University of Nevada

Reno

The Effects of Increasing Ionic Strength, Collector Chain Length, and Temperature on the Anionic Flotation of Oxide Minerals

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by

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ABSTRACT

The effect of increasing ionic strength on the flotation characteristics of hematite and silica has been investigated. Alkyl sulfate collector chain length and pretreatment temperature were critical parameters related to the varying ionic strength. Sodium hexadecyl sulfate was shown to be a superior flotation collector to sodium dodecyl sulfate for recovery of hematite with no salt addition. Similar observations were made when sodium sulfate or sodium chloride was used to control ionic strength. Sodium dodecyl sulfate floated hematite and silica better than its longer chained counterpart under conditions of low pretreatment temperature and increasing calcium chloride concentration. The flotation recovery for all salt containing pulps was almost always improved after preboiling.

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INTRODUCTION

The water chemistry of the froth flotation process is one of many parameters which can affect the separation. The fluid may contain certain inorganic salts that with increasing ionic strength, could produce undesirable depression or activation in the flotation pulp. A source of a salt could stem from the use of calcium chloride to prevent freezing in ore cars, chutes, and bins[1]. Alternately, the salt or salts could be initially contained in the water as in the case of sea water and some other available sources. These salts may become more concentrated because of the need for recycling of plant water attributable to stricter environmental regulations and/or economic considerations[2].

The presence of inorganic salts in flotation pulps and their effects upon the recoveries and surface chemistries of different oxide minerals have been the object of various studies. Some researchers[3,4] have reported that addition of a salt can increase or decrease flotation recovery depending upon the particular system. Fuerstenau and Modi[5,6] have shown that in the absence of collector, increased ionic strength will reduce the charge on an oxide mineral surface, and with addition of a multivalent salt charge reversal is possible.

Despite the work performed on the subject of ionic strength, a more complete investigation focusing on high ionic strength pulps would further expand the understanding of its effect upon oxide mineral flotation. Consequently, a flotation-adsorption study has been conducted relating critical variables that include differing oxide minerals, normal salts, ionic strengths, pH's, pretreatment temperatures, and alkyl sulfate collector chain lengths.

LIST OF NOMENCLATURE AND ABBREVIATIONS

SDS	Sodium dodecyl sulfate
STS	Sodium tetradecyl sulfate
SHS	Sodium hexadecyl sulfate
HCl	Hydrochloric acid
mV	Millivolts
$\underline{M}$	Moles per liter
ml(s)	Milliliter(s)
cm	Centimeter
NaCl	Sodium chloride
$CaCl_2$	Calcium chloride
Na_2SO_4	Sodium sulfate
pzc	Point of zero charge

THEORETICAL CONSIDERATIONS

Recovery of oxide minerals via flotation is often dependent upon the electrostatic attraction between ions of a collector and an oppositely charged mineral surface. This is particularly evident in the use of strong acid collectors such as alkyl sulfonates and sulfates[7]. Consequently, modulation of the charge between the two should enable optimum flotation conditions to be developed. Factors such as pH, ionic strength, ion valence, collector chain length, and temperature are some of the variables which can influence these conditions, too. Therefore, a knowledge of mineral surface chemistry and the effects of the preceeding variables upon it would contribute much to the controlling of an oxide mineral flotation process.

Theories of the surface charge origin on minerals have been postulated by several researchers[8,9,10,11,12]. For simple oxide minerals such as quartz and hematite in an aqueous environment, one possible mechanism is the adsorption of hydrogen and hydroxyl ions onto a "broken-bond" surface, followed by dissociation of the hydrated surfaces. An alternate charging mechanism involves the dissolution of the mineral and readsorption of complexes formed by hydrolysis of the dissolved material. For both, pH plays an important role in determining surface charge. To illustrate this, some of the possible reactions for the former mechanism are written:

$$\mathrm{M}\,]\!\!-\!\mathrm{OH} \rightleftharpoons \mathrm{M}\,]\!\!-\!\mathrm{O}^- + \mathrm{H}^+ \qquad (1)$$

$$\mathrm{M}\,]\!\!-\!\mathrm{OH} + \mathrm{H}^+ \rightleftharpoons \mathrm{M}\,]\!\!-\!\mathrm{OH}_2^+ \qquad (2)$$

Where:

M represents a metal and] the surface species

Eq. (1) represents the ionization of the hydrated surface, while eq. (2) indicates the occurrence imparted by the addition of excess hydrogen ions. Thus, hydrogen and hydroxyl ions have been labelled as potential-determining ions for simple oxide minerals.

Because of the presence of these potential-determining ions at the mineral particle-solution interface, oppositely charged ions are drawn into the vicinity of the surface to maintain electroneutrality. Hence, a structure is produced which surrounds the particle. It is known as the electrical double layer. Figure 1 shows a schematic representation of the electrical double layer[13] according to Stern.

Zone 1 of the double layer contains the potential-determining ions. These are ions of which the solid is composed along with ions which are chemisorbed and therefore can be regarded as part of the solid lattice. Zone 2 is known as the Stern or anchor layer in which the counter ions (or gegen-ions) are held directly to the surface. The Gouy or diffuse layer occupies zone 3 and essentially forms the atmosphere about the particle. In

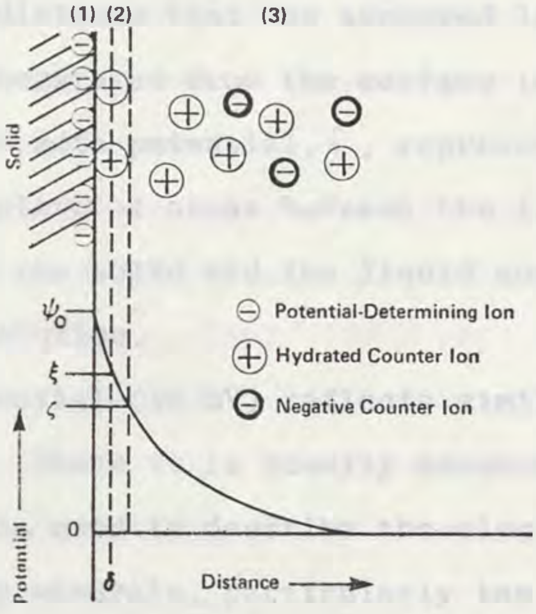

Figure 1. Schematic representation of the structure of the electrical double layer and potential across the double layer.

this layer, the potential drop decreases exponentially with increasing distance from the surface.

Also shown is ψ_0, which is the potential relative to the bulk of the solution at the original surface of the solid. The potential relative to the bulk of the solution at the center of charge of the Stern layer is labelled ξ. The distance that the anchored layer of counter ions are separated from the surface is given by δ. Finally the zeta potential, ζ, represents the potential at the plane of shear between the fixed layer of liquid next to the solid and the liquid constituting the bulk of the solution.

The zeta potential (in mV) reflects similar changes in both ψ_0 and ξ. Since it is readily measured by various techniques[14], it is used to describe the electrokinetic properties of many minerals, particularly the simple oxides.

With the addition of enough inorganic salt, the zeta potential of a mineral can be altered. Monovalent salts such as sodium chloride have been shown to reduce the zeta potential of a mineral, however it will not reverse it[15]. Because of this, salts like the above have been termed indifferent electrolytes. Their ions have no special affinity for a mineral surface and function merely as gegen-ions in the double layer.

On the other hand, with the presence of enough multivalent ion which is oppositely charged to the mineral surface, the zeta potential can be reversed. Multivalent ions such as barium and sulfate which are able to change the sign on an oppositely charged mineral surface have been labelled specifically adsorbed ions[7]. They exhibit a special affinity for the surface and cause a zeta reversal due to the presence of more charge in the anchor layer than on the surface.

Polyvalent metal ions, which have formed their first hydroxy complex through hydrolysis, have also been shown to produce zeta reversal[7]. They differ from the aforementioned specifically adsorbed ions since certain complexes may be adsorbed on a mineral surface of the same charge, while the others function as counter ions in a parallel situation.

Collector ions of opposite charge to the mineral surface are adsorbed as individual ions when introduced to the solution in low concentrations. However, when a certain concentration is surpassed, the collector ions begin to illustrate a special affinity toward the surface producing zeta reversal and a marked increase in flotation rate, adsorption, and contact angle[16]. This phenomenon has been attributed to the association of hydrocarbon chains, caused by the free energy decrease produced through removal of the chains from water. It is analogous to the formation of micelles in the bulk solution and therefore has been classified as hemimicelle formation[13]. The adsorption of a collector when this condition prevails is given by the equation[17]:

$$\Gamma_i = 2\, r_i n_i \exp - \frac{(Ve\zeta + \lambda_p + a\phi)}{kT} \qquad (3)$$

Where:

Γ_i = adsorption density of the collector (ions per cm^2)

r_i = radius of the head of the adsorbing ion in cm

n_i = number of collector ions per cc in bulk solution

V = valency of the adsorbing ion

e = electronic charge

ζ = zeta potential in mV

λ_p = contribution to adsorption not attributable to electrostatic interaction or to association of hydrocarbon chains

a = number of carbon atoms in the alkyl chain

ϕ = work of adsorption for each CH_2 group that results from association of hydrocarbon chains

k = Boltzmann's constant

T = Temperature, ^oK

The $a\phi$ term in eq. (3) makes a significant contribution to adsorption of collector onto a mineral surface. For instance, in the case of a 14 carbon chain collector the value of $a\phi$ would be zero with no hemimicelle existence, but near 14kT with strong hemimicelle formation. It is also evident from eq. (3) that collector adsorption is dependent upon its chain length. That is, a longer chained collector will adsorb more strongly than one of shorter chain, possibly enhancing flotation.

When both a salt and a collector are added to the same system, there are some interesting occurrences. One such occurrence is the competition between the two for adsorption sites on the mineral surface, with multivalent inorganic ions being more competitive than monovalent ions. Upon substantial adsorption in the anchor layer, the competition for these sites is expressed in the relation[15]:

$$\frac{\Gamma_a}{\Gamma_b} = \frac{C_a}{C_b} \exp \frac{\phi_a - \phi_b}{kT} \qquad (4)$$

Where:

Γ_a, Γ_b = adsorption densities of ions a and b

C_a, C_b = bulk concentrations of ions a and b

ϕ_a, ϕ_b = adsorption potentials of ions a and b

With regard to eq. (4), it has been demonstrated that an increased amount of amine collector is required to reduce the zeta potential of quartz to zero, when sodium chloride is present in the solution[15]. Consequently, adsorption of collector ions in the Stern layer is reduced. This could adversely affect the flotation recovery.

Multivalent ions of salts may cause activation (floatability) or depression (nonfloatability) of specific minerals depending upon the particular collector present in the system. The occurrence may be attributable to specific adsorption of the ion or adsorption of the first hydroxy complex formed from a polyvalent cation. Examples of the former have been given by Fuerstenau and Modi[3], while numerous cases of the latter have been reported by Fuerstenau and Palmer[7].

The introduction of a salt will also lower the critical micelle concentration (CMC) of a collector, and thus lead to the formation of micelles in the bulk solution. The critical micelle concentration is the concentration at which micelles begin to form, while micelles are colloidal size aggregates of organic ions that have their nonpolar chains removed from water through the association of the chains inward and their polar heads outward. Shinoda[18] has given a relation which explains the effect of total ionic strength upon the CMC's of a homologous series of surfactants (surface active substances). The expression is:

$$\ln \text{CMC} = -\frac{mw}{kT} - K_g \ln C_i + K_1 \qquad (5)$$

Where:

m = number of methylene groups in the hydrocarbon chain

w = standard free energy change per methylene group upon micellization $\simeq 1.08kT$

K_g, K_1 = constants for a specific homologous series of collectors

C_i = total concentration of gegen-ions

Table 1 is a list of CMC's for some of the surfactants belonging to the alkyl sulfate and sulfonate groups[7]. With regard to Table 1 and eq. (5), it is observed that the longer chained surfactants will have a much lower CMC with the addition of an equivalent amount of salt, than the shorter chained counterpart. Because of this occurrence, there will be less of the longer chained surfactant remaining in ionic form, that will be able to adsorb on the mineral surface. Thus, the shorter chained surfactant may give better flotation recovery. The addition of a divalent salt should produce an even greater decrease in CMC in contrast to an equal concentration of monovalent salt, due to the increase in ionic strength.

The metal ion from an inorganic salt may react with anionic collector ions in solution to form a metal salt precipitate. The precipitate will form if the cation from the inorganic salt forms a metal organic salt which has surpassed its solubility. Alternately, the electrolyte concentration may become so high, that the gegen-ions of the salt precipitate out the organic ions[19]. Removal of collector from solution in such a manner should reduce the

Table 1

Critical micelle concentrations of various alkyl sulfates and sulfonates at 25°C

Surfactant	CMC ($\underline{M}$ x 10^{-4})
Sodium dodecyl sulfate	82
Sodium tetradecyl sulfate	20
Sodium hexadecyl sulfate	2.1
Sodium dodecyl sulfonate	98
Sodium tetradecyl sulfonate	24.1
Sodium hexadecyl sulfonate	5.94

amount of adsorption on the mineral surface and possibly flotation recovery.

Table 2 gives the solubilities of several calcium and sodium salts of the alkyl sulfonate family[20]. The difference between the two are most notable. The increase in solubility upon increase in temperature is substantial, particularly with the 12 carbon sodium sulfonate. A decrease in solubility with collector chain length is also observed. The solubilities of these salts should be very similar to those of identical chain length alkyl sulfates, due to the chemical similarity of their structures and CMC's.

The solubilities and CMC's for micelle forming surfactants like the above are related. These substances will exhibit a rapid increase in solubility above a certain temperature known as the Krafft point[21]. The marked increase in solubility is attributable in part to the formation of micelles, which are highly soluble, at and above the Krafft temperature.

Table 2

Solubilities of various sodium and calcium sulfonates in water

Carbon Atoms in Molecule	Calcium ($\underline{M} \times 10^{-5}$)		Sodium ($\underline{M} \times 10^{-3}$)	
	25°C	60°C	25°C	60°C
12	38.0	114	9.29	>1763*
14	4.41	15.8	1.36	1292*
16	1.45	3.76	0.222	197.6

* approximate values

EXPERIMENTAL

Minerals and Their Preparations

Black specular hematite from Republic, Michigan and rock crystal quartz from Hot Springs, Arkansas were the two oxide minerals selected for the investigation. Both were purchased from Ward's Natural Science Establishment. Table 3 gives an indication of the contaminants present in the hematite as determined by spectrographic analysis.

Hematite samples for the microflotation experiments were prepared by initially crushing to -8 mesh in a mortar and pestle followed by leaching in a hot 0.1M HCl solution for fifteen minutes. After leaching, the ore was rinsed with double distilled water until the pH of the pulp supernatant was that of the double distilled water alone. Next the sample was oven dried, then further crushed in a mortar and pestle to -65 mesh. This product was wet screened with double distilled water on a 150 mesh screen, oven dried, and finally ro-tapped for 0.5 hours to remove any remaining -150 mesh material.

Quartz flotation samples were prepared by first crushing to -65 mesh in a mortar and pestle. The -65 mesh material was dry screened by hand for a few minutes to remove some of the -150 mesh size fraction, then leached in a hot concentrated HCl solution for fifteen minutes. As with hematite, the quartz was rinsed with double distilled water until the washing solution pH was

Table 3

Spectrographic analysis of hematite

Metal	Percentage
Al	1.0
Fe	Major
Mg	0.05
Mn	0.01
Si	0.60
Ti	0.03

that of the double distilled water alone. Next, the sample was wet screened with double distilled water on a 150 mesh screen, followed by oven drying. The -65 + 150 mesh flotation feed was obtained after ro-tapping for 0.5 hours on the smaller screen.

Both hematite and quartz adsorption samples were prepared in the exact manner as their flotation counterparts, except a 325 mesh replaced the 150 mesh screen.

Reagents

The collectors used for both adsorption and flotation investigations were long chain alkyl sulfates. Specifically, they were reagent grade sodium dodecyl sulfate purchased from the Aldrich Chemical Co., and sodium hexadecyl and tetradecyl sulfates acquired from Research Plus Laboratories.

The normal salts studied included reagent grade sodium chloride obtained from the J. T. Baker Co. and Fisher Scientific Co., sodium sulfate from MCB Manufacturing Chemists, and calcium chloride dihydrate from J. T. Baker Co.

Reagent grade sodium hydroxide and hydrochloric acid were used for pH adjustment.

Certified A.C.S. chloroform purchased from Fisher Scientific Co., pH 2 buffer capsules from Micro Essential Laboratory, and methylene blue reagent were used in the adsorption procedure.

Double distilled water was used to prepare all solutions.

Microflotation

The microflotation experiments were preformed with a Hallimond tube as the flotation cell. The test results should represent the relative floatabilities of the minerals studied under the various conditions. Figure 2 is a diagram of the entire flotation apparatus. A description of its operation immediately follows.

The first step involved in the operation is the correct positioning of stopcocks 4, 5, and 12. Once done, nitrogen gas is introduced through a pressure regulator at about 7 psi into a gas washing bottle partially filled with saturated sodium hydroxide solution. At the same time stopcock 8 is opened. The cleansed gas forces water contained in the buret through a bypass line into the water storage bottle. The incoming water produces pressure inside this bottle and consequently in the gas-water storage flask. Once the pressure becomes large enough, water is forced from the flask into the head tank. The increased water level in the head tank provides the force which delivers gas to the Hallimond tube.

After passing 150 mls of water from the buret into the water storage bottle, stopcock 8 is closed and the pressure is relieved in the gas washing bottle through

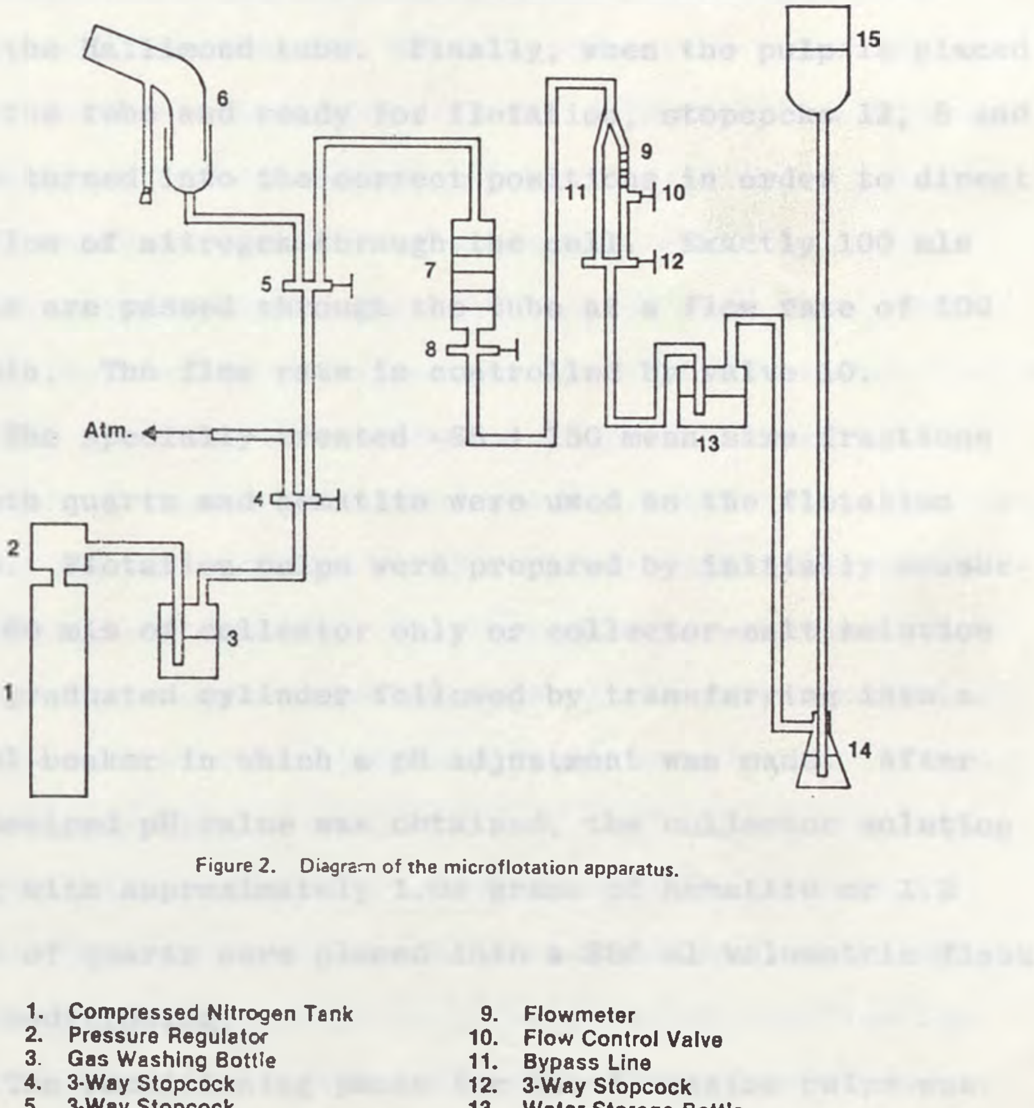

Figure 2. Diagram of the microflotation apparatus.

1. Compressed Nitrogen Tank
2. Pressure Regulator
3. Gas Washing Bottle
4. 3-Way Stopcock
5. 3-Way Stopcock
6. Hallimond Tube
7. 500 Ml Buret
8. Stopcock
9. Flowmeter
10. Flow Control Valve
11. Bypass Line
12. 3-Way Stopcock
13. Water Storage Bottle
14. Gas-Water Storage Flask
15. Head Tank

stopcock 4 and in the buret through stopcock 5. Next, 50 mls of water are allowed to flow from the water storage bottle into the buret. This ensures there is enough pressure within the buret to produce instant gas flow into the Hallimond tube. Finally, when the pulp is placed into the tube and ready for flotation, stopcocks 12, 8 and 5 are turned into the correct positions in order to direct the flow of nitrogen through the cell. Exactly 100 mls of gas are passed through the tube at a flow rate of 100 mls/min. The flow rate is controlled by valve 10.

The specially treated -65 + 150 mesh size fractions of both quartz and hematite were used as the flotation feeds. Flotation pulps were prepared by initially measuring 160 mls of collector only or collector-salt solution in a graduated cylinder followed by transferring into a 250 ml beaker in which a pH adjustment was made. After the desired pH value was obtained, the collector solution along with approximately 1.05 grams of hematite or 1.2 grams of quartz were placed into a 250 ml volumetric flask for conditioning.

The conditioning phase for the flotation pulps was carried out at two different temperatures. One pretreatment temperature was 25°C while the other was 95°C.

The pulps conditioned at 25°C were placed on a table for 6.5 minutes, followed by 3.5 minutes of hand agitation (twirling motion). During the preceeding period the temperature was maintained constant by heating or cooling as necessary. As required for each test, the pulp was poured into a plastic funnel which was plugged by a rod with a tapered rubber stopper on the end. The final pH measurement was made and the microflotation apparatus was set up for operation. Finally the pulp was placed into the Hallimond tube, and after a total of fifteen minutes conditioning time flotation was commenced.

Flotation pulps pretreated at 95°C were also conditioned for a total of fifteen minutes. Each one was heated on a hot plate until the desired temperature was reached. The heating time required was about 6.5 minutes. Next the temperature was reduced to 25°C by hand agitating under a stream of cold water. This consumed approximately 3.5 minutes. As before, the final pH of the pulp supernatant was then recorded, followed by flotation after preparation of the apparatus.

Once flotation was completed, the floatable and nonfloatable products were collected. The floatables were comprised of the mineral in the cell froth overflow and particles trapped in the long stem attached to the upper portion of the cell. The nonfloatables consisted of the mineral particles remaining in the bottom portion of the cell. Each product was filtered, oven dried, and weighed. The percent flotation recovery was determined by dividing the weight of the floatable product by the total weight of two products from each test.

The bottom section of the Hallimond tube was specially constructed with sloping sides down to a small diameter fritted glass disc. The reason for this design was to maintain the mineral particles within the gas bubble flow. However, to facilitate bubble-particle contact a light finger tapping was provided at the bottom of the cell. A larger bottom cell equipped with magnetic stirring could not be used because of the iron containing hematite.

Adsorption Studies

A colorimetric method was used to determine the amount of alkyl sulfate adsorption onto a mineral surface. The adsorption measurements should provide some relationship between the microflotation results and possible mechanisms of collector adsorption. The actual method used was an adaptation of that described by Jones[22], which is based upon the combination of methylene blue reagent with the sulfate collector ion to form a colored salt. Although the principles remained the same, a description of the modified procedure is warranted in order to illustrate the differences.

The procedure began with the determination of a calibration curve. This was accomplished by first preparing solutions of various concentrations of the desired collector. The range of concentrations were selected to provide data above and below the concentration to be used in the adsorption studies. Next 20 mls of each collector solution were pipetted into separate 100 ml beakers followed by placement into a 25°C constant temperature water bath operated at 190 rpm.

After a two hour conditioning period, the solutions were removed. A volume of 10 mls was pipetted from each beaker into individual 250 ml separatory funnels to which 25 mls of double distilled water, 1 ml of pH 2 buffer solution, 1 ml of 0.1% methylene blue solution, and 25 mls of filtered chloroform were added. Each funnel was stoppered and moderately rock funneled for one minute. Upon completion, it was placed on a rack for five minutes to allow phase separation. Following separation, the delivery tube was wiped with a towel, and the organic phase withdrawn into a 100 ml volumetric flask.

The extraction procedure was repeated twice more, each time adding 25 mls of chloroform to the separatory funnel. After the third extraction, the colored chloroform solution was diluted to the 100 ml mark and then mixed well. A small portion was poured into a cuvette for analysis on a Bausch and Lomb Spectrophotometer at a wavelength of 652 nanometers. The absorbance reading for each concentration was recorded and a plot of absorbance versus concentration was constructed.

The adsorption experiments differed slightly from the above procedure. To begin with, 20 mls of collector only or collector-salt solution were pipetted into separate 100 ml beakers, one which contained 0.2 grams of mineral. Next, the pH of each solution was adjusted to the desired value. The beakers were placed into the water bath for the same conditioning time, temperature, and speed previously used. Upon removal, the solutions were processed in the same manner as before.

After the absorbance readings were obtained, the adsorption (moles/gram of mineral) was calculated through the use of the calibration curve. This simply involved plotting the absorbance readings for the mineral containing solution and the one without on the calibration curve, with the difference in concentration giving the amount adsorbed per 0.2 grams of mineral.

RESULTS

Hematite Flotation with Collectors Only

The effects of alkyl sulfate chain length, concentration, and varying pH upon the flotation of hematite are shown in Figure 3. Flotation response is greatest using SHS as the collector, with decreasing recovery as the length of the hydrocarbon chain is reduced. Increasing the concentration of SDS by ten times produces flotation over a wider pH range. For each system, flotation decreases at the basic pH values.

The collectors used throughout the remainder of the experimentation were SHS and SDS. They were chosen because of their significantly different CMC's and solubilities. The concentrations selected were 10^{-4}<u>M</u> SHS and 10^{-3}<u>M</u> SDS. The lower concentration of SDS, 10^{-4}<u>M</u>, was not chosen because of the limited pH range in which good recovery was obtained.

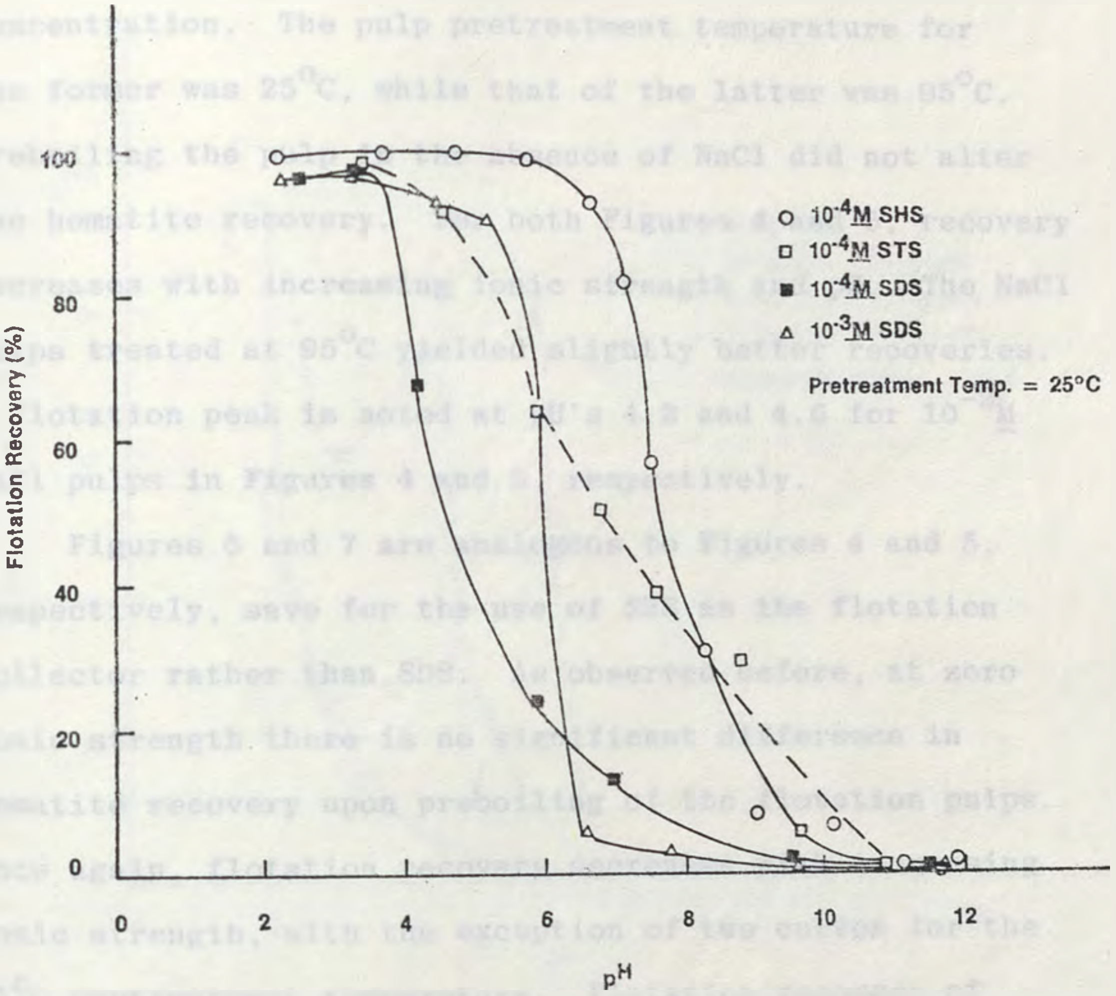

Figure 3. Flotation of hematite as a function of pH, collector chain length, and collector concentration.

Hematite Flotation as a Function of Sodium Chloride Concentration

Figures 4 and 5 illustrate the flotation recovery of hematite with SDS as a function of pH and NaCl concentration. The pulp pretreatment temperature for the former was 25°C, while that of the latter was 95°C. Preboiling the pulp in the absence of NaCl did not alter the hematite recovery. For both Figures 4 and 5, recovery decreases with increasing ionic strength and pH. The NaCl pulps treated at 95°C yielded slightly better recoveries. A flotation peak is noted at pH's 4.2 and 4.6 for 10^{-2} M NaCl pulps in Figures 4 and 5, respectively.

Figures 6 and 7 are analogous to Figures 4 and 5, respectively, save for the use of SHS as the flotation collector rather than SDS. As observed before, at zero ionic strength there is no significant difference in hematite recovery upon preboiling of the flotation pulps. Once again, flotation recovery decreases with increasing ionic strength, with the exception of two curves for the 95°C pretreatment temperature. Flotation recovery of hematite is greater for the NaCl pulps that were preboiled.

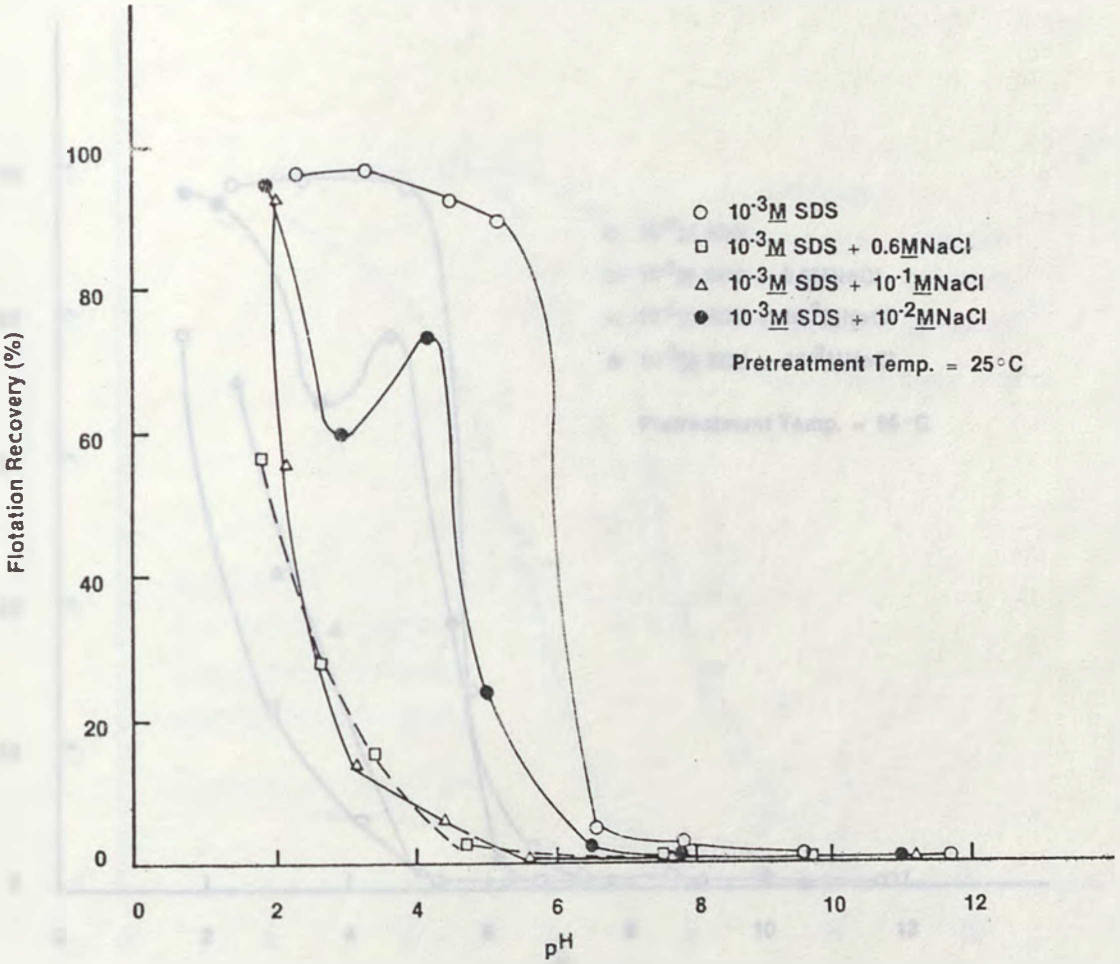

Figure 4. Flotation of hematite with SDS as a function of pH and NaCl concentration.

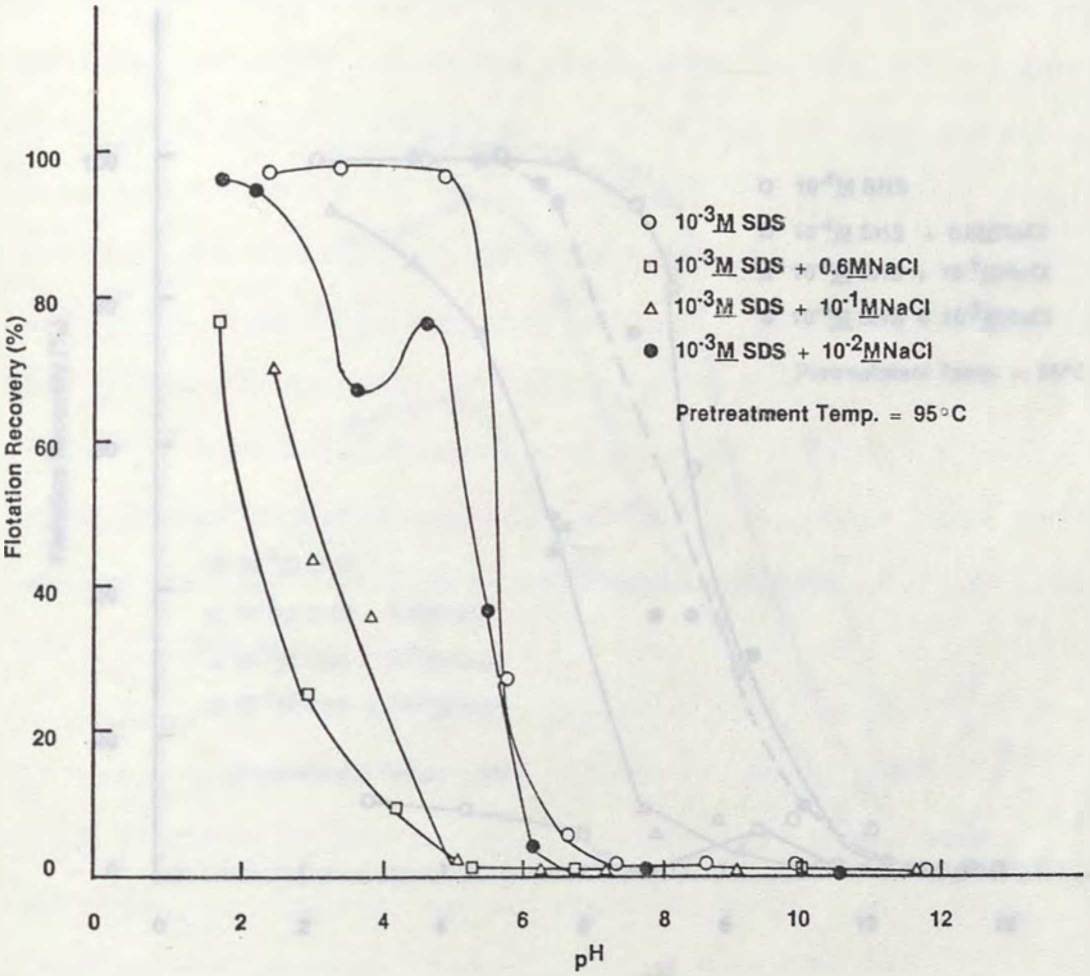

Figure 5. Effects of boiling, NaCl concentration, and pH on the recovery of hematite with SDS.

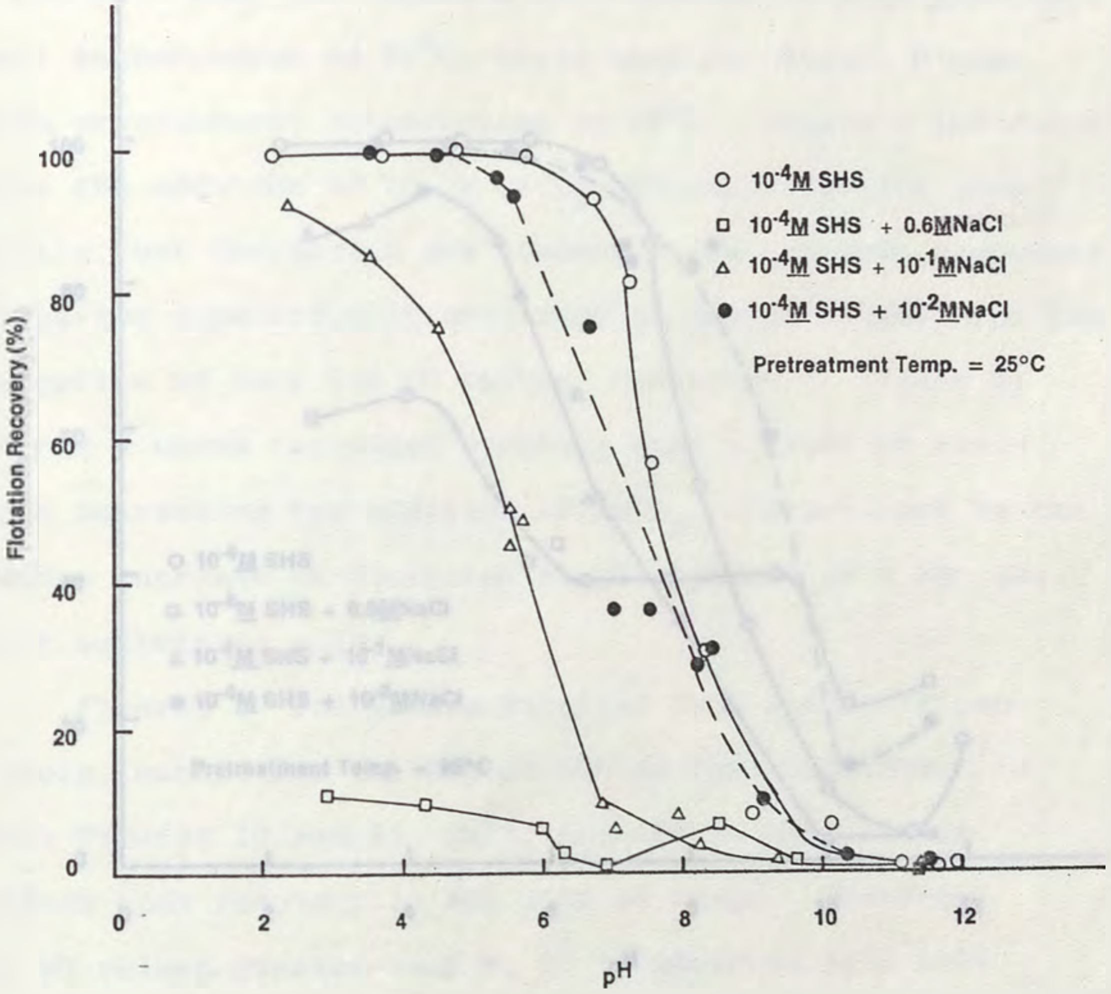

Figure 6. Flotation of hematite with SHS as a function of pH and NaCl concentration.

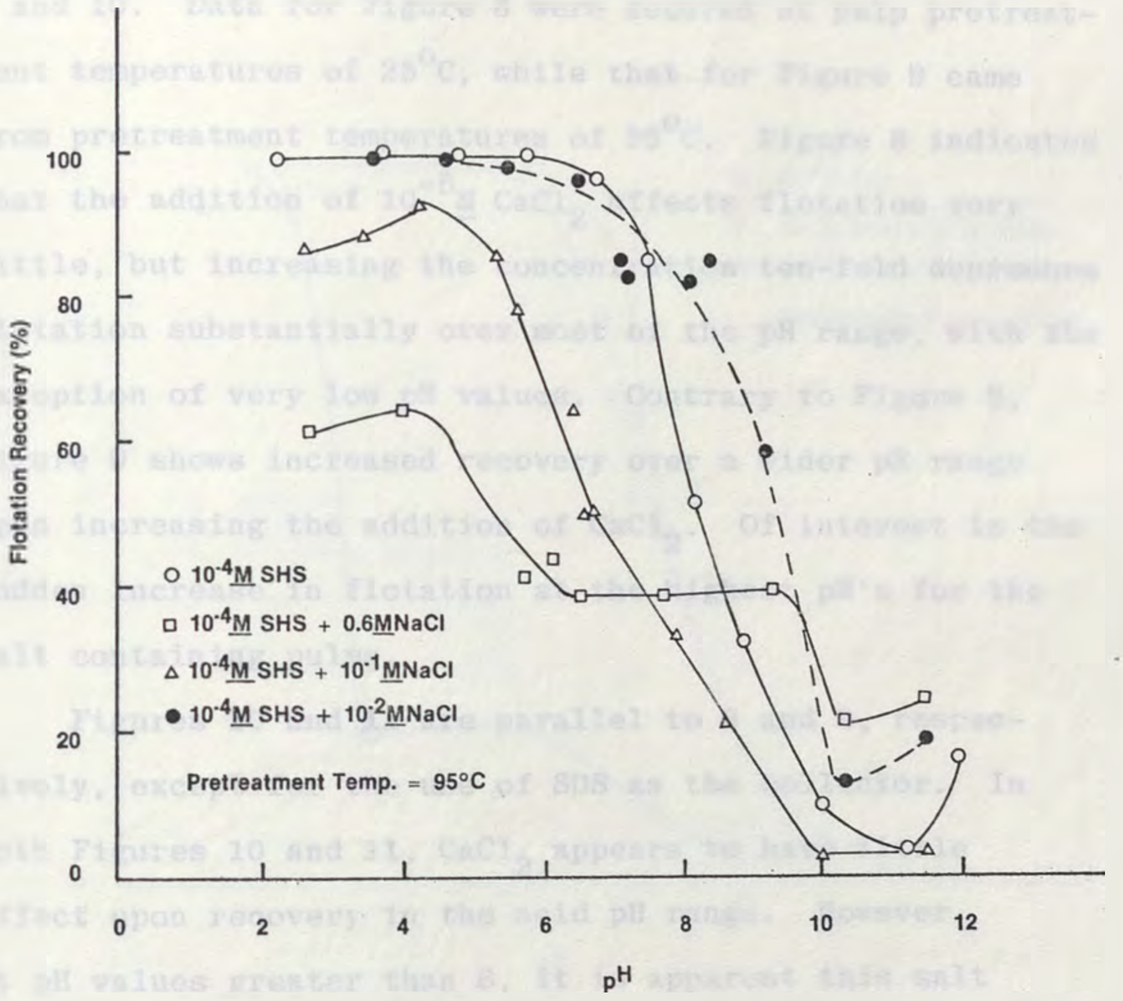

Figure 7. Effects of boiling, Na Cl concentration, and pH on the recovery of hematite with SHS.

Hematite Flotation as a Function of Calcium Chloride Concentration

The effects of varying pH and $CaCl_2$ concentration on the flotation of hematite with SHS are shown in Figures 9 and 10. Data for Figure 8 were secured at pulp pretreatment temperatures of $25^{o}C$, while that for Figure 9 came from pretreatment temperatures of $95^{o}C$. Figure 8 indicates that the addition of $10^{-5}\underline{M}$ $CaCl_2$ affects flotation very little, but increasing the concentration ten-fold depresses flotation substantially over most of the pH range, with the exception of very low pH values. Contrary to Figure 8, Figure 9 shows increased recovery over a wider pH range upon increasing the addition of $CaCl_2$. Of interest is the sudden increase in flotation at the highest pH's for the salt containing pulps.

Figures 10 and 11 are parallel to 8 and 9, respectively, except for the use of SDS as the collector. In both Figures 10 and 11, $CaCl_2$ appears to have little effect upon recovery in the acid pH range. However, at pH values greater than 6, it is apparent this salt has a positive effect on recovery. With increasing $CaCl_2$ concentration, flotation response becomes greater. A slight flotation depression occurs in the middle pH range for all $CaCl_2$ containing pulps in Figure 10. The depression is only evidenced for the $10^{-4}\underline{M}$ $CaCl_2$ pulp in Figure 11.

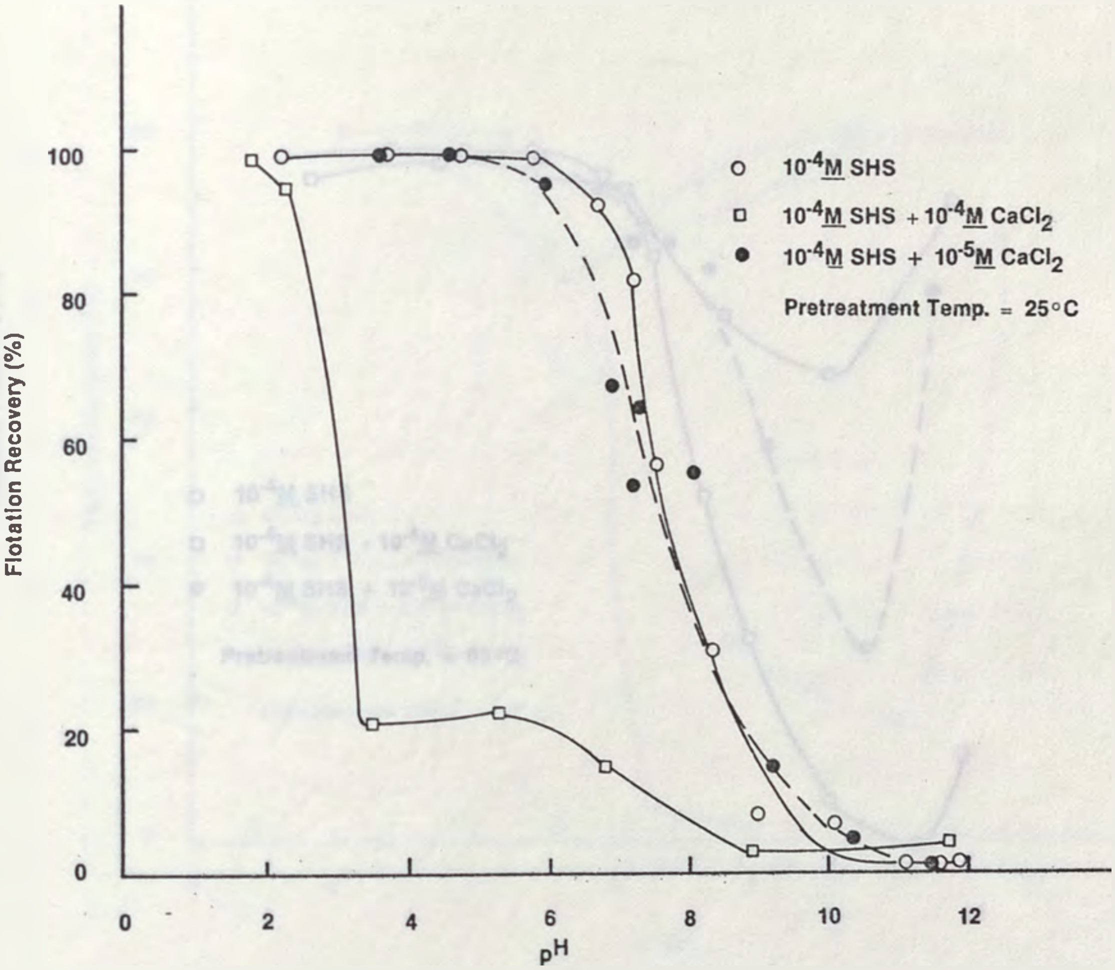

Figure 8. Flotation of hematite with SHS and varying Ca Cl$_2$ concentration and pH.

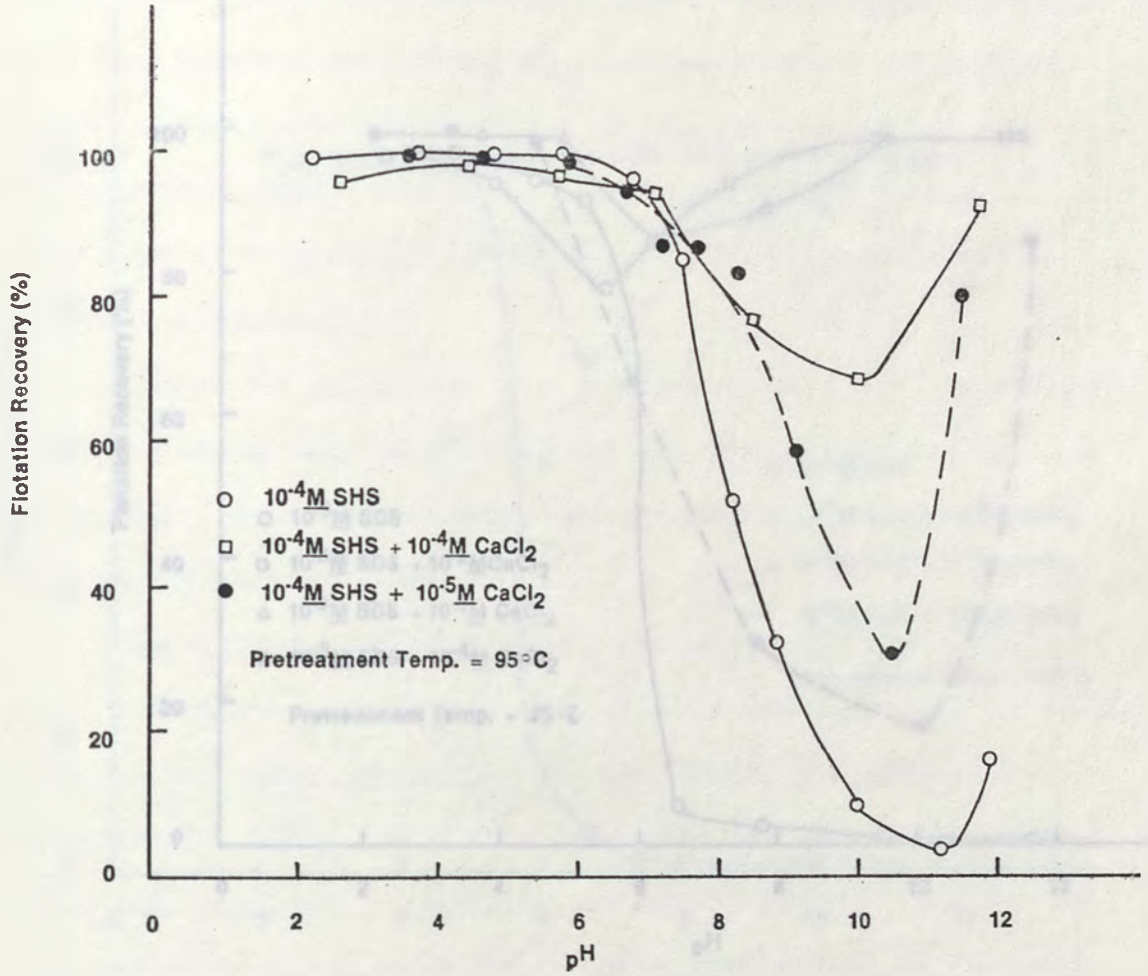

Figure 9. Effects of boiling, Ca Cl_2 concentration, and pH on the recovery of hematite with SHS.

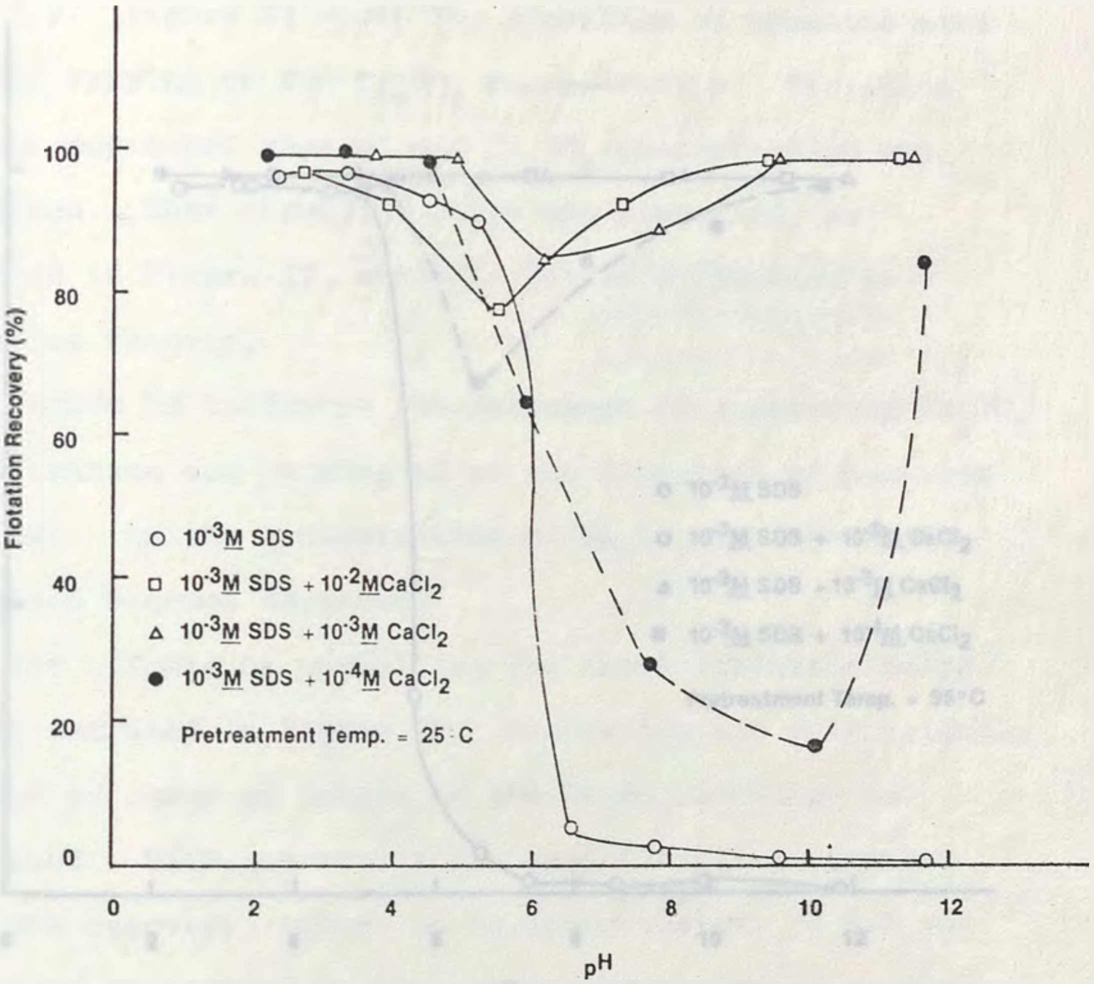

Figure 10. Flotation of hematite with SDS and varying Ca Cl_2 concentration and pH.

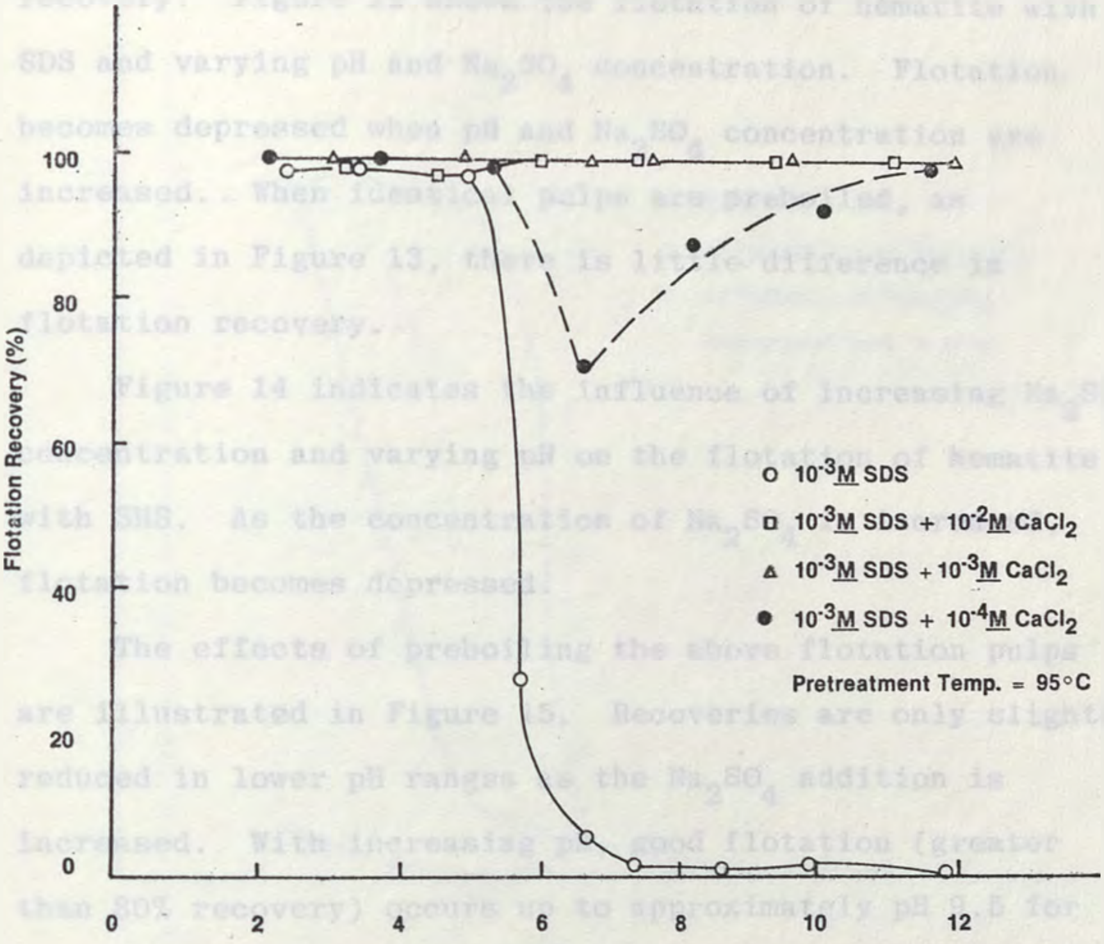

Figure 11. Effects of boiling, $CaCl_2$ concentration, and pH on the recovery of hematite with SDS.

Hematite Flotation as a Function of Sodium Sulfate Concentration

Addition of sodium sulfate to a hematite flotation pulp has some interesting effects upon the mineral recovery. Figure 12 shows the flotation of hematite with SDS and varying pH and Na_2SO_4 concentration. Flotation becomes depressed when pH and Na_2SO_4 concentration are increased. When identical pulps are preboiled, as depicted in Figure 13, there is little difference in flotation recovery.

Figure 14 indicates the influence of increasing Na_2SO_4 concentration and varying pH on the flotation of hematite with SHS. As the concentration of Na_2SO_4 is increased, flotation becomes depressed.

The effects of preboiling the above flotation pulps are illustrated in Figure 15. Recoveries are only slightly reduced in lower pH ranges as the Na_2SO_4 addition is increased. With increasing pH, good flotation (greater than 80% recovery) occurs up to approximately pH 9.5 for the pulps containing Na_2SO_4. This phenomenon is similar to that observed in Figure 7, however much more marked.

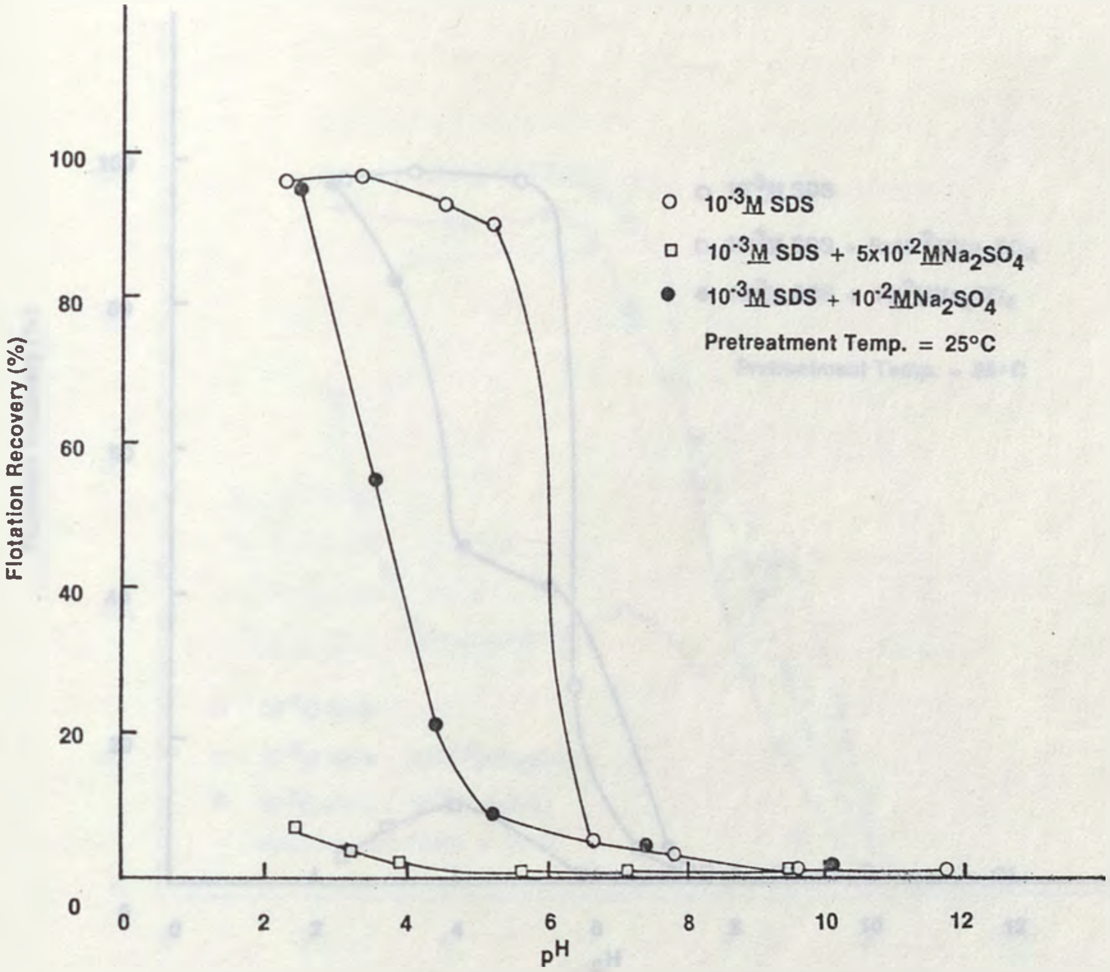

Figure 12. Flotation of hematite with SDS as a function of pH and Na_2SO_4 concentration.

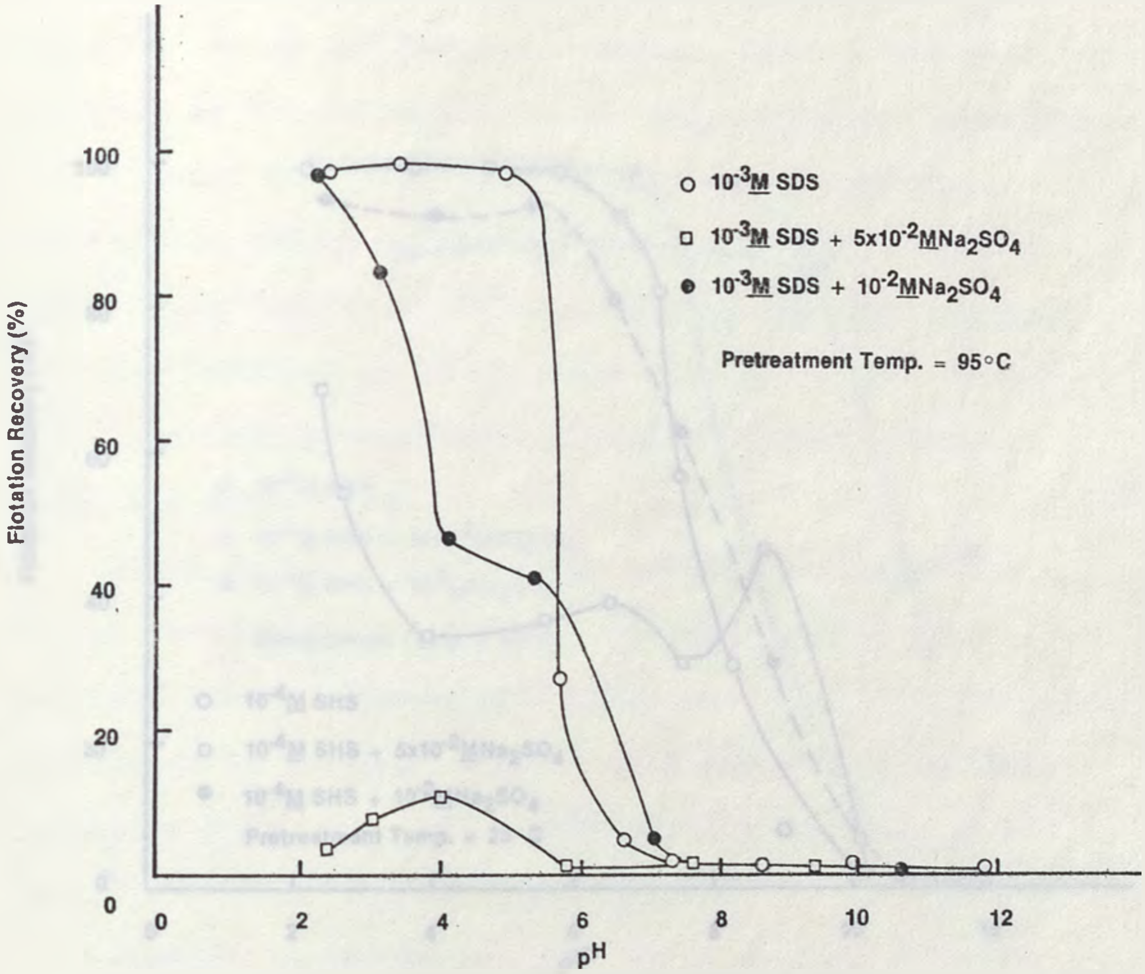

Figure 13. Effects of boiling, Na_2SO_4 concentration, and pH on the recovery of hematite with SDS.

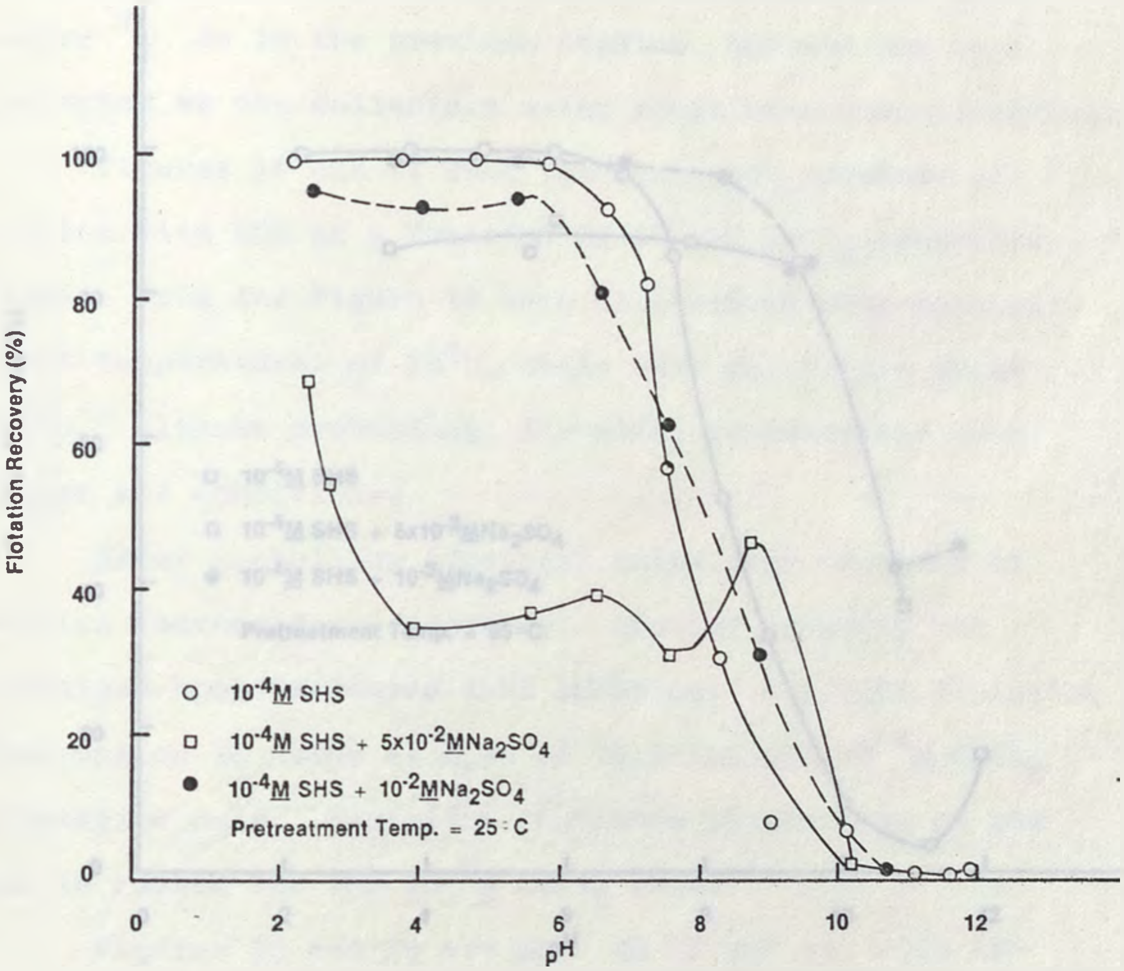

Figure 14. Flotation of hematite with SHS as a function of pH and Na_2SO_4 concentration.

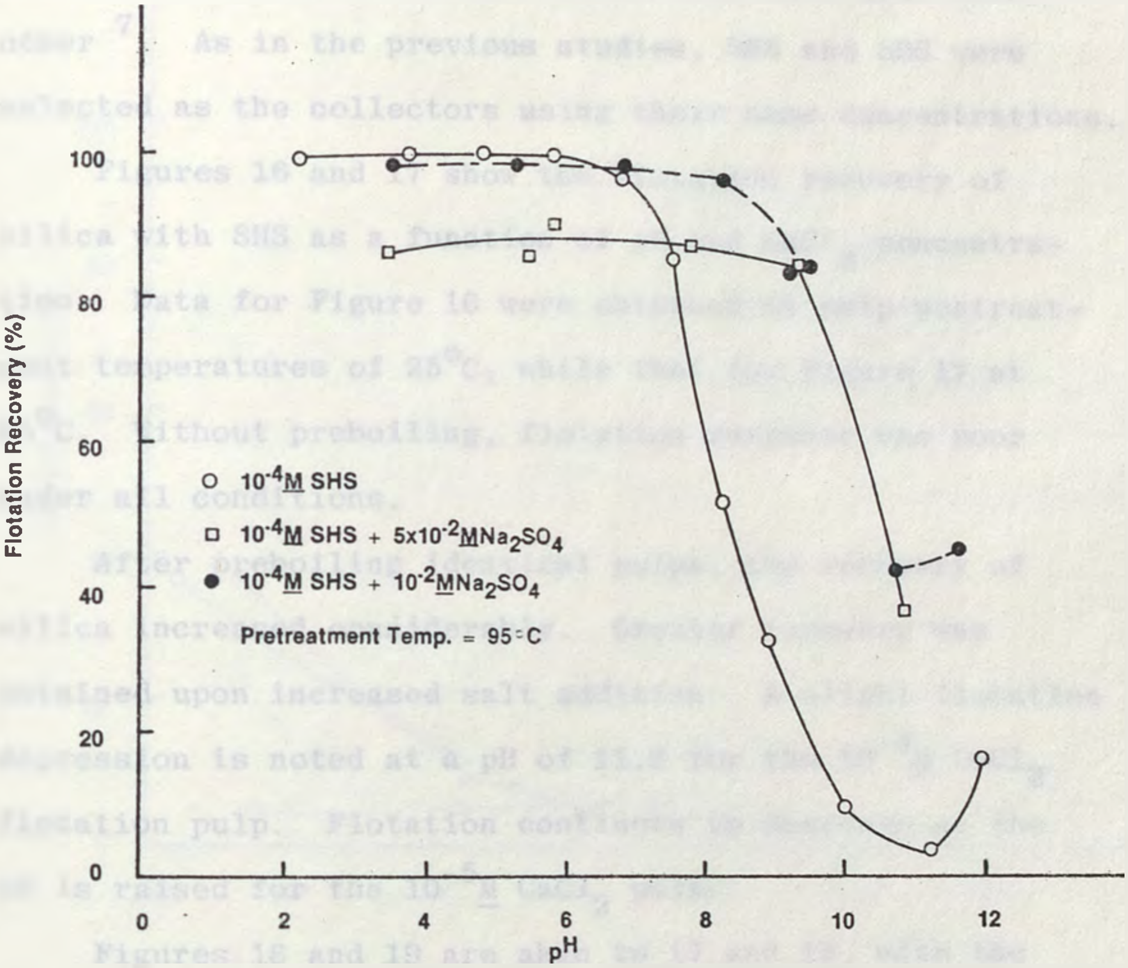

Figure I5. Effects of boiling, Na_2SO_4 concentration, and pH on the recovery of hematite with SHS.

Silica Flotation Studies

The flotation of silica was studied as a function of $CaCl_2$ concentration in the pH range 9.5 to 12.5. This pH range and salt were chosen as the parameters to investigate because of the interesting effects they have upon each other [7]. As in the previous studies, SHS and SDS were selected as the collectors using their same concentrations.

Figures 16 and 17 show the flotation recovery of silica with SHS as a function of pH and $CaCl_2$ concentration. Data for Figure 16 were obtained at pulp pretreatment temperatures of 25°C, while that for Figure 17 at 95°C. Without preboiling, flotation response was poor under all conditions.

After preboiling identical pulps, the recovery of silica increased considerably. Greater recovery was obtained upon increased salt addition. A slight flotation depression is noted at a pH of 11.6 for the $10^{-4}\underline{M}$ $CaCl_2$ flotation pulp. Flotation continues to decrease as the pH is raised for the $10^{-5}\underline{M}$ $CaCl_2$ pulp.

Figures 18 and 19 are akin to 17 and 18, with the exception of the employment of SDS as the flotation collector. In both Figures 18 and 19, flotation response increases substantially by raising the $CaCl_2$ concentration from 10^{-5} to $10^{-4}\underline{M}$. However, as the pH surpasses 11, recovery drops off. Preheating the pulps to 95°C increases the recoveries, particularly with the addition of $10^{-4}\underline{M}$ $CaCl_2$.

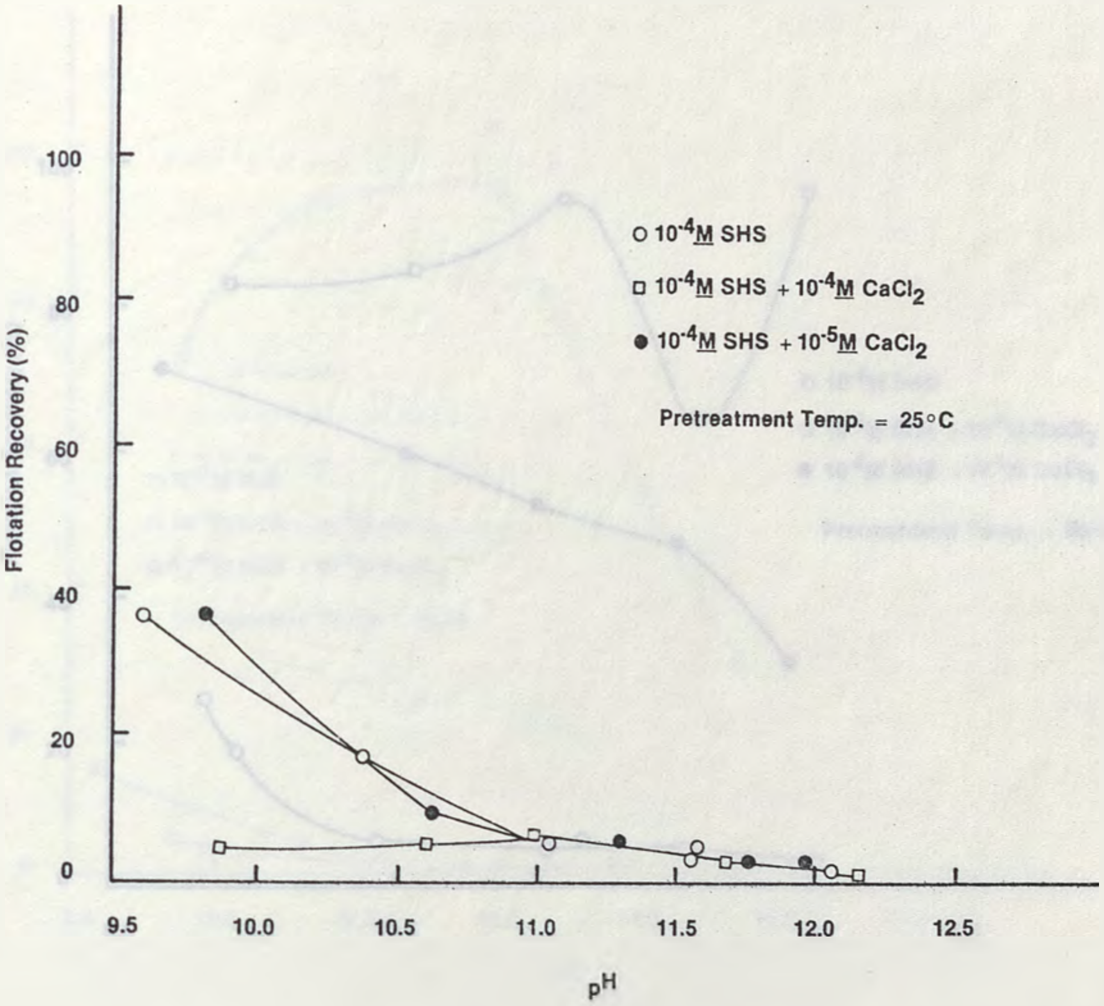

Figure 16. Flotation of silica with SHS and varying pH and Ca Cl_2 concentration.

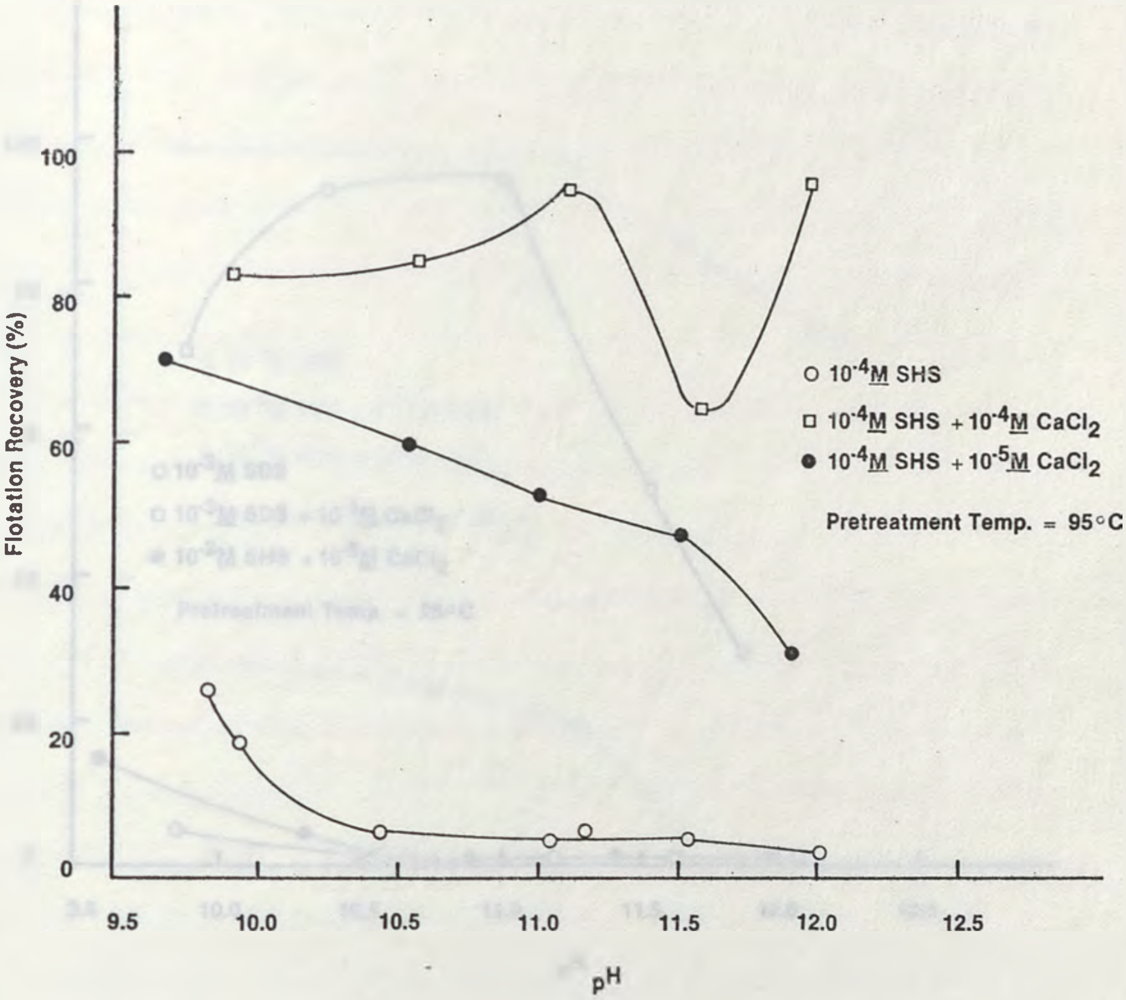

Figure 17. Effects of boiling, Ca Cl_2 concentration, and pH on the flotation of silica with SHS.

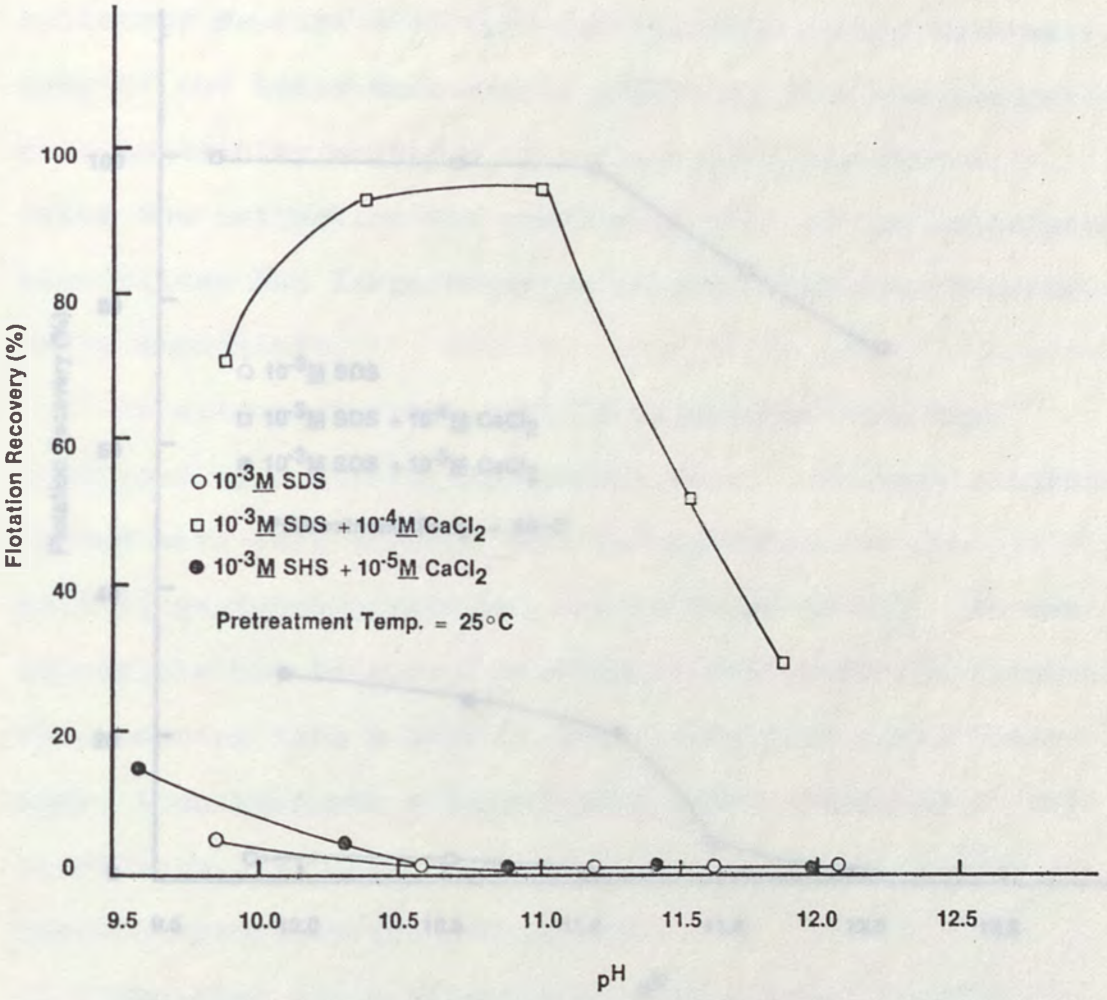

Figure 18. Flotation of silica with SDS and varying pH and Ca Cl_2 concentration.

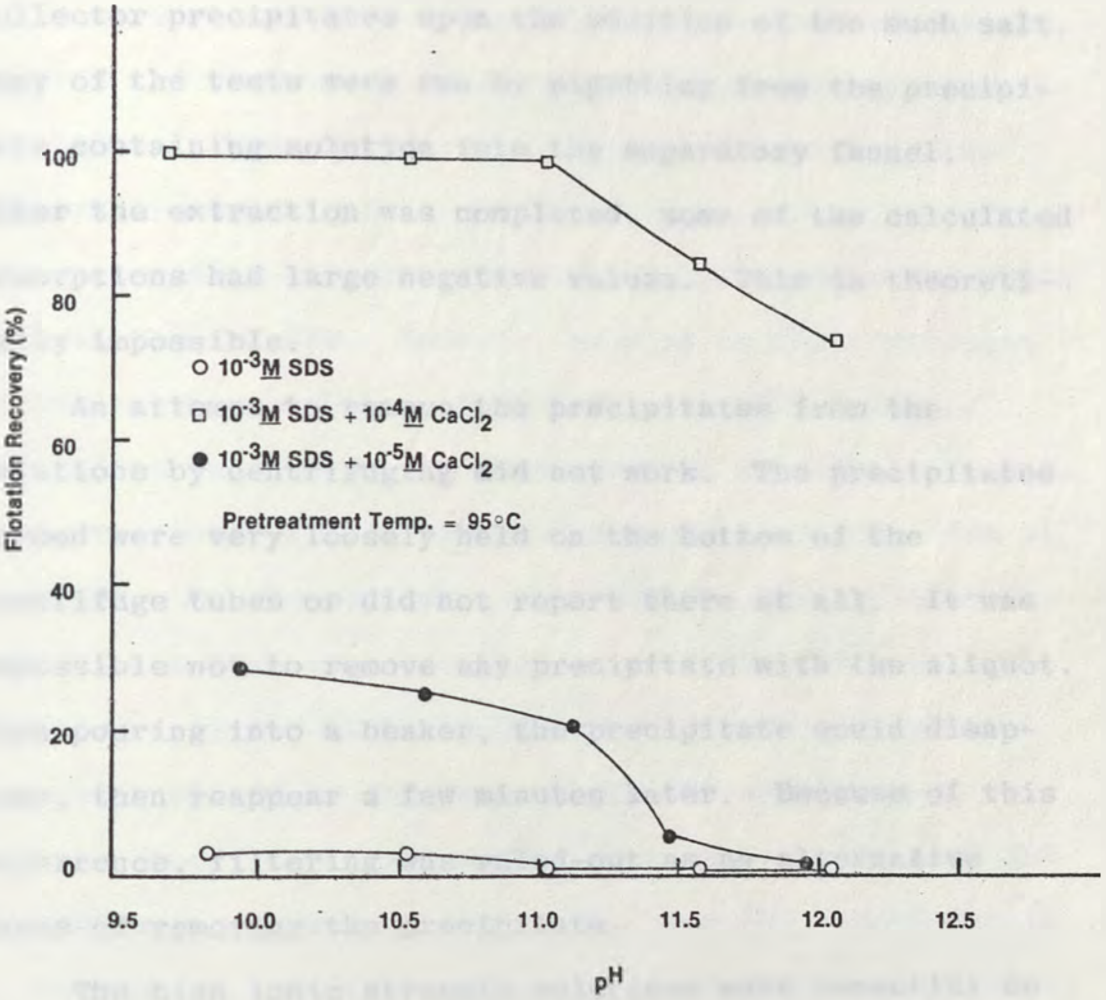

Figure 19. Effects of boiling, $CaCl_2$ concentration, and pH on the flotation of silica with SDS.

Adsorption Studies

Results obtained from the adsorption studies did not correlate well with those from the flotation experiments. The most important problem was the formation of metal collector precipitates upon the addition of too much salt. Many of the tests were run by pipetting from the precipitate containing solution into the separatory funnel. After the extraction was completed, some of the calculated adsorptions had large negative values. This is theoretically impossible.

An attempt to remove the precipitates from the solutions by centrifuging did not work. The precipitates formed were very loosely held on the bottom of the centrifuge tubes or did not report there at all. It was impossible not to remove any precipitate with the aliquot. Upon pouring into a beaker, the precipitate would disappear, then reappear a few minutes later. Because of this occurrence, filtering was ruled-out as an alternative means of removing the precipitate.

The high ionic strength solutions were essential to this investigation because they produced the most significant effects in the results. Since this was the case, the graphs obtained from the adsorption experiments were not included along with those from flotation. The adsorption data are presented in Appendix II.

The Effect of Increasing Ionic Strength on the CMC's of SDS and SHS

Table 4 illustrates the variation in the calculated CMC's for SDS and SHS under the influence of increasing ionic strength at 25°C. The CMC's were calculated using eq. (5) and the actual ionic strengths used in the experimentation. These values will increase slightly as the temperature is raised.

Increasing the concentration of NaCl lowers the CMC's of both SDS and SHS. However, even at an ionic strength equivalent to sea water, 0.6M NaCl, the CMC of SDS is lowered to just below its concentration in solution. This means that very little of the SDS would be in the form of micelles. On the contrary, with SHS the CMC is lowered below its actual concentration in solution for each NaCl addition. At the higher NaCl concentrations, micelle formation should be abundant in the SHS solutions.

As above, $CaCl_2$ and Na_2SO_4 decrease the CMC's of SDS and SHS with increasing additions. For SDS, there should be no micelle formation since all of the CMC's are larger than its concentration in solution. With SHS, micelle formation will only occur in Na_2SO_4 solutions because the CMC's become increasingly lower than its solution concentration, upon adding more of this salt.

Table 4

CMC's with increasing NaCl concentration for $10^{-3}\underline{M}$ SDS and $10^{-4}\underline{M}$ SHS at 25°C

NaCl Conc. ($\underline{M}$)	SDS CMC ($\underline{M} \times 10^{-4}$)	SHS CMC ($\underline{M} \times 10^{-5}$)
0	250	115
0.01	68.5	9.54
0.1	20.7	2.76
0.6	7.89	1.05

CMC's with increasing $CaCl_2$ concentration for $10^{-3}\underline{M}$ SDS and $10^{-4}\underline{M}$ SHS at 25°C

$CaCl_2$ Conc. ($\underline{M} \times 10^{-5}$)	SDS CMC ($\underline{M} \times 10^{-3}$)	SHS CMC ($\underline{M} \times 10^{-4}$)
1		10.4
10	22.6	6.37
100	13.8	
1000	4.83	

CMC's with increasing Na_2SO_4 concentration for

10^{-3} M SDS and 10^{-4} M SHS at 25°C

Na_2SO_4 Conc. (M x 10^{-2})	SDS CMC (M x 10^{-3})	SHS CMC (M x 10^{-5})
1	4.83	6.58
5	2.07	2.76

DISCUSSION

In the present investigation, the pH of the collector solution is demonstrated to have an important influence upon the flotation recovery of hematite. At basic pH values a decrease in flotation is observed for each particular system. This is caused by the charge reversal from positive to negative (pzc) of the hematite surface at about pH 6.7[23], thereby producing repulsion of the negative polar heads of the collector ions. Good recovery above this pH is obtained with SHS because of the formation of hemimicelles. This conclusion is supported by the results of Iwasaki and co-workers[23]. Hydrocarbon association is also responsible for the increased flotation rate using 10^{-3} M rather than 10^{-4} M SDS.

The significant role that pH has in determining the sign and magnitude of the oxide mineral surface charge is also illustrated in several hematite flotation curves that were obtained under the influence of ionic strength. For these curves, flotation is poor over most of the pH range except at very low values. The increased recovery at an acid pH value (ie. pH 2) can be attributed to the more strongly adsorbed, negatively charged collector ions onto a highly positive charged surface. The large positive charge was imparted by the copious quantities of hydrogen ions present in solution at a low pH.

The reduction in hematite recovery with increasing NaCl concentration, using SDS as the collector, can be credited to the strong competition for surface sites between the chloride and organic sulfate ions. At the high ionic strengths, chloride ions will occupy many of the sites because of its greater concentration[3]. The formation of micelles would contribute a small part in the flotation depression at 0.6M NaCl. The solubility of SDS would be of no consequence here as all solutions remained clear throughout the testing. Slightly better recoveries are secured when the pulps are preboiled because the collector ions are held more strongly to the surface than the chloride ions, under conditions of thermal agitation. The association of the hydrocarbon chains provides this strength.

The flotation peaks noted in Figures 4 and 5 for 10^{-2}M NaCl solutions, occur in the pH range where the first hydroxy complex of aluminum, $AlOH^{++}$, is present[7]. Since a spectrographic analysis of hematite (Table 3) indicated the presence of 1% Al, the increases in flotation can be attributed to activation by $AlOH^{++}$. The peak is masked at higher and lower concentrations of NaCl because of the depressing effect of ionic strength, and then its disappearance.

Flotation of hematite with SHS is also reduced by increasing amounts of NaCl. Three phenomena are responsible for this depression. One is the decrease in the CMC of the collector with increasing NaCl addition (Table 4), thereby tieing-up collector ions in the form of micelles. The others are the reduced collector solubility and increased competition for surface sites with increasing ionic strength.

The greater recoveries obtained by preboiling identical pulps to the above can be attributed to the increased solubility of SHS upon heating. Most of the solutions became clear before the 95°C temperature was reached, except for 0.6M NaCl. This would produce more collector ions available for adsorption onto the mineral surface. For preboiled pulps at concentrations of 0.1M and 0.6M NaCl, flotation becomes greater than using SHS alone, beyond a pH of about 8. This phenomenon is explained by the reduction in coulombic forces between like-charged collector ions and particle surfaces with the addition of a salt[4], thus allowing for some collector adsorption. However, it is noted this did not occur with a 0.1M NaCl flotation pulp.

Comparison of the flotation curves on Figures 6 and 7 with Figures 4 and 5 shows that SHS is a much better collector for hematite in the presence of increasing concentrations of NaCl. When the SHS pulps are preboiled, they produce almost the same recovery at 0.1M NaCl as SDS without any NaCl addition. This occurs even though the SDS concentration is ten times greater than that of SHS.

Obviously, SHS is adsorbed much more strongly at the solid-water interface and possibly air-water interface, than its shorter chained counterpart.

Increasing the dosage of $CaCl_2$ to a SHS collector solution hinders the flotation of hematite. The decrease in recovery is caused by the removal of collector ions from solution by the formation of an insoluble organic metal salt (Table 2).

On the contrary, when the identical $CaCl_2$ + SHS pulps are preboiled, the precipitated organic metal salt becomes soluble, thus rendering collector ions available for adsorption. At basic pH values, flotation is increased because of the activation produced by the specific adsorption of calcium ion, Ca^{++}, in the hematite double layer. Enhanced flotation at the highest pH's (greater than 11.5) is due to the formation of the first hydroxy complex of calcium, $CaOH^+$, whose adsorption causes increased activation[7].

Even though the solubility of the collector is reduced, the addition of $CaCl_2$ has little effect upon the flotation of hematite with SDS in the acid pH range. At higher pH values where no flotation occurs using SDS alone, the recovery is greatly enchanced with increasing amounts of $CaCl_2$. Specific adsorption of Ca^{++} or $CaOH^+$ on hematite is responsible for this activation. The recoveries of the preboiled pulps are greater than those which were not due to the increased solubility of the collector at a higher temperature. This is most notable in the higher acid and lower basic pH ranges.

Analysis of the results obtained for both collectors at 25°C pretreatment temperatures, illustrates that SDS is a superior collector to SHS under conditions of increasing $CaCl_2$ concentration and pH. In spite of that, when the pulps are preboiled Ca^{++} or $CaOH^+$ act as good activators using either collector. Obviously, the difference in the solubilities of the calcium salts of SHS and SDS plays an important role in the low temperature flotation of hematite.

The addition of Na_2SO_4 to a SDS collector solution has a similar effect to NaCl on the flotation of hematite. The decrease in recovery brought about by the specific adsorption of the sulfate ion is however, much more marked than that produced by the chloride ion. Fuerstenau and Modi[3] have reported parallel effects of Na_2SO_4 and NaCl on the flotation of corundum with SDS.

When SHS is used as the collector, Na_2SO_4 also depresses the floatability of hematite with increasing concentration. The primary reason for the depression can be accounted for by the decrease in solubility with increasing additions of salt. Other reasons of less importance are the increase in micelle formation of SHS with greater Na_2SO_4 concentration and the competition for surface sites provided by sulfate anions. After preboiling identical pulps, recoveries continue declining with greater salt dosages, but to lesser extent. The increased solubility of SHS is responsible for the improved recoveries. The improved flotation upon boiling of the Na_2SO_4 containing pulps in the basic pH range, can again be credited to the lowering of the coulombic forces between collector ions and particle surfaces.

By comparing the flotation curves on Figures 14 and 15 with those on Figures 12 and 13, it is evident SHS floats hematite more readily than SDS when the pulps are subjected to increasing Na_2SO_4 addition and pH. The hexadecyl sulfate ion is again shown to be strongly adsorbed on the particle surface, since the sulfate ion provided limited competition and the formation of micelles should have been abundant (Table 4). As with $CaCl_2$, the adverse effect of reduced collector solubility at lower temperatures appears to hinder flotation with the addition of larger amounts of salt.

Increasing $CaCl_2$ concentration has an analogous effect upon the flotation of silica with SHS, to that of hematite. Without preboiling the salt-collector pulps, flotation is very poor because of the precipitation of the collector out of solution. But following preboiling of identical flotation pulps, recovery is enhanced, particularly at the higher salt concentration. The enhanced recoveries in the lower pH range can be attributed to the specific adsorption of Ca^{++} onto the silica surface. At the highest pH value for the $10^{-4}\underline{M}$ $CaCl_2$ pulp, the recovery is the greatest. This is credited to silica activation by the first hydroxy complex of calcium.

When the $CaCl_2$ content is lowered by ten times, strong activation of silica by $CaOH^+$ does not occur. This could be due to the insufficient amount of $CaOH^+$, necessary for quartz activation by this mechanism. Thus, contrary to previous studies[7], it would be indicative that Ca^{++} is a stronger activator for silica at lower concentrations of $CaCl_2$. Another possible explanation could stem from research demonstrating silica to become soluble at high pH values[24]. Since this phenomenon takes place, the smaller concentrations of $CaOH^+$ would be removed faster from the surface than those higher. Consequently, adsorption and flotation would be reduced.

The flotation of calcium activated quartz with SDS is enhanced by increasing the supply of Ca^{++}. Raising the $CaCl_2$ concentration from 10^{-5} to $10^{-4}\underline{M}$, produces much improved recovery. This can be attributed to the increased adsorption of the extra calcium ions. Preboiling of the flotation pulps also produces greater recoveries because of the increased solubility of SDS upon heating (Table 2).

Whether preboiled or not, silica flotation is shown to lessen as the pH becomes more basic. Similar reasons that were given to explain the reduced flotation with SHS at lower $CaCl_2$ concentrations can be applied here. It is noted however, that the silica recovery with SDS decreases with increasing pH, even for the higher salt concentration. This could be owed to the weaker adsorption of SDS in comparison to SHS, as observed in previous results of this investigation.

When the flotation recoveries obtained with calcium containing SDS and SHS pulps are compared with each other, it is apparent the floatability of silica is superior using the shorter chained collector under conditions of low pretreatment temperatures. Upon boiling, both SDS and SHS will collect the activated quartz. These observations are in agreement with those of the $CaCl_2$-hematite flotation studies.

SUMMARY AND CONCLUSIONS

Microflotation studies were performed to determine the effects of increasing ionic strength, collector chain length, and pretreatment temperature on the flotation recoveries of hematite and silica. Sodium chloride, calcium chloride dihydrate, and sodium sulfate were the three salts used to control ionic strength. The collectors employed were SDS and SHS, both members of the alkyl sulfate group. The pulp pretreatment temperatures were 25°C and 95°C. From the results of the investigation, the following conclusions can be made:

1. Without any salt addition, longer chained alkyl sulfates give better flotation recovery of hematite. Preboiling these flotation pulps alters recovery insignificantly.
2. Flotation of hematite with SDS or SHS is adversely effected upon increasing additions of NaCl. Preboiling the flotation pulps improves recoveries for both collectors. In comparison, hematite flotation is greater with SHS than SDS as NaCl concentration is raised.
3. At low pretreatment temperatures, increasing the concentration of $CaCl_2$ decreases the flotation of hematite with SHS, but has the opposite effect on recovery using SDS. When $CaCl_2$ pulps of either collector are preboiled, the floatability of

hematite increases with greater additions of salt. Specific adsorption of Ca^{++} and $CaOH^{+}$ are responsible for the increased recoveries of hematite in the basic pH range.

4. Increasing amounts of sodium sulfate depress hematite flotation with SDS or SHS at 25°C pretreatment temperatures. Preboiling of identical Na_2SO_4 flotation pulps does not change the recovery using SDS. However, it does improve the recovery with SHS, particularly in the basic pH range.
5. Silica flotation with SHS and SDS is poor in the pH range 9.5 to 12.5. With the addition of $CaCl_2$, flotation response increases using SDS, but is effected very little with SHS. Preboiling and increasing the $CaCl_2$ dosage to pulps of either collector improves the floatability of silica. Activation by Ca^{++} is credited for the increased flotation up to a pH of about 11 in both systems. $CaOH^{+}$ strongly activates quartz only for a preboiled $10^{-4}\underline{M}$ $CaCl_2$ + SHS solution.
6. The mechanism of depression by Na_2SO_4 and NaCl on the flotation of hematite with SDS appears to be the ion competition for adsorption sites in the double layer. For recovery of hematite with SHS the mechanisms of depression by the same salts, along with $CaCl_2$, appear to be collector solubility, CMC

lowering, and ion competition. Collector solubility seems to be the dominant mechanism, especially for pulps containing $CaCl_2$.

RECOMMENDATIONS FOR FUTURE RESEARCH

Other experimental techniques would aid in substantiating the flotation results obtained. Electrokinetic investigations using a Zeta Meter would elucidate some of the collector-mineral adsorption mechanisms. The calculated collector CMC's could be checked by performing surface tensions experiments (ie. capillary rise) at different temperatures and salt concentrations. These measurements would also give an indication of the collector adsorption at the air-solution interface. Collector solubilities at various salt concentrations and temperatures should be measured in order to determine the actual "solubility effect" upon flotation response. Finally, microflotation studies could be carried out at different conditioning times and temperatures than the ones previously used to explain any additional influences of these variables on the mineral recoveries.

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APPENDIX I

Microflotation of Hematite as a Function of pH in Different Systems

Table 1

With 10^{-4} M SHS Present; Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	2.2	99.0
2	3.7	99.6
3	4.8	99.9
4	5.8	98.8
5	6.7	93.0
6	7.2	82.3
7	7.5	56.9
8	8.3	30.9
9	9.0	8.0
10	10.1	6.5
11	11.1	1.6
12	11.6	0.5
13	11.9	1.4

Table 2

With 10^{-4} M SDS Present; Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	2.6	96.3
2	3.3	97.1
3	4.2	67.1
4	5.9	24.4
5	7.0	12.3
6	9.5	2.5
7	11.5	0.5

Table 3

With $10^{-4}\underline{M}$ STS Present; Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	3.4	98.1
2	4.6	92.0
3	5.9	63.4
4	6.8	50.4
5	7.6	39.0
6	8.8	29.7
7	9.7	7.0
8	10.9	1.3

Table 4

With $10^{-3}\underline{M}$ SDS Present; Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	2.3	96.0
2	3.3	96.8
3	4.5	92.6
4	5.2	90.4
5	6.6	5.5
6	7.8	2.9
7	9.6	1.0
8	11.7	0.4

Table 5

With $10^{-3}\underline{M}$ SDS + $0.6\underline{M}$ NaCl Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	1.8	56.7
2	2.6	28.0
3	3.5	15.2
4	4.7	2.6
5	7.5	0.8
6	9.7	0.6

Table 6

With 10^{-3} M SDS + 10^{-1} M NaCl Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	2.0	92.6
2	2.1	55.3
3	3.1	13.6
4	4.4	5.7
5	5.6	0.8
6	7.6	0.5
7	11.2	0.3

Table 7

With 10^{-3} M SDS + 10^{-2} M NaCl Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	1.9	94.8
2	2.9	59.6
3	4.2	73.8
4	5.0	24.2
5	6.5	2.4
6	7.8	1.3
7	11.0	0.4

Table 8

With 10^{-3} M SDS Present; Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	2.4	97.1
2	3.4	98.0
3	4.9	97.2
4	5.7	27.6
5	6.6	5.3
6	7.3	1.8
7	8.6	1.6
8	9.9	2.0
9	11.8	0.3

Table 9

With 10^{-3}M SDS + 0.6M NaCl Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	1.7	76.2
2	2.9	25.0
3	4.1	9.5
4	5.3	1.7
5	6.7	0.7
6	10.0	0.2

Table 10

With 10^{-3}M SDS + 10^{-1}M NaCl Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	2.5	69.9
2	3.0	43.5
3	3.8	35.5
4	5.0	1.7
5	6.2	0.8
6	7.1	0.4
7	9.0	0.5
8	11.6	0.4

Table 11

With 10^{-3}M SDS + 10^{-2}M NaCl Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	1.8	96.0
2	2.2	94.6
3	3.6	67.1
4	4.6	76.8
5	5.5	36.9
6	6.1	4.1
7	7.7	0.7
8	10.5	0.2

Table 12

With $10^{-4}\underline{M}$ SHS + $0.6\underline{M}$ NaCl Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	2.9	11.0
2	4.3	9.7
3	6.0	6.6
4	6.3	2.4
5	6.9	0.8
6	8.5	6.2
7	9.6	0.6
8	11.4	0.1

Table 13

With $10^{-4}\underline{M}$ SHS + $10^{-1}\underline{M}$ NaCl Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	2.4	92.1
2	3.5	85.6
3	4.5	75.6
4	5.5	50.6
5	5.5	45.3
6	5.7	49.0
7	6.8	9.2
8	7.0	6.0
9	7.9	8.1
10	8.2	3.8
11	9.3	1.4
12	11.4	0.5

Table 14

With 10^{-4} M SHS + 10^{-2} M NaCl Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	3.5	99.4
2	4.5	99.3
3	5.4	96.4
4	5.6	93.6
5	6.7	75.7
6	7.0	36.4
7	7.5	36.2
8	8.2	28.9
9	8.4	31.2
10	9.1	10.5
11	10.3	2.2
12	11.5	1.3

Table 15

With 10^{-4} M SHS Present; Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	2.2	98.9
2	3.7	100.0
3	4.8	99.9
4	5.8	99.9
5	6.8	96.9
6	7.5	85.8
7	8.2	52.0
8	8.9	32.6
9	10.0	9.9
10	11.2	3.9
11	11.9	16.1

Table 16

With 10^{-4}M SHS + 0.6M NaCl Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	2.7	61.5
2	4.0	64.5
3	5.7	40.9
4	6.1	43.9
5	6.5	38.8
6	7.7	39.1
7	9.3	39.7
8	10.3	21.2
9	11.5	24.6

Table 17

With 10^{-4}M SHS + 10^{-1}M NaCl Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	2.6	86.8
2	3.4	87.9
3	4.2	92.8
4	5.3	85.7
5	5.6	78.5
6	6.4	64.2
7	6.5	49.8
8	6.7	50.3
9	7.9	33.5
10	8.6	21.3
11	10.0	2.7
12	11.5	3.1

Table 18

With $10^{-4}\underline{M}$ SHS + $10^{-2}\underline{M}$ NaCl Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	3.6	99.1
2	4.6	99.2
3	5.5	98.2
4	6.5	96.3
5	7.1	85.1
6	7.2	83.2
7	8.1	82.3
8	8.4	85.5
9	9.2	59.1
10	10.3	12.9
11	11.5	18.7

Table 19

With $10^{-3}\underline{M}$ SDS + $10^{-2}\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	2.7	96.5
2	3.9	92.6
3	5.5	77.7
4	7.3	92.8
5	9.4	99.0
6	11.3	99.7

Table 20

With $10^{-3}\underline{M}$ SDS + $10^{-3}\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = $25^{o}C$

Test No.	pH	Flotation Recovery (%)
1	3.7	98.8
2	4.9	98.7
3	6.1	85.3
4	7.8	89.5
5	9.6	99.2
6	11.6	99.8

Table 21

With $10^{-3}\underline{M}$ SDS + $10^{-4}\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = $25^{o}C$

Test No.	pH	Flotation Recovery (%)
1	2.2	99.1
2	3.3	99.5
3	4.5	98.5
4	5.9	65.1
5	7.7	28.1
6	10.1	16.6
7	11.7	84.9

Table 22

With $10^{-3}\underline{M}$ SDS + $10^{-2}\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = $95^{o}C$

Test No.	pH	Flotation Recovery (%)
1	3.3	97.9
2	4.5	97.0
3	6.0	99.2
4	7.4	99.5
5	9.4	99.6
6	11.1	99.8

Table 23

With $10^{-3}\underline{M}$ SDS + $10^{-3}\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	3.1	98.8
2	4.9	99.4
3	6.7	99.0
4	7.6	99.2
5	9.7	99.6
6	12.0	99.6

Table 24

With $10^{-3}\underline{M}$ SDS + $10^{-4}\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	2.2	99.4
2	3.7	99.5
3	5.3	98.6
4	6.6	70.9
5	8.2	88.0
6	10.1	92.4
7	11.6	98.3

Table 25

With $10^{-4}\underline{M}$ SHS + $10^{-4}\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	1.8	98.6
2	2.3	94.7
3	3.5	20.4
4	5.3	22.1
5	6.8	14.2
6	8.9	2.8
7	11.7	4.0

Table 26

With $10^{-4}\underline{M}$ SHS + $10^{-5}\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	3.6	99.8
2	4.6	99.8
3	5.9	95.9
4	6.9	67.4
5	7.2	53.9
6	7.3	64.4
7	8.1	55.5
8	9.2	15.0
9	10.3	4.6
10	11.5	1.2

Table 27

With $10^{-4}\underline{M}$ SHS + $10^{-6}\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	3.5	99.7
2	4.5	99.4
3	5.9	98.8
4	6.8	69.7
5	7.1	56.0
6	7.7	46.9
7	8.3	38.9
8	9.3	11.2
9	10.5	3.4
10	11.5	1.8

Table 28

With $10^{-4}\underline{M}$ SHS + $10^{-4}\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	2.6	95.5
2	4.4	98.1
3	5.8	96.8
4	7.1	95.0
5	8.5	76.8
6	10.0	68.7
7	11.8	93.6

Table 29

With $10^{-4}\underline{M}$ SHS + $10^{-5}\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	3.6	99.7
2	4.6	99.6
3	5.9	98.4
4	6.7	95.1
5	7.2	87.6
6	7.7	87.1
7	8.3	83.6
8	9.2	58.9
9	10.5	30.3
10	11.5	80.2

Table 30

With $10^{-4}\underline{M}$ SHS + $10^{-6}\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	3.6	99.5
2	4.6	99.6
3	5.9	99.1
4	6.8	92.6
5	7.8	74.1
6	7.9	59.0
7	8.3	70.7
8	8.7	68.6
9	9.0	44.8
10	10.4	9.8
11	11.5	25.3

Table 31

With $10^{-3}\underline{M}$ SDS + $0.05\underline{M}$ Na_2SO_4 Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	2.4	7.6
2	3.2	3.0
3	3.9	2.2
4	5.6	0.1
5	7.1	0.4
6	9.4	0.3

Table 32

With $10^{-3}\underline{M}$ SDS + $10^{-2}\underline{M}$ Na_2SO_4 Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	2.5	94.6
2	3.5	54.3
3	4.4	21.6
4	5.2	8.8
5	7.4	4.2
6	10.1	1.4

Table 33

With $10^{-3}\underline{M}$ SDS + $0.05\underline{M}$ Na_2SO_4 Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	2.4	2.9
2	3.0	7.6
3	4.0	10.3
4	5.8	0.7
5	7.6	1.6
6	9.4	0.6

Table 34

With $10^{-3}\underline{M}$ SDS + $10^{-2}\underline{M}$ Na_2SO_4 Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	2.2	96.7
2	3.1	83.4
3	4.1	46.4
4	5.3	41.5
5	7.0	4.8
6	10.6	0.3

Table 35

With $10^{-4}\underline{M}$ SHS + $0.05\underline{M}$ Na_2SO_4 Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	2.4	69.1
2	2.7	54.5
3	3.9	34.7
4	5.6	36.8
5	6.5	39.5
6	7.6	31.9
7	8.8	46.2
8	10.2	2.2

Table 36

With $10^{-4}\underline{M}$ SHS + $10^{-2}\underline{M}$ Na_2SO_4 Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	2.5	94.7
2	4.0	92.8
3	5.4	94.6
4	6.6	81.7
5	7.5	63.2
6	8.8	31.5
7	10.7	1.2

Table 37

With $10^{-4}\underline{M}$ SHS + $0.05\underline{M}$ Na_2SO_4 Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	3.4	86.3
2	5.4	86.0
3	5.8	90.3
4	7.8	87.6
5	9.4	84.3
6	10.9	37.2

Table 38

With 10^{-4} $\underline{M}$ SHS + 10^{-2} $\underline{M}$ Na_2SO_4 Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	3.5	98.3
2	5.2	99.0
3	6.8	98.5
4	8.2	96.8
5	9.2	84.0
6	9.5	84.6
7	10.7	42.6
8	11.6	45.9

Microflotation of Silica as a Function of pH in Different Systems

Table 39

With 10^{-4} $\underline{M}$ SHS Present; Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	9.60	36.0
2	10.37	17.0
3	11.06	4.4
4	11.54	2.8
5	11.58	5.6
6	12.06	2.0

Table 40

With 10^{-4} M SHS Present; Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	9.83	26.1
2	9.93	18.5
3	10.43	6.2
4	11.03	4.6
5	11.16	7.1
6	11.53	5.1
7	11.99	3.3

Table 41

With 10^{-3} M SDS Present; Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	9.86	4.7
2	10.58	1.0
3	11.18	0.6
4	11.62	0.9
5	12.08	0.6

Table 42

With 10^{-3} M SDS Present; Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	9.83	3.4
2	10.52	2.3
3	11.03	1.0
4	11.58	0.9
5	12.04	0.4

Table 43

With $10^{-4}\underline{M}$ SHS + $10^{-4}\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	9.87	4.5
2	10.60	4.6
3	10.99	6.4
4	11.68	2.6
5	12.16	1.2

Table 44

With $10^{-4}\underline{M}$ SHS + $10^{-5}\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	9.82	36.8
2	10.62	9.5
3	11.28	5.7
4	11.76	2.4
5	11.96	2.5

Table 45

With $10^{-4}\underline{M}$ SHS + $10^{-4}\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	9.91	83.6
2	10.56	85.5
3	11.10	95.0
4	11.57	64.9
5	11.98	96.1

Table 46

With $10^{-4}\underline{M}$ SHS + $10^{-5}\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	9.67	71.4
2	10.52	60.0
3	10.99	53.0
4	11.50	47.8
5	11.90	31.2

Table 47

With $10^{-3}\underline{M}$ SDS + $10^{-4}\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	9.87	70.4
2	10.38	93.2
3	11.01	95.3
4	11.52	52.3
5	11.88	29.4

Table 48

With $10^{-3}\underline{M}$ SDS + $10^{-5}\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Flotation Recovery (%)
1	9.58	14.6
2	10.30	4.5
3	10.89	1.6
4	11.40	1.3
5	11.99	0.6

Table 49

With 10^{-3} M SDS + 10^{-4} M $CaCl_2$ Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	9.69	99.7
2	10.53	99.5
3	11.03	99.1
4	11.58	85.0
5	12.06	74.5

Table 50

With 10^{-3} M SDS + 10^{-5} M $CaCl_2$ Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Flotation Recovery (%)
1	9.94	28.2
2	10.58	25.5
3	11.11	20.6
4	11.48	5.2
5	11.96	1.6

APPENDIX II

Adsorption of Alkyl Sulfate Collectors on Hematite as a Function of pH in Various Systems

Table 51

With 10^{-4} M SHS Present; Pulp Pretreatment Temp. = 25°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	1.8	2.5
2	3.2	10.25
3	3.8	10.25
4	4.3	9.25
5	5.2	5.25
6	6.1	3.75
7	6.3	2.75
8	6.7	1.5
9	7.0	2.0
10	7.4	0.6
11	8.2	0
12	9.0	0
13	9.8	1.5
14	10.5	0.75
15	11.4	3.75
16	11.7	4.0
17	12.2	3.75

Table 52

With 10^{-4} M STS Present; Pulp Pretreatment Temp. = 25°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	1.6	1.25
2	2.7	2.0
3	3.8	1.5
4	4.6	0
5	5.0	0
6	5.4	0
7	6.1	0
8	7.7	0
9	9.7	0
10	10.4	0
11	11.3	0.5
12	12.1	0

Table 53

With 10^{-4} M SDS Present; Pulp Pretreatment Temp. = 25°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	2.8	0
2	3.1	0.75
3	3.8	0.75
4	5.8	0
5	6.0	0

Table 54

With 10^{-3} M SDS Present; Pulp Pretreatment Temp. = 25°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	1.2	17.5
2	1.9	17.5
3	2.5	17.5
4	3.8	12.5
5	4.3	20.0
6	4.6	10.0
7	5.8	10.0
8	6.3	10.0
9	6.4	0
10	6.8	0
11	7.1	0
12	7.7	0
13	8.9	0
14	9.6	0
15	10.4	0
16	11.3	0
17	11.6	0
18	12.1	0

Table 55

With 10^{-4} M SHS Present; Pulp Pretreatment Temp. = 95°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	3.8	10.0
2	5.7	2.75
3	6.6	2.5
4	7.0	0.6
5	7.3	0
6	7.6	0.6
7	8.0	0.6
8	9.2	0
9	11.4	0
10	11.8	0

Table 56

With 10^{-3}M SDS Present; Pulp Pretreatment Temp. = 95°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	3.7	10.0
2	5.5	10.0
3	6.6	0
4	8.6	0
5	11.3	0

Table 57

With 10^{-4}M SHS + 10^{-2}M NaCl Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	3.7	0
2	5.8	0
3	6.6	0
4	7.4	7.25
5	8.3	1.5
6	8.7	1.0
7	9.2	3.0
8	10.2	2.25
9	11.3	0.25

Table 58

With 10^{-4}M SHS + 10^{-2}M NaCl Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	3.7	0
2	6.0	0
3	6.8	9.0
4	7.1	0
5	7.4	0
6	8.0	21.25
7	9.2	0
8	9.8	5.5
9	11.2	0

Table 59

With 10^{-4}M SHS + 0.005M NaCl Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	3.7	3.5
2	5.9	0
3	6.7	0
4	7.2	0
5	8.5	0
6	9.2	0
7	10.2	0
8	11.3	0

Table 60

With 10^{-4}M SHS + 0.005M NaCl Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	3.6	0
2	5.9	0
3	6.6	12.75
4	7.3	10.75
5	8.4	12.0
6	8.6	0
7	9.9	0
8	11.2	0

Table 61

With $10^{-4}\underline{M}$ SHS + $10^{-3}\underline{M}$ NaCl Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	3.7	8.25
2	6.0	0.6
3	6.7	1.5
4	7.2	0
5	8.0	2.5
6	9.4	0
7	10.3	0.25
8	11.4	0

Table 62

With $10^{-4}\underline{M}$ SHS + $10^{-3}\underline{M}$ NaCl Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	3.6	6.75
2	6.0	0.6
3	6.8	2.75
4	7.3	0
5	7.8	0
6	9.0	2.0
7	9.5	0
8	9.8	1.5
9	11.1	0

Table 63

With 10^{-4} *M* SHS + 10^{-4} *M* NaCl Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	3.7	7.25
2	6.1	2.5
3	6.7	2.65
4	6.9	0
5	7.5	1.5
6	7.8	0
7	8.5	0
8	8.8	0.6
9	10.1	0
10	11.5	0

Table 64

With 10^{-4} *M* SHS + 10^{-4} *M* NaCl Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	3.7	7.5
2	6.1	2.5
3	6.8	3.5
4	7.0	0
5	7.4	2.25
6	7.6	0.25
7	8.3	2.25
8	9.7	1.5
9	11.2	0

Table 65

With 10^{-3}M SDS + 1.0M NaCl Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	5.2	10.0
2	6.1	10.0
3	10.6	0

Table 66

With 10^{-3}M SDS + 0.1M NaCl Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	5.2	10.0
2	6.3	10.0
3	10.6	0

Table 67

With 10^{-4}M SHS + 10^{-5}M $CaCl_2$ Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	3.7	6.25
2	6.1	0
3	6.9	0.75
4	7.3	0
5	8.4	0
6	9.3	0.6
7	10.1	0.75
8	11.4	0

Table 68

With $10^{-4}\underline{M}$ SHS + $10^{-5}\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	3.6	6.5
2	6.2	0
3	6.9	3.0
4	7.3	1.5
5	7.5	0
6	8.0	0.25
7	9.1	0
8	9.3	0.6
9	9.8	1.5
10	11.2	0

Table 69

With $10^{-4}\underline{M}$ SHS + $10^{-6}\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	3.7	8.25
2	6.1	3.0
3	6.9	3.0
4	7.6	0
5	8.1	0
6	8.7	2.75
7	10.2	2.0
8	11.4	0

Table 70

With $10^{-4}\underline{M}$ SHS + $10^{-6}\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	3.6	8.0
2	6.2	2.0
3	7.0	9.5
4	7.3	2.25
5	7.7	2.75
6	8.4	0.6
7	8.7	3.25
8	10.0	0
9	11.3	0

Table 71

With $10^{-3}\underline{M}$ SDS + $1.0\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	5.4	15.0
2	8.2	0
3	11.3	0

Table 72

With $10^{-3}\underline{M}$ SDS + $0.1\underline{M}$ $CaCl_2$ Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	4.6	12.5
2	8.7	2.5
3	10.7	0
4	11.5	25.0

Adsorption Isotherms of Alkyl Sulfate Collectors on Hematite in Various Systems

Table 73

For SHS; pH = 3.8; Pulp Pretreatment Temp. = 25°C

Test No.	Conc. ($\underline{M} \times 10^{-5}$)	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	10.0	10.25
2	5.0	7.75
3	1.0	1.5

Table 74

For STS; pH = 3.8; Pulp Pretreatment Temp. = 25°C

Test No.	Conc. ($\underline{M} \times 10^{-5}$)	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	20.0	2.0
2	10.0	1.5
3	5.0	0.9
4	1.0	0.62

Table 75

For SDS; pH = 3.8; Pulp Pretreatment Temp. = 25°C

Test No.	Conc. ($\underline{M} \times 10^{-5}$)	Adsorption (Moles x 10^{-5}/gm Fe_2O_3)
1	100.0	12.5
2	50.0	12.5
3	10.0	0.75
4	5.0	1.0
5	1.0	0.15

Adsorption of Alkyl Sulfate Collectors on Silica as a Function of pH in Various Systems

Table 76

With 10^{-4} M SHS Present; Pulp Pretreatment Temp. = 25°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm SiO_2)
1	1.4	2.0
2	2.9	0.75
3	3.8	0.25
4	4.8	0
5	5.9	0
6	6.6	0
7	9.3	0
8	10.5	0
9	11.4	0
10	12.1	0

Table 77

With 10^{-4} M SDS Present; Pulp Pretreatment Temp. = 25°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm SiO_2)
1	0.5	0
2	1.0	0
3	1.8	2.5
4	3.1	0
5	3.8	1.25
6	5.4	0
7	5.8	0
8	6.8	1.25
9	6.9	0
10	7.3	1.25
11	7.8	1.25
12	8.4	0
13	9.8	0
14	10.4	0
15	11.1	0
16	11.8	2.5
17	11.9	3.75
18	13.1	1.25

Table 78

With 10^{-3}M SDS Present; Pulp Pretreatment Temp. = 25°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm SiO_2)
1	1.7	0
2	2.5	0
3	3.6	0
4	4.5	0
5	5.1	0
6	6.5	0
7	7.2	0
8	8.1	0
9	10.4	0
10	11.4	0
11	12.1	0

Table 79

With 10^{-4}M SDS + 1.0M NaCl Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm SiO_2)
1	1.7	0
2	5.8	0
3	9.0	5.0
4	10.0	0
5	11.3	10.0
6	12.3	7.5

Table 80

With 10^{-4}M SDS + 0.1M NaCl Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm SiO_2)
1	1.8	0
2	5.7	0
3	9.0	0
4	11.4	5.0
5	12.3	0

Table 81

With 10^{-4} M SHS + 10^{-5} M $CaCl_2$ Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm SiO_2)
1	10.1	0
2	10.6	0.25
3	11.0	0.6
4	11.5	0
5	11.9	0
6	12.1	0

Table 82

With 10^{-4} M SHS + 10^{-5} M $CaCl_2$ Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm SiO_2)
1	9.7	0
2	10.7	0
3	11.0	0
4	11.5	0
5	11.7	0
6	12.1	0

Table 83

With 10^{-4} M SHS + 10^{-6} M $CaCl_2$ Present;

Pulp Pretreatment Temp. = 25°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm SiO_2)
1	10.0	0
2	10.7	0
3	11.1	0
4	11.5	0
5	11.7	0
6	12.1	1.5

Table 84

With 10^{-4} M SHS + 10^{-6} M $CaCl_2$ Present;

Pulp Pretreatment Temp. = 95°C

Test No.	pH	Adsorption (Moles x 10^{-5}/gm SiO_2)
1	10.0	0
2	10.5	0
3	11.1	0
4	11.5	0
5	11.8	0
6	12.1	0