditions of mineral surface zero charge potential. The pH value corresponding to these conditions can be calculated using thermodynamic analysis of "mineral – pure water" system. The method can determine the pH values of minimum mineral solubility. They turned out to be as follows for apatite group minerals: 8.1 for fluorapatite, 8.2 for carbonatapatite, 9.8 for hydroxyapatite and carbonate minerals: 9.97 for calcite, 10.05 for magnesite and 9.95 for dolomite. Since mineral state in the conditions is defined by surface energy minimum, pH values calculated can be considered to be pH of surface zero charge potential. The statement is confirmed by results of zeta-potential measurements carried out with calcite in close "mineral – pure water" systems (Le Bell and Lindstrom, 1982). The highest considered floatability of minerals is proved by experimental researches (Figure 1, a).

The hypothesis proposed allowed us to elaborate quantitative physico-chemical model of salt-type minerals flotation (Equation 1). Its essence bases on determination of equilibrium conditions between potential-determining ions and ions of the collector which are competitive on the mineral surface:

\[ \lg[O^-_{\text{req}}]_{\text{pH}} = \lg[O^-_{\text{z.c.p.}}] + \frac{1}{m} \cdot \lg \left( \frac{[An^{-\text{m}}_p]}{[An^{-\text{m}}_{\text{z.c.p.}}]} \right) \]  

where: \( \lg[O^-]_{\text{pH}} \) - logarithm of oleate ions concentration in pulp required for complete flotation at any pH value; \( \lg[O^-]_{\text{z.c.p.}} \) - logarithm of oleate ions concentration in pulp under zero charge point condition; \( m \) - potential-determining anion valence; \( [An^{-\text{m}}_p] \) - potential-determining anion concentration under consideration; \( [An^{-\text{m}}_{\text{z.c.p.}}] \) - potential-determining anion concentration under zero charge point condition.

Since there are usually all varieties of apatite in the ore it is obvious that the necessary collector concentration should be set for the mineral that requires the higher concentration of collector in the pulp. The comparison of \([O^-]_{\text{x}}\) values necessary for flotation of fluor-, hydroxy- and carbonatapatite (Figure 1, b) shows that when pH values are less 6.5 and more than 8.4 \([O^-]_{\text{x}}\) should not be less than that for flotation of carbonatapatite; at pH values from 6.5 up to 7.5 it should not be less than that for flotation of fluorapatite; at pH values from 7.5 up to 8.4 it
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TABLE 1 Sodium silicate condition in aqueous solutions

<table>
<thead>
<tr>
<th>Reactions</th>
<th>pK</th>
</tr>
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<tbody>
<tr>
<td>$\text{SiO}_2(\text{aq}) + 2\cdot \text{H}_2\text{O}$</td>
<td>12,04 *</td>
</tr>
<tr>
<td>$\text{H}_4\text{SiO}_4$</td>
<td>9,70 **</td>
</tr>
<tr>
<td>$\text{H}_3\text{SiO}_4$</td>
<td>11,90 **</td>
</tr>
<tr>
<td>$\text{H}_2\text{SiO}_4$</td>
<td>12,20 **</td>
</tr>
<tr>
<td>$\text{HSiO}_4$</td>
<td>12,20 **</td>
</tr>
<tr>
<td>$\text{SiO}_2(\text{aq}) + \text{H}_2\text{O}$</td>
<td>13,22 ***</td>
</tr>
<tr>
<td>$\text{H}_2\text{SiO}_3$</td>
<td>10,00 ***</td>
</tr>
<tr>
<td>$\text{HSiO}_3$</td>
<td>11,99 ***</td>
</tr>
<tr>
<td>$2\cdot \text{SiO}_2(\text{aq}) + 3\cdot \text{H}_2\text{O}$</td>
<td>22,92 *</td>
</tr>
<tr>
<td>$\text{H}_6\text{Si}_2\text{O}_7$</td>
<td>9,27 ****</td>
</tr>
<tr>
<td>$\text{H}_5\text{Si}_2\text{O}_7$</td>
<td>10,78 ****</td>
</tr>
</tbody>
</table>

* [Garrels and Christ, 1968];
*** [Pourbaix et al., 1963];
** [Nikolsky et al., 1965];
**** [Sjoberg et al., 1985]

should not be less than that for flotation of hydroxyapatite (Kalugin and Abramov, 1998).

Generally speaking, "sodium silicate" term refers to a whole number of chemicals whose composition can be represented by formula $m\cdot\text{SiO}_2\cdot n\cdot\text{Na}_2\text{O}$, where $r = m/n$ is called the modul of the reagent.

The ion composition of aqueous sodium silicate solutions depends mainly on the silica concentration. Dilute solutions containing silica less than the solubility of amorphous silica ($1.99 + 2.33 \times 10^{-3}\text{ mol/l at 298K}$) can be described by reactions shown in Table 1. It has been established (Marinakis and Shergold, 1985) that solutions of such kind are not affected by aging and polymerization processes. The silica distribution diagram constructed using data in Table 1 is shown in Figure 2, a. Meanwhile in solutions saturated with respect to soluble silica, polymerization of silica takes place. The polymerization rate depends on the pH value, silica concentration and temperature. The structure of various polymeric species isn't well defined, but it's known that under certain conditions the polymers or colloidal sized particles exhibit a considerable negative charge.

The process of depolymerization is reversible but it proceeds very slowly (Marinakis and Shergold, 1985).

Previous research results (Bogdanov et al., 1990; Sjoberg et al., 1985 and other) indicated that separation of minerals belonging to the same type cannot be realized effectively in conditions of high sodium silicate concentration due to polymeric colloidal species presence in flotation systems. In the case of salt-type minerals depression, the attachment of highly hydrated polymeric silicate species on mineral surface raised its wettability (Bogdanov et al., 1990). Increase in reagent selectivity is possible at the expense of its concentration reduction down to values not exceeding amorphous silica solubility ($1.99 + 2.33 \times 10^{-3}\text{ mol/l at 298K}$). It has been established that salt-type minerals depression by the reagent of such concentration does not depend on metastable colloidal species' presence in the solution (Marinakis and Shergold, 1985).

Analysis of salt-type monomineral flotation results (Figure 2, b) as well as regularities of modifier sorption on apatite and calcite have shown that the mechanism of sodium silicate action under conditions of its chosen concentration is...
determined by chemical composition change of mineral surface, whose floatability increases or reduces according to silicate compounds formed on it. The most important factors are quantity of the reagent attached and correspondence between lattice parameters of minerals and newly-formed substances. These substances can be determined on the basis of thermodynamic analysis by definition of both mineral surface and sodium silicate conditions in the solution:

\[
 n\text{Me}^{2+} + m\text{SiO}_2n\text{H}_2\text{O} \Leftrightarrow m\text{SiO}_2n\text{MeO} + 2n\text{H}^+; \\
 [\text{Me}^{2+}] = -\frac{\lg K}{n} - 2\text{pH} - \frac{\lg[m\text{SiO}_2n\text{H}_2\text{O}]}{n}
\]  

Analysis of “mineral - solution” diagram (Figure 3) constructed using Equation 2 for sodium silicates with different ratio \( r \) has allowed to establish that the substance corresponding to chemical compound of wollastonite (\( \text{CaSiO}_3 \)) is formed on the surface of apatite (at \( \text{pH} > 6.15 \) for fluorapatite, \( \text{pH} > 5.80 \) for carbonatapatite, \( \text{pH} > 4.88 \) for hydroxyapatite) and calcite (at \( \text{pH} > 2.79 \)).

The maximum apatite recovery reaching at \( \text{pH} \sim 8 \) corresponds to wollastonite flotation regularities achieving optimum value at its surface zero charge potential (\( \text{pH} = 7.85 \)). The most effective wollastonite flotation at this pH established on the basis of thermodynamic analysis of “\( \text{CaSiO}_3 \cdot \text{H}_2\text{O} \)” isolated system is proved by results of single mineral flotation (Figure 4, a).

The process of calcite flotation with use of sodium silicate as a depressant is characterized by some increase in mineral floatability at \( \text{pH} 7 \sim 8 \) as in the previous case. However calcite recovery is much lower due to the discrepancy of elementary cell parameters of calcite and wollastonite leading to less precisely formed layer of calcium silicate on mineral surface. The further increase in mineral floatability achieving maximum value at \( \text{pH} \) about 10 is explained by sharp downturn of modifier sorption on calcite in alkaline medium and thus keeping by the mineral its own flotation properties getting maximum recovery at \( \text{pH} \) of zero point charge (\( \text{pH} = 9.97 \)).

Sodium silicate introduction in the flotation system results in magnesium metasilicate formation on the surface of magnesite (at \( \text{pH} > 1.01 \)) and dolomite (at \( \text{pH} > 1.47 \)). Optimum flotation of these carbonate minerals in conditions established is at \( \text{pH} \) value corresponding to zero charge potential of clinoenstatite (\( \text{MgSiO}_3 \)) (\( \text{pH} = 7.47 \)). Dolomite’s better floatability is determined by more correspondence of its crystalline latter parameters (4.81 Å) to clinoenstatite ones (4.78 Å) (Horiuchi et al., 1987) in comparison with magnesite (4.64 Å), which is depressed by sodium silicate more effectively.
FIGURE 3 "Mineral—solution" diagrams for fluorapatite (A), carbonapatite (B), hydroxypatite (C), calcite (D), dolomite (E), magnesite (F) in the case of sodium silicate ($1 \times 10^{-3}$ mol/l) presence.
Silicate anions become potential-determining in relation to mineral surface under conditions of its composition change. In this case (at pH > 6 for all considered minerals) elaborated physicochemical model of salt-type minerals flotation is expressed by Equation 3:

\[ \lg([O^-]) = \lg([O^-]_{z.e.p.}) + \frac{1}{2} \lg \left( \frac{[\text{SiO}_2^-]}{[\text{SiO}_2^{2-}]} \right) \]  

Equations established on the basis of Equation 3 connecting oleate ions minimum concentration in pulp necessary for complete mineral flotation and pH values (Figure 4, b) allow to conclude that sodium silicate application in conditions of its chosen concentration promotes efficient increase in apatite recovery from carbonate-containing ores.

Analysis of curves constructed (Figure 4, b) shows that optimal conditions of apatite and carbonate minerals separation corresponding to maximum difference in oleate ions concentration necessary for their separation can be achieved at pH = 8–9.

The hypothesis that zero charge potential of mineral surface in the presence of collector is the optimal condition for fluorite, barite, fluorite and calcite flotation is also true for other salt-like minerals. For example, it allowed to explain the optimal conditions of selective flotation of carbonates and phosphate minerals (fluorapatite, hydroxyapatite, carbonatapatite) on an industrial scale (Abramov et al., 1993).

Flowsheet developed for the reverse flotation process of calcereous phosphate ores involve a preliminary bulk carbonate-phosphate flotation followed by concentrate carbonate flotation with phosphoric acid as depressant of phosphate minerals.

Depression of phosphate minerals (fluorapatite, hydroxyapatite, carbonatapatite) with phosphoric acid \((2.55-5.00) \times 10^{-2} \text{ mol/l} \) at pH = 5.5–6.3 and flotation of carbonate minerals (calcite, dolomite) in the presence of small amounts of sodium oleate cannot be explained by selective formation in such conditions of hydrophilic compounds on the phosphate minerals surface only. On the contrary, under these conditions the formation of calcium phosphate \(\text{Ca}_3(\text{PO}_4)_2\) must take place only on the surface of floating carbonate minerals. The surface nature of phosphate minerals – fluorapatite and hydroxyapatite – in the presence of phosphoric acid does not change in the pH range from 5.0 to 9.7 (Attia and Fuerstenau, 1988/89). The same results have
been obtained with carbonatapatite (Abramov and Abramov, 1993). It follows from this that reverse selective flotation of carbonate-phosphate concentrates in the presence of phosphoric acid contradicts the current views. The explanation of this phenomenon can be afforded from the point of hypotheses that optimal flotation conditions for minerals take place at zero charge of their surface.

Concentration of potential-determining ions in phosphate mineral – water system as a function of pH value at a total phosphoric acid concentration of 2.55 x 10^{-2} mol/l is shown in Figure 5, A. The selectivity in flotation will be determined by the ratio of collector concentrations required for the complete flotation of each respective mineral, i.e., apatite varieties and calcite ([\text{[Ol]}_\text{1}] / [\text{[Ol]}_\text{2}]). The selectivity will increase with increasing the ratio of required collector concentrations.

The ratio of required oleate concentrations calculated for various phosphate minerals as a function of pH value is presented in Figure 5, B. The intercorrelation of maximum values ratio ([\text{[Ol]}_\text{1}] / [\text{[Ol]}_\text{2}]) for all apatite varieties (Figure 5, B, curves 1–3) and difference \( \Delta \gamma \) between fluorapatite and calcite floatability (Figure 5, B, curve 4) prove the reliability of the hypotheses presented.

Similarly, the floatability of a mineral at the constant collector concentration in the liquid phase of pulp will sharply decrease upon moving away from the zero point of charge of the mineral. Different conditions for zero charge of various minerals is the main reason for their different flotation behavior under the same conditions.

Investigation of mineral slime's influence on flotation has shown that if mineral floats better its slimes affect its flotation to a greater extent. Slimes of poor floatable minerals actually do not influence on flotation process. Negative influence of good floatable minerals' slimes can be neutralized by adding liquid glass. It's quite harder to treat hydrophobic slimes.

The cause of incomplete water recycling of industrial waters in processing of phosphate-containing ores and materials at plants is the sharp deterioration of processing indexes under the action of "harmful" soluable and insoluable compounds and thin slime particles accumulating in turnaround waters.

The analysis of Jt. St. Co. "Apatite" plant's transition to circulating water supply shows that circulating water exerts a detrimental effect on apatite flotation. Calcium and iron ions influence on the process to the greatest extent (Kozlov and Abramov, 1998). As a result of nepheline dissolution, aluminium ions can influence on the flotation process too. Their harmful effect is defined through collector bonding in metal oleates; unfavorable MeOl\(_2\) influence as slimes species determining "depression by hydrophobic slimes" effect (Abramov, 1994) activation of gangue minerals and froth strength disturbance (Golovanov, 1976). In order to check possibility of apatite flotation decline calculations of calcium, iron and aluminium oleates formation possibilities in solutions have been carried out. They have shown that under condition of collector concentration using at the plant (4.1 x 10^{-5} mol/l) calcium oleate formation is initiated with 5-mg/l calcium and 55-mg/l iron (see Figures 6, 7) while aluminium oleate does not form because of its high solubility ([Al\(_3^+\)] x [\text{[Ol]}] = 30.0). Metal oleates formation causes collector equilibrium concentration increase as much as at the plant (see Figure 8).

Thus, minimum allowed calcium ions concentration at apatite flotation from apatite-nepheline ores is 5 mg/l, with iron ions being at 55 mg/l.

For checking of minimum allowed calcium and aluminium ions concentration influence on apatite flotation the laboratory tests in Hallimond tube were carried out on nepheline, sphene and egerine flotation in pure water at different calcium and aluminium concentrations (see Figures 9–12). The materials submitted show that significant apatite recovery reduction doesn't occur at 5-mg/l calcium concentration under plant circumstances (pH = 9.5) while aluminium (10 mg/l) to some extent decreases mineral recovery. Calcium influences on nepheline behavior recoils just under concentration exceeding 12 mg/l. Egerine doesn't change its behavior at pH = 9.0. Sphene is activated but taking into account its low content in the ore, it will not influence on the process of apatite flotation from apatite-nepheline ores.
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FIGURE 5 Effect of pH on concentration of potential-determining ions (C) in phosphate mineral – water system at the total phosphoric acid concentration $2.55 \times 10^{-2}$ mol/l (A) and on the ratio of required olate concentrations at the same conditions for fluorapatite (1), carbonatapatite (2), hydroxyapatite (3) and the difference ($3'-1$) in calcite and fluorapatite flotation recoveries (4) (B).

FIGURE 6 Effect of calcium concentration on possibility of calcium olate formation pH = 9.5

Hence, calcium concentration of 5mg/l can be considered to be minimum allowed for apatite flotation. The corresponding values for iron and aluminum are 55 mg/l and 10 mg/l respectively.

For calcium, iron and aluminium concentrations maintenance in within ranges required it is possible to use sodium phosphate, sodium carbonate and liquid glass (Kozlov and Abramov, 1998).

The calculation results of proper equations show that under condition of optimum pH value for apatite flotation (pH = 9.5) calcium ions maintenance on the level not exceeding 5 mg/l and iron ions not exceeding 55 mg/l may
be accomplished by sodium phosphate addition of 36 g/m³, sodium carbonate of 29.9 g/m³, or liquid glass of 259 g/m³. Analysis of reagents consumption at their application in conditioning process of circulating water has shown that sodium phosphate use is more economically preferable (Kozlov and Abramov, 1998).

The system for automatic control and regulations of the conditioning circuit should include transducers determining calcium, iron and aluminium concentrations, pH meter, circulating water flowmeter, functional module generating the necessary consumption of phosphate, regulator and batchmeter of phosphate ions.

CONCLUSION

1. It has been established that separation of minerals belonging to the same type can't be realized effectively when sodium silicate dosage is so high as to cause polymeric colloidal species presence in flotation systems and resulting in both fluorite and carbonate gangue minerals depression. Increase of reagent selectivity is possible at the expense of its concentration reduction down to values not exceeding amorphous silica solubility (1.99 - 2.33 × 10⁻³ mol/l at 298°K).

2. The mechanism of sodium silicate action under conditions of its chosen concentration (1 × 10⁻³ mol/l) is determined by chemical composition change of mineral surface whose floatability increases or reduces according to silicate compounds formed on it. The most important factor is the quantity of the reagent attached as well as the interaction between lattice parameters of minerals and newly-formed silicate substances. These substances can be determined on the basis of thermodynamic analysis of flotation systems.

3. Sodium silicate action mechanism definition at salt-type minerals flotation made it possible to determine optimum parameters of apatite recovery from carbonate-containing ores.

4. The main reasons for harmful influence of soluable salts in recycling waters on flotation of phosphate-containing minerals are attributed to the precipitation of collector in the pulp, activation of gangue minerals and the effect of “depression by hydrophobic slimes.” Optimal conditions for recycled water conditioning can be determined from diminution of soluable salts concentration down to the level when they will be unable to interact with collector. This concentration is equal to the minimum-necessary one for flotation of phosphate-containing minerals at pH values used.

REFERENCES


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FIGURE 9 Effect of pH on floatability of apatite in the presence of Ca²⁺ (a); in the presence of Al³⁺ (b). Total oleate concentration in solution 7 x 10⁻³ mol/l

FIGURE 10 Effect of pH on floatability of neoflame in the presence of Ca²⁺ (a); in the presence of Al³⁺ (b). Total oleate concentration in solution 7 x 10⁻³ mol/l

FIGURE 11 Effect of pH on floatability of egline in the presence of Ca²⁺. Total oleate concentration in solution 7 x 10⁻³ mol/l

FIGURE 12 Effect of pH on floatability of sphene in the presence of Ca²⁺. Total oleate concentration in solution 7 x 10⁻³ mol/l


