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Foam Separation of Nickel

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In this report we discuss the results of our theoretical and experimental investigations on the thermodynamics of foam separation for nickel; the technique of foam separation is applied on a large scale for mineral ore enrichment.

In foam separation, gas bubbles generated in solution are used to extract matter from an aqueous phase into the foam. The aqueous phase initially contains the mixture of solutes to be separated and a surfactant. The latter can be adsorbed at the gas/liquid interface, or, if the surfactant is of an opposite charge from the solute, a surfactant–solute ion associate may be formed and adsorbed at the interface. In this latter case the solute can be extracted into the foam.

According to the principle of foam separation and by using sodium dodecylsulfate (SDS) as a collector, the relative adsorption of Ni^{2+} in the mutual system can be determined. Thus, the foam separation method is simple and rapid and is applicable to the flotation and determination of trace Ni^{2+} in water.

Many publications on foam separation are typically for practical purposes.[1–4] However, in spite of the practical significance of foam separation, the thermodynamic foundation of this technique has so far been insufficiently elaborated.

We present here a simple method of estimating the adsorption isotherm parameters of heavy metal cations (in particular, Ni^{2+} cations) at the air–water interface.

As a basis for calculation of relative adsorptions, the adsorption equation is used for an aqueous solution containing electrolytes, including ionic surfactants,[5] equation (1),

$$-\frac{\mathrm{d}\sigma}{RT}=\sum_{i=1}^{n-2}\sum_{j=1}^{n-2}\Gamma_{j(n)}\left(\frac{\delta_{ij}}{c_i}-\frac{z_i z_j}{z_{n-1}\sum\limits_{k=1}^{n-2}c_k z_k}-\frac{A z_i z_j}{2\sqrt{2}\sum\limits_{k=1}^{n-2}z_k(z_k-z_{n-1})c_k}\right)\mathrm{d}c_j \qquad (1)$$

where σ is the surface tension, $\Gamma_{j(n)}$ is the relative adsorption, c_i, z_i are the concentration and charge of ion i, respectively, R is the gas constant, T is the temperature, σ_{ij} is Kronecker's symbol and A is the Debye–Hückel constant.

We applied this equation to the particular system: H_2O–Na^+,Ni^{2+}||DS^-,SO_4^{2-} (DS^-, dodecylsulfate ion).

Thus, we obtained equation (2):

$$-\frac{1}{RT}\left(\frac{\partial\sigma}{\partial c_1}\right)_{c_2,c_3}=\Gamma_1\left(\frac{1}{c_1}+a-4b\right)+\Gamma_2(2a-24b)+\Gamma_3(3b-a)$$

$$-\frac{1}{RT}\left(\frac{\partial\sigma}{\partial c_2}\right)_{c_1,c_3}=\Gamma_1(2a-24b)+\Gamma_2\left(\frac{1}{c_2}+4a-64b\right)+\Gamma_3(8b-2a)$$

$$-\frac{1}{RT}\left(\frac{\partial\sigma}{\partial c_3}\right)_{c_1,c_2}=\Gamma_1(3b-a)+\Gamma_2(8b-2a)+\Gamma_3\left(\frac{1}{c_3}+a-b\right)$$

$$a\equiv\frac{1}{2\sqrt{c_1+2c_3-c_2}};\ b\equiv\frac{1.15}{2\sqrt{6c_1+16c_3-2c_2}}$$

$$\mathrm{Na}^+=1,\ \mathrm{DS}^-=2,\ \mathrm{Ni}^{2+}=3 \qquad (2)$$

The method of foam separation is applied to dilute electrolyte solutions, which essentially permits us to simplify the equations describing the foam separation lines (lines in the concentration space which reflect a change in composition of solution during the foam separation processes) using the adsorption of the ions, equation (3).

$$\frac{\mathrm{d}C_{\mathrm{Ni}^{2+}}}{\mathrm{d}C_{\mathrm{DS}^-}}\simeq\frac{\Gamma_{\mathrm{Ni}^{2+}}}{\Gamma_{\mathrm{DS}^-}} \qquad (3)$$

To sum up, knowledge of the adsorption of ions as a function of concentration permits the prediction of the direction of the foam separation process.

The concentration space of the mutual system: H_2O–Na^+,Ni^{2+}||DS^-,SO_4^{2-} is given in Fig. 1. This is a pyramid at the base of which Ianëke's square lies.[6] The surface tension was determined by the optical method[7] (the method of reflection of a laser beam from a liquid meniscus). In Fig. 2, a graph is given showing the dependence of surface tension on concentration, which corresponds to a composition of solutions in the pyramid where the addition of $Ni(DS)_2$ is 10 mol%.

The concentration of the dissolved salts was varied from 0 to 10^{-3} mol dm^{-3}. It was found that the relative adsorption of Ni^{2+} and DS^- ions is positive, whereas the relative adsorption

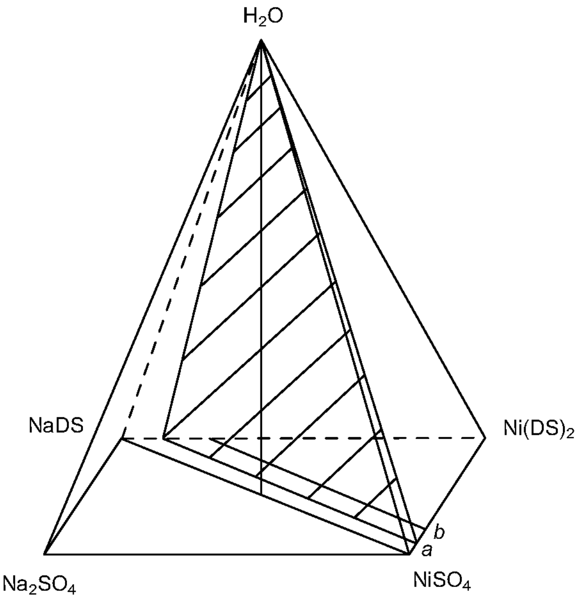

Fig. 1 Composition of solutions in the mutual system H_2O–Na^+,Ni^{2+}||DS^-,SO_4^{2-}; *a*, 10 mol% $Ni(DS)_2$; *b*, 20 mol% $Ni(DS)_2$.

of the remainder of the ions is either negative or approaches zero. It follows that at the air–water interface DS^- (and Ni^{2+}) ions are accumulated (Fig. 3).

This allows for removal of nickel(II) from the aqueous solution by foam separation using an anionic surfactant.

We have also obtained experimental data about the change of aqueous solution compositions in the mutual system: H_2O–Na^+,Ni^{2+}||DS^-,SO_4^{2-} during the process of foam separation. Consumption of SDS for achieving LPC are given in Table 1.

The possibility of using the foam separation method for the removal of Ni^{2+} ions from water has therefore been confirmed.

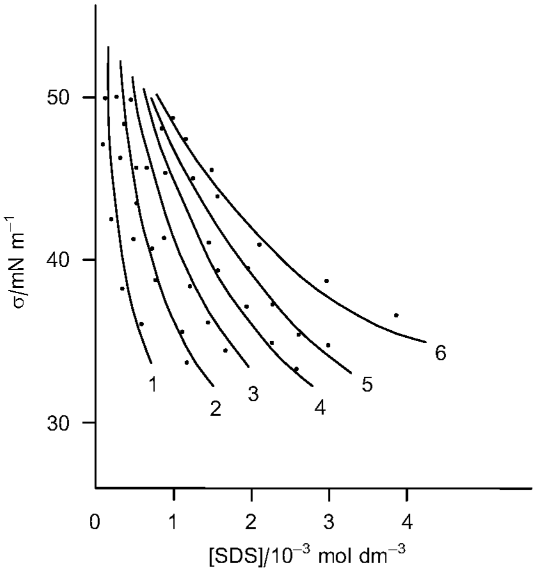

Fig. 2 Surface tension isotherms in the mutual system: H_2O–Na^+,Ni^{2+}||DS^-,SO_4^{2-} with 10 mol% $Ni(DS)_2$; 1–6, numbers of curves corresponding to coefficients $K = [NaDS]/[NiSO_4]$.

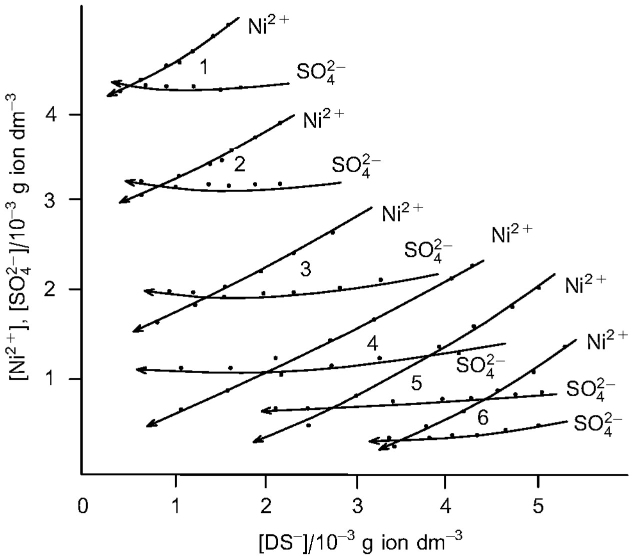

Fig. 3 Foam separation lines in the mutual system: H_2O–Na^+,Ni^{2+}||DS^-,SO_4^{2-} with 10 mol% $Ni(DS)_2$ (this corresponds to *a* in Fig. 1).

Table 1 The limit permissible concentration (LPC) and consumption of SDS.

Ion	$c_0/10^{-3}$ g ion dm^{-3}	LPC	Consumption of SDS g mol^{-1} SDS/g ion
Ni^{2+}	1	0.1	3.0
Co^{2+}	1	1.0	3.3
Cu^{2+}	1	1.0	2.8
DS^-	–	20	–

Thus, we have established that *ca.* 3 g mol^{-1} of SDS is required for the removal of 1 g ion of Ni^{2+}.

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