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ION EXCHANGE: ZEOLITES

See **III / ZEOLITES: ION EXCHANGERS**

ION FLOTATION

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Introduction

Sebba published a paper in 1959 in which he discussed a new method (ion flotation) for recovering solute from dilute solutions by adding surfactant, with subsequent adsorption of the solute onto bubbles. The principles of the process and the characteristics of the solute–surfactant product formed in solution were discussed in his monograph on ion flotation published in 1962. The method rapidly became popular and researchers in several countries have studied various aspects of the separation of metallic ions, trace elements, molecules, inorganic anions and organic matter from aqueous solutions. Many laboratory-scale studies have been carried out, most of them aimed at development, analytical applications, water purification, resource recycling, removing radionuclides from solutions, and recovering metals from sea water.

A comprehensive development of all aspects of the subject was presented in a monograph on adsorptive bubble separation techniques, edited by Lemlich in 1972, in which details and applications of ion and precipitate flotation methods were reported by Pinfold.

The research group directed by Grieves made an important contribution to the theoretical and applied aspects of ion and precipitate flotation during the 1960s, particularly on wastewater treatment. They showed that flotation efficiency of long-chain surfactants was the result of physicochemical aspects of particle growth and dispersion. But the adsorption of surfactant onto the solid and gas phases was identified as a factor limiting bubble-particles attachment in some cases of ion flotation.

The adsorption of the surface-active solutes to the gas–liquid interface was studied by Rubin. An analysis based on the Gibbs and Langmuir isotherm and on an originally developed approach of long-chain ion adsorption in a solution containing several surface-active species was used to determine the effect of their concentrations on the ratio of distribution coefficients. This author also described the kinetic parameters for ion and precipitate flotation.

A detailed review of the precipitate and adsorbing colloid flotation technique with a comprehensive literature review appears in the monograph published in 1983 by Clarke and Wilson.

Golman has given a qualitative description of the chemical and kinetic aspects of ion flotation and some industrial applications, including the removal of molybdenum from solutions of hydrometallurgical flowsheets. He has also given methods for treating foam products and purifying process residual solutions.

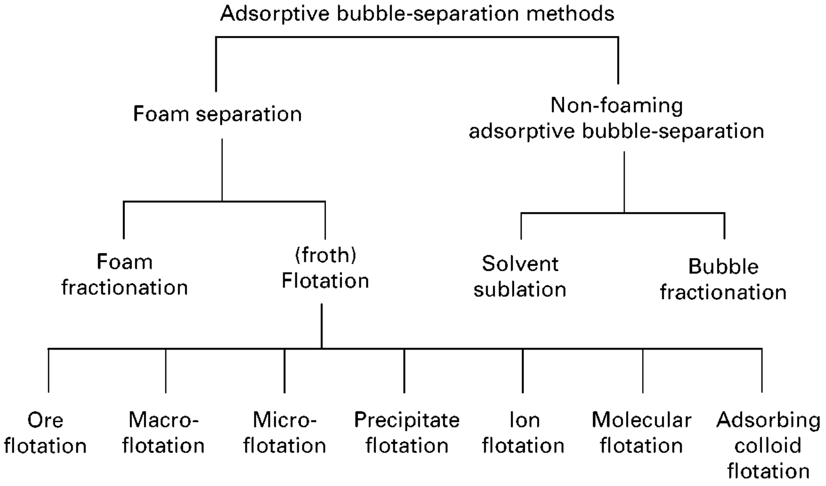

Figure 1 Schematic classification of the adsorptive bubble-separation techniques. (Reproduced with permission from R Lemlich (1972) *Adsorptive Bubble Separation Techniques*. New York: Academic Press. Copyright.)

Relatively few studies on this subject have been published recently. They focus mainly on extending the applications of the method. The progress made in column flotation techniques, especially with bubble generation systems, offers hydrodynamic conditions favourable for ion flotation. Filippov has reported on the results of recent pilot-scale studies applying this technique to precipitate and ion flotation. It was demonstrated that aggregate formation and destruction under low dissipation energy are the parameters controlling precipitate flotation. The combined use of column and bubble spargers in ion flotation provided a removal rate for metals equivalent to that of laboratory-scale trials.

Phenomenology and Classification

Separation by adsorption onto bubbles is based on the difference between the surface activities of the solute species. These species can be ionic, molecular, or colloidal, and their adsorption onto the bubble–liquid interface depends on their surface-active, adhesion or electric properties. A species that is not adsorbed onto bubbles can be made to do so by adding a surfactant to the solution.

The classification of methods based on these separation phenomena are shown in **Figure 1**. Lemlich called these processes ‘adsbubble (adsorptive bubble) separation methods’, while the term ‘adbubble method’ was recommended by Sasaki, since the method involves both adsorption and adhesion. The classification of these techniques in Figure 1 is based on the formation of the foam, which leads to two main groups:

- foam adsorptive separation and
- non-foaming bubble separation.

The nature of the entity is introduced later.

The Golman classification based on the phenomena at the various levels of process leads to another classification of ion recovery process (**Table 1**). This classification take into account:

- the type of phase that accumulates the floated species: foam, scum, organic or aqueous phase;
- the nature of the components to be adsorbed onto the bubble surface: ions or molecules, particles of the precipitate or carrier; and
- the collector use to modify the hydrophobic properties of the entities

Ion Flotation

Definition

Ion flotation, developed by Sebba, is a surface-inactive separation method that involves the removal of ions or molecules (*colligend*) from aqueous solution by adding surfactant, that is adsorbed onto the surface of rising bubbles. The surfactant–colligend product (*sublat*) may be formed in bulk solution or

Table 1 Classification of ion-recovery method

Flotation	*Flotation*			
	Froth	*Foam*	*Solvent sublation*	*Bubble fractionation*
Adsorptive		Without collector With collector		
Precipitate		Hydrophobic Hydrophobized		
Carrier		Hydrophobic Hydrophobized		

only at the higher concentrations produced by preferential adsorption on the bubble surface. The process is called *adsorption* ion flotation if the sublat is a soluble complex or a pair of ions. The process is *adhesion* ion flotation if the sublat forms a new phase in aqueous solution. A hydrophobic product (*scum*) is formed at the surface of the solution by destruction of the rising bubbles.

The formation of foam is not necessary for ion flotation. The hydrophobic nature of the scum makes it stable on the solution surface. A foam thin-layer phase may be needed to isolate the scum from the liquid phase and to evacuate it later to avoid it redissolving. Stable foam is a factor limiting the application of ion flotation, because it requires less foam formed or a lower gas rate. Solution entrainment also decreases the colligend concentration in the foam.

If the formation of a foam during ion flotation is undesirable or impossible (i.e. recovery of organic ions or quantitative separation), the process of *solvent sublation* is used. This method involves spreading a thin immiscible organic solvent layer on the surface of the water causing dissolution of the floating sublat.

Theory

There are several ways to describe ion flotation and to determine the quantity of surfactants required for optimal separation. One considers the bubble surface to be an ion exchanger owing to surfactant adsorption. The charge created is compensated for by the adsorption of inactive ions of opposite charge. Jorne and Rubin assumed that the radius of the hydrated ions determined the maximum approach of opposite ions to the bubble surface, based on the theory of a double electrical layer. Their theoretical calculations were confirmed experimentally. Another approach highlights the stability constants of soluble compounds (complexes and pairs of ions) formed by the surfactant with the colligend and an oppositely charged ion, according to Moore and Philipps. Some believe that a solid phase is formed (assumed to be two-dimensional) in the adsorption layer on the bubble surface. These assumptions mostly concern the adsorption mechanism of ion flotation.

Sebba and Golman used the product of the activities of the collector and colligend (L_A) to explain adhesion. The equilibrium of the system is determined by the constant of stability of sublat K_A and the solubility of its molecular form S_{AM}, when $L_A = K_A S_{AM}$. If we assume that a sublat flotation occurs as a colloid rather than molecules, the fraction P of the stoichiometric ratio Φ of collector/colligend molar concentrations is given according to Golman by:

$$P = R + \frac{l}{m}\sqrt[m]{\frac{L_A}{f_{RX}^{m} f_A^{l} (1-R)^{l} C_A^{m+l}}} \qquad [1]$$

where R is the rate of colligend recovery; f_{RX}, f_A are the surfactant RX and colligend A activity coefficients respectively; C_A is the colligend concentration; m and l are the stoichiometric coefficients of the reaction of sublation of A by RX.

The parameter $(L_A)_{P/R}$ calculated from this formula allows the deduction of the value of L_A that is needed to obtain a recovery R for a given Φ. This formula does not take into consideration changes in the ionic strength I with collector concentration. However, for the characteristic colligend concentrations and for Φ being practically stoichiometric the parameter I does not limit the application of this approach. This was confirmed by Golman for the ion flotation of various species.

The influence of the surface-active species concentration and solubility product P_S of sublat (P_S = constant for I = constant) on the recovery of the colligend and the residual surfactant concentration is given in **Figure 2**. This confirms the experimental results. It is preferable to carry out ionic flotation in the concentration ranges of the collector so that $P = 1$ (values of Φ are stoichiometric). Colligend recovery when $P < 1$ is often reduced. The

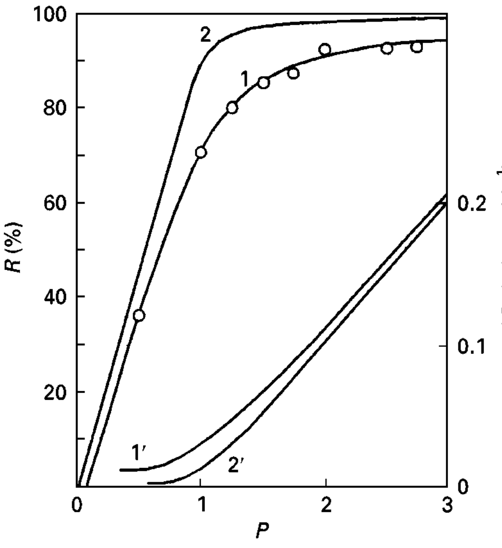

Figure 2 Colligend recovery R (1, 2) and surfactant residual concentration $C_{(RX)r}$ (1′, 2′) vs. surfactant consumption for a given sublat solubility product P_s: 1,1′ – $P_s = 10^{-9}$, 2,2′ – $P_s = 10^{-10}$. Solid lines, calculated results from eqn (1); ○, experimental results of ion flotation of ReO_4^- with laurylammonium chloride, $L_A = 3.9 \times 10^{-7}$. (Adapted from AM Golman (1982) *Ionnaya Flotatsiya*, p. 42. Moscow: Nedra.)

considerable residual concentration of collector in the bulk solution when $P > 1$ decreases the process efficiency (economic). This makes it difficult to reuse a solution without purification and/or environmental problems. The excess collector also prevents flotation because of secondary adsorption onto bubbles and sublat surfaces if the sublat is solid, as demonstrated by Grieves and Golman.

Colligend : Collector Ratio

Ion flotation operates with dilute solutions of the colligend (10^{-5} to 10^{-3} mol L^{-1}). Higher colligend concentrations require significant collector consumption, increasing the operation costs. The ratio Φ of collector and colligend molar concentrations is one of the main parameters of ion flotation. The changes in the amount of colligend removed with Φ is shown in **Figure 3**, which are typical of ion-flotation systems.

As noted by Pinfold, the ratio Φ required for complete flotation must be at least stoichiometric (Φ_{st}). This is true for the adhesion mechanism of ion flotation, but with adsorption, the amount of collector that can float without sublation depends on the bubble residence time in the liquid. The colligend cannot be completely removed in this case with a stoichiometric Φ. The experimental results of Doyle, available in the literature, show that slightly more than stoichiometric amounts ($P = 1.1$–1.2) of sodium dodecyl sulfate were needed to reduce the heavy metals ion concentration to very low levels. Moreover, the curve behaviour around point $P = 1$ in Figure 3 could indicate the mechanism of ion flotation.

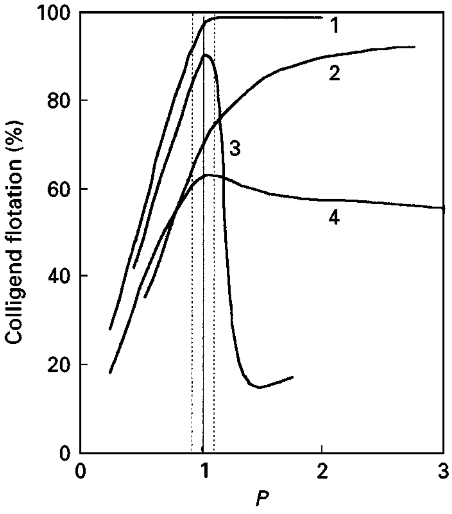

Figure 3 Dependence of the flotation of various colligends on the fraction (P) of collector : colligend ratio (Φ): (1) Ge^{3+} + tetradecylammonium chloride ($\Phi_{st} = 2$); (2) ReO^{4-} + laurylammonium ($\Phi_{st} = 1$); (3) Cr^{6+} with hexadecylammonium bromide ($\Phi_{st} = 1.04$); (4) Ga^{3+} + amide oxime ($\Phi_{st} = 3$). (Adapted respectively from: (1,2) AM Golman (1983) *Fiziko-khimitcheskie Aspekty Ionnoi Flotatsii*, p. 245, Moscow: Nauka; (3) *The Chemical Engineering Journal* 9: R Grieves Foam Separations: A Review, 93, Copyright (1975), with permission from Elsevier Science; (4) with permission from A Masuyama et al. *Industrial Engineering Chemical Research* 29: 290, Copyright (1990) American Chemical Society.)

Role of Electrolytes and Anions

The role of electrolytes is significant during the collector-colligend and sublat–bubbles interaction. Their role must be taken into account because of their significant quantities in real industrial solutions. Electrolytes modify the ionic strength and can react with the collector. For I = constant, two cases are possible:

1. The opposite-charged ion forms a soluble product with the collector. The separation is more selective for higher colligend and for low opposite-charged ion concentrations. A higher collector concentration than that required by Φ also renders ion flotation more efficient.
2. The collector–colligend interaction product is insoluble. A critical concentration of the opposite ion can be defined, below which it does not react with the collector and consequently does not influence further colligend recovery.

Changing the ionic strength by adding NaCl allows the selective separation of metal oxyanions (MeO^{4-} or MeO^{2-}) with hexadecyldimethylbenzylammonium chloride as collector (**Figure 4**). The recovery of oxyanion flotation as a function of p[NaCl] illustrates the phenomena described above.

The change in ionic strength of the medium caused by adding anions reduces the effectiveness of ion flotation. The flotation of dichromate with a quaternary amine (adhesion mechanism) is blocked in the sequence, according to Grieves: $PO_4^{3-} > SO_4^{2-} > Cl^-$. The recovery of $Fe(CN)_6^{4-}$ with a cationic collector is influenced by: $CN^- > NO_3^- > Cl^- > SO_4^{2-} > CO_3^{2-} > PO_4^{3-} > P_2O_7^{4-}$. This contradiction can be explained by the process taking place in each case.

The foam flotation of dichromate is controlled by the preliminary formation of a solid phase followed by adsorption onto bubbles (similar to precipitate flotation). The adsorption of differently charged ions influences surface hydration of the bubbles and the precipitate, the importance of which is directly related to the charge of the anion. Ferricyanide flotation is by solvent sublation. As was noted by Pinfold, the smaller ionic radius of the anion, the more effective the collector competes with the colligend. The use of 2-octanol to collect the sublat on the solution

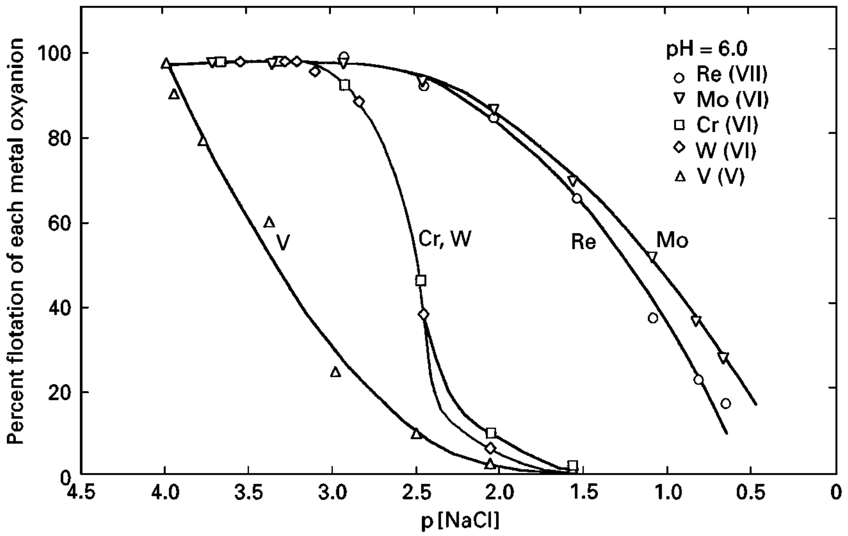

Figure 4 Effect of the negative logarithm of the sodium chloride concentration on the percentage flotation of each of five metal oxyanions. (Reprinted from *The Chemical Engineering Journal* 9: R Grieves Foam Separations: A Review, 93, Copyright (1975), with permission from Elsevier Science.)

surface can cause solvent to dissolve and become adsorbed onto the bubble surface instead of the collector. Under these conditions the lower charged anions neutralize the adsorbed collector, so that it is no longer available to float the colligend.

pH

Ion flotation is particularly sensitive to the pH because the pH determines the nature and the charge of the collector (the degree of ionization) and the colligend (hydrolysis), and causes variations in the ion-collecting mode. Pinfold also notes that the following phenomena that can take place when the pH changes:

- colligend hydroxides may form, and precipitate flotation may take place instead of ion flotation;
- extreme values of pH block flotation because the ionic strength is higher;
- the stability of scum could be affected because of sublat redispersion in the solution.

Temperature

The temperature influences all aspects of ion flotation, i.e. the collector and sublat solubility, the sublat particle size and the flotation results. Its role were confirmed by Grieves for the flotation of Cr^{6+} at $pH = 4.1$ with quaternary amine salts with hydrocarbon chains of C_{14}, C_{16} and C_{18}. The collector used acted as a precipitant, dispersing and flocculating agent depending on the temperature, determining the orientation of the collector molecules adsorbed on the sublat surface. The surfactant also acted as foaming agent because of the free collector adsorbed on the bubbles.

Optimal metal removal with C_{16}- and C_{18}-amine salts occurred with $\Phi = 1.04$ and 33 or 40°C. The abrupt drop in removal rate at higher values of Φ was explained by excess surfactant adsorbing to the particles, stabilizing them and preventing further aggregation. One of the most significant conclusions deduced from these experiments is that the particles of the precipitate > 25 μm are completely removed from solution, while almost no particles < 7 μm are floated.

Precipitate Flotation

According to Pinfold, precipitate flotation includes all processes in which an ionic species is precipitated in the liquid phase and is subsequently removed by attachment to the bubble surface. It is difficult to clearly distinguish between 'ion flotation' and 'precipitate flotation' when a collector is used as a precipitation agent.

If the colligend is first precipitated by a non-surface-active ion and made hydrophobic by adsorption of a surfactant, the process is termed *precipitate flotation of the first kind*. Many studies have been carried out on the removal of metal ions from aqueous solution (i.e. sea water) by this method. Heavy metals are generally precipitated with an alkali as the hydroxide and then removed by flotation with an ionic collector. The other insoluble salts (sulfide, carbonate, sulfate) can be precipitated.

The *precipitate flotation of the second kind* uses no surfactant for bubble-particle attachment because it suggests that the solid phase formed by interaction of two hydrophilic species (colligend and precipitation agent) is hydrophobic. The following precipitants have been used for various metal ions: benzoinoxime (Mo, Cu), benzoylacetone (U), α-furyldioxime (Ni), hydroxyquinoline (Cu, Zn, U), α-nitroso-β-naphthol (Ag, Co, Pd), dodecylpyridinium with a collector (Sr, V), etc.

Kinetics

Ion flotation controlled by adhesion is a precipitate-like flotation because the sublat formed is a solid phase that can also be flocculated by adding active chemical agents or by the action of the collector. The two ionic flotation modes (adsorption and adhesion) may be distinguished at the level of particle–bubble interaction, depending on the nature of the sublat.

- The sublat formed is an ionic pair or a soluble complex (adsorption): the adsorption activity of these species on the bubbles determines the effectiveness of the process.
- The sublat is formed in the liquid phase as particles of 10^{-3} to 10^{-1} μm: the interaction of the sublat and the bubbles is controlled by the diffusion of the particles in the hydrodynamic fields of the bubbles.
- The sublat is a precipitate with micron- or millimetre-sized particle: the interaction results in sedimentation of the particles of negligible mass on the bubbles if the surface forces support the attachment of the entities.

The time necessary for 90–99% colligend recovery at colligend concentrations of 10^{-5} to 10^{-2} mol L^{-1} indicates that sublat flotation as a precipitate is kineticically preferable than flotation of the molecules (**Figure 5**). The flotation mechanism was concluded from independent experiments on the solubility product, microscopy, separation of the precipitated phase by centrifugation and filtration.

Few studies on the kinetics of ion flotation are published, while there are many papers on mineral particle flotation. However the kinetic parameters of the process determine the practical applications of flotation because they determine the scale-up procedure adopted.

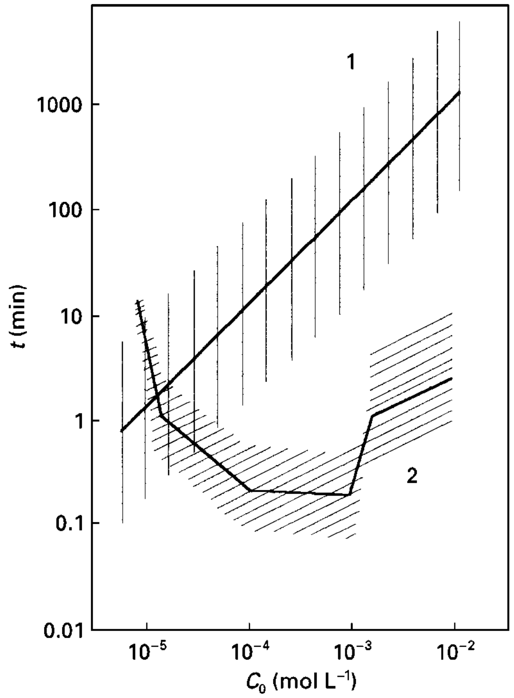

Figure 5 Comparison of the kinetic of adsorption and adhesion mechanism of ion flotation. (1) Adsorption mechanism; (2) adhesion mechanism. (Adapted from AM Golman (1982) *Ionnaya Flotatsiya*, p. 29. Moscow: Nedra.)

Colligend	*Collector*
Ba^{2+}	Laurylsulfonate-Na
$Ag(S_2O_3)^-$	Cetyldiethylbenzylammonium-Br
$UO_2(CO_3)_3^{4-}$	Cetyltrimethylammonium-Br
$H_3W_6O_{21}^{3-}$	Laurylammonium-Cl
$H_3Mo_7O_{24}^{3-}$	Cetylpyridinium acetate
	Cetyltrimethylammonium-Br
	Amine-C14
Ge^{3+}	Laurylammonium-Cl
	Cetyltrimethylammonium-Br

Apparatus: Future Developments

Almost all ion flotation tests are carried out in cells (batch or continuous mode) equipped with a sintered-glass device to generate bubbles. The use of the column-type cells allows the user to: vary the introduction point of the collector and feed solution containing the colligend; vary the height of the foam; carry out sampling and/or *in situ* measurements if radioactive 'tracers' are used.

The most recent bubble-generating systems make column flotation a flexible tool for ion flotation.

A study of sublat formation and its structural organization showed that a column 75 mm in diameter and 3 m high could be used for ion flotation (Cr^{6+}) and for precipitate flotation (molybdenum). The bubble diameter determined the efficiency of separation by ion and precipitate flotation because of collision probability and aggregate stability in the microturbulence created by the rising bubbles. The flotation with small bubbles as in the dissolved-gas technique increases the collision probability. However, the low feed-flow rate of the process is a limiting parameter because of the low velocity of small rising

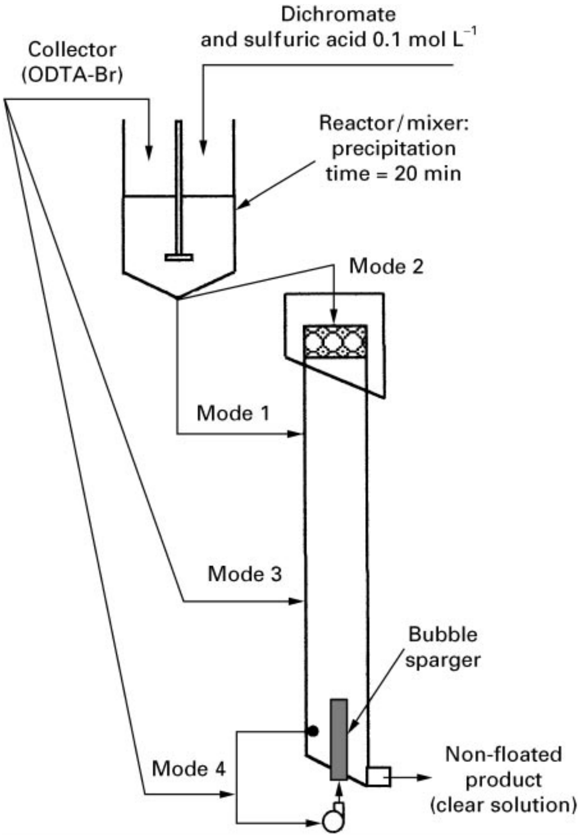

Figure 6 Ion flotation modes using column for Cr^{6+} recovery with ODTA-Br. Mode 1: precipitation–flotation. Mode 2: foam fractionating. Mode 3: ion flotation. Mode 4: precipitation on bubbles. (Reprinted from Filippov LO *et al*. Physicochemical mechanisms and ion flotation possibilities using column for Cr^{6+} recovery from sulphuric solutions, *International Journal Mineral Processing* 51: 229, Copyright (1997), with permission from Elsevier Science.)

bubbles. In addition, the flotation mechanism in this kind of technique, in which several small rising bubbles are trapped in a large precipitate floc structure, can cause transfer of the liquid present in the aggregate to the froth and reduce the separation efficiency.

Ion Flotation in a Column

The ion flotation of Cr^{6+} from sulfuric acid solutions (pH 1.5–2.0) with octadecyltrimethylammonium bromide (ODTA-Br) as collector is particularly difficult because a single chemical acts as precipitating, flocculating, dispersing and frothing agent. This is in addition to the problems of floating an element of negligible mass. It is thus nearly impossible for the precipitate to become adsorbed on bubbles because of an electrical charge of the same sign (owing to free collector) on the bubbles and precipitate particles. Several modes of ion flotation have been tested on a pilot scale (**Figure 6**).

In the classical mode of ion flotation (precipitation–flotation as described by Grieves), only the 200–240 μm diameter bubbles provide a low chromium recovery of 56.2–60.8%. An exceptionally stable, loaded froth with the liquid (7.0–19.0%) was carried over, which decreased the separation efficiency (**Table 2**). Some column/bubble generator assemblies can be used to solve the problems of bubble-precipitate electrostatic repulsion and collision. It has thus been possible to develop a new mode of ion flotation in which the chromium solution is introduced directly at the feeding point of column and the collector is introduced to the bubble generator. The strong surfactant properties of the collector caused to be adsorbed on the bubbles so that the chromium was precipitated on the gas phase. This new method gives about 81.6% Cr^{6+} removal by column flotation for a $\Phi = 1.2$ and a liquid residence time of 15–20 min. Retreatment of the solution can increase the total Cr recovery to 91.6%, with a Cr residual concentration of 4.5 mg L^{-1}, which corresponds to separation results by filtration.

Precipitate Column Flotation

The limiting conditions for molybdenum metal–organic precipitate flotation in columns are owing to aggregate stability under the turbulence created by upward movement of bubbles, which depends directly on the average bubble diameter. Pilot-scale flotation studies revealed the fundamental influence of the average bubble diameter and dissipation energy on molybdenum recovery in the form of precipitate obtained with the collector α-benzoin oxime for a molar concentration ratio of 2. It was therefore necessary to identify a bubble-size distribution and the gas hold-up in the column to ensure the flotation of low hydrophobic precipitate flocs, as they are extremely brittle with very low values of dissipated energy (0.01–0.05 W kg^{-1}). Destruction is conditioned by the aggregation mechanism (cluster–cluster type) and not only causes mean floc size to decrease from 150–350 μm to 30–50 μm, but also produces very fine particles that could elude collision with bubbles. Bubble spargers (Microcel, Flotaire, Imox) tested on a pilot scale provided the required values of these parameters for efficient column flotation (recovery up to 95%) of the precipitate for low superficial gas ($J_g = 0.22$–0.55 cm s^{-1}) and feed flow rates ($J_l = 0.19$–0.47 cm s^{-1}). An adjustment of the J_g/J_l ratio to optimal hydrodynamic conditions in countercurrent pilot column corroborated laboratory-scale tests in the cell equipped with a fine porosity frit (No. 4).

Table 2 Main results on the hexavalent chromium removal by column flotation according to Figure 6[a]

Ion-flotation mode	*Chromium concentration in initial solution*		*Chromium residual concentration*	*Chromium removal (%)*	*Stoichiometric ratio* (Φ)	*Average bubble diameter*	*Liquid entrainment* (%)
	(mg L $^{-1}$*)*	*(mol L* $^{-1}$*)*	*(mg L* $^{-1}$*)*			*(mm)*	
Mode 1	52.3	10^{-3}	22.9	56.2	2.0	0.23	12.5
Precipitation–flotation	52.3	10^{-3}	20.5	60.8	2.0	0.21	7.5
	52.25	10^{-3}	25.7	50.4	2.0	0.21	19.0
	52.24	10^{-3}	21.0	59.8	1.2	0.22	6.6
Mode 2	52.52	10^{-3}	17.7	66.3	2.0	—	4.5
Foam fractionating							
Mode 3	32.1	6×10^{-4}	14.8	53.9	1.5	0.29	8.3
Ion flotation	52.38	10^{-3}	33.0	37.0	1.2	0.27	6.2
Mode 4	23.6	4×10^{-4}	8.0	66.1	1.2	0.36	4.2
Precipitation on bubbles	34.9	6×10^{-3}	8.2	76.5	1.2	0.38	1.0
	52.33	10^{-3}	8.7	83.0	2.0	0.33	1.7
	52.33	10^{-3}	10.1	80.7	1.2	0.26	0.8
	Retreatment of tail solution		4.4	91.6		0.32	—

[a](Reprinted from Filippov LO *et al.* Physicochemical mechanisms and ion flotation possibilities using column for Cr^{6+} recovery from sulphuric solutions, *International Journal Mineral Processing* 51: 229, Copyright (1997) with permission from Elsevier Science.)

Other Ion Flotation Related Processes

Bubble Fractionation

This is the partial separation of components within a solution by the selective adsorption of surfactants, colloid or ultrafine particle species onto the bubble. The effect of separation is demonstrated by a concentration gradient along the column-like cell that allows removal of a colligend-rich solution from the top and depleted solution from the bottom of the cell. Separation efficiency clearly decreases with increasing column diameter as a result of axial diffusion of rising bubbles, which breaks up the concentration gradient.

Adsorbing Colloid Flotation or Carrier Flotation

This consists of the preliminary capture of colligend by the carrier particles (by adsorption, absorption, or co-precipitation), followed by charged-bubble flotation. Ion-exchange resin, activated charcoal, or the precipitate particles can be used as a carrier. The carrier particles can have flotation properties or be made hydrophobic by adding collector.

Molecular Flotation (Koisumi)

This is the recovery of molecules using a surfactant. The name molecular flotation is use for all flotation processes that involve the recovery of the molecular colligend or those analogous to ion flotation.

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