

SIMULATION OF SURFACTANT CONTRIBUTION TO INK REMOVAL SELECTIVITY IN FLOTATION DEINKING LINES

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ABSTRACT

Transport coefficients and correlations recently used to describe surfactant contribution to particle and water transport in a laboratory flotation column were used to simulate the impact of surfactant contamination on the flotation selectivity of industrial two-stage deinking lines. Simulation results showed that surfactants are slightly removed in the first flotation stage and are concentrated in the second one, where they induce a drop in ink flotation and in fibre entrainment. Subsequently, flotation units in the second stage displayed lower ink removal than in the first stage. In the presence of a constant water reject flow, the increase in surfactant contamination in the pulp stock gave a general decrease in the removal of suspended solids. Surfactant removal increased from 5 to 50%, however, this increase was not sufficient to prevent surfactant accumulation in the deinking line.

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Simulation results were compared with data collected in an industrial deinking line running in similar conditions and pulp composition, ink and surfactant removal obtained with low surfactant contamination were in line with experimental data.

Keywords: flotation deinking, non-ionic surfactant, frothing, separation selectivity, simulation.

INTRODUCTION

The large diffusion of froth flotation as efficient separation technology relies on the ability of gas bubbles to collect and remove hydrophobic materials from aqueous media via the direct adsorption/adhesion of solutes/suspended particles at the air/water interface [1,2]. Flotation is currently used in several industrial areas, namely, in water treatment to remove surfactants and residual reagents from industrial effluents [3–5], in minerals processing to separate minerals from the gangue [6–8] and in plastics recycling to selectively remove specific polymer families from blends upon the addition of an adequate collector chemistry [9–11]. In the papermaking industry, the high separation selectivity of hydrophobic ink particles from hydrophilic cellulose fibres designates froth flotation as the best technology to remove ink from recovered paper slurries [12,13] and to recover cellulose fibres that can be reprocessed for paper manufacturing.

Despite its versatility and apparent simplicity, froth flotation is governed by complex physicochemical and hydrodynamic phenomena which depend on pulp slurry/process chemicals composition [6,14,15] and on gas sparger [16,17] and flotation cell design [18,19].

As for minerals flotation, research in the flotation deinking field focuses on specific sub-processes and, to the best of our knowledge, a basic mechanistic description of the flotation deinking process accounting for both physicochemical and hydrodynamic phenomena is actually missing. Recent studies investigated the contribution of fibre type and consistency on gas hold-up [21,22] and deinking [23,24], the effect of froth drainage on fibre transport [25,26] and of de-inking chemicals on ink attachment to air bubbles and their removal [27–31]. Few works try to simulate industrial flotation processes using a semi-empirical approach [32,33] and the design of flotation deinking units often relies on empiricism and on the extrapolation of laboratory results to the industrial scale.

In previous works [26,33] a specific laboratory procedure and a mathematical model were developed to simulate the influence of deinking chemicals

and process design on ink removal selectivity and good agreement was obtained between process simulation and data collected during preliminary mill trials. Nevertheless, surfactant transport in multistage flotation lines and its contribution to the efficiency of each flotation unit were neglected. The aim of this work was to simulate the effect of non ionic surfactant concentration on the ink removal selectivity in industrial deinking lines and to compare simulation results with data collected during recent mill trials.

MATERIALS AND METHODS

Simulation of flotation deinking units

Particle transport in flotation cells was simulated using semi-empirical equations recently used to model deinking selectivity in a laboratory flotation column [26] and in industrial multistage systems [33]. These equations account for hydrophobic particle flotation, entrainment, water hold-up and particle/water drainage in the froth.

Flotation

In flotation systems, the gas and the solid phases are finely dispersed in water as bubbles and particles with size ranging between ~0.2–2 mm and ~10–100 μm , respectively. The collision between bubbles and hydrophobic particles can induce the formation of stable aggregates which move towards the surface of the liquid phase by convection (Fig. 1.a). Similarly, lyphophilic molecules adsorbed at the air/water interface are carried out from the pulp slurry by air bubbles (Fig. 1.b). The variation in concentration due to the removal of hydrophobic materials by adsorption/adhesion at the surface of air bubbles, $\frac{dc_n^f}{dt}$, was described using the typical first order kinetic equation

$$\frac{dc_n^f}{dt} = -k_n \cdot c_n \quad (1)$$

where c_n is the concentration of the particle in class n (namely, ink, ash, organic fine elements and cellulose fibres) and k_n is the flotation rate constant,

$$k_n = \frac{K_n \cdot Q_g}{S} \quad (2)$$

Q_g is the gas flow, S is the cross sectional area of the flotation cell and K_n is an

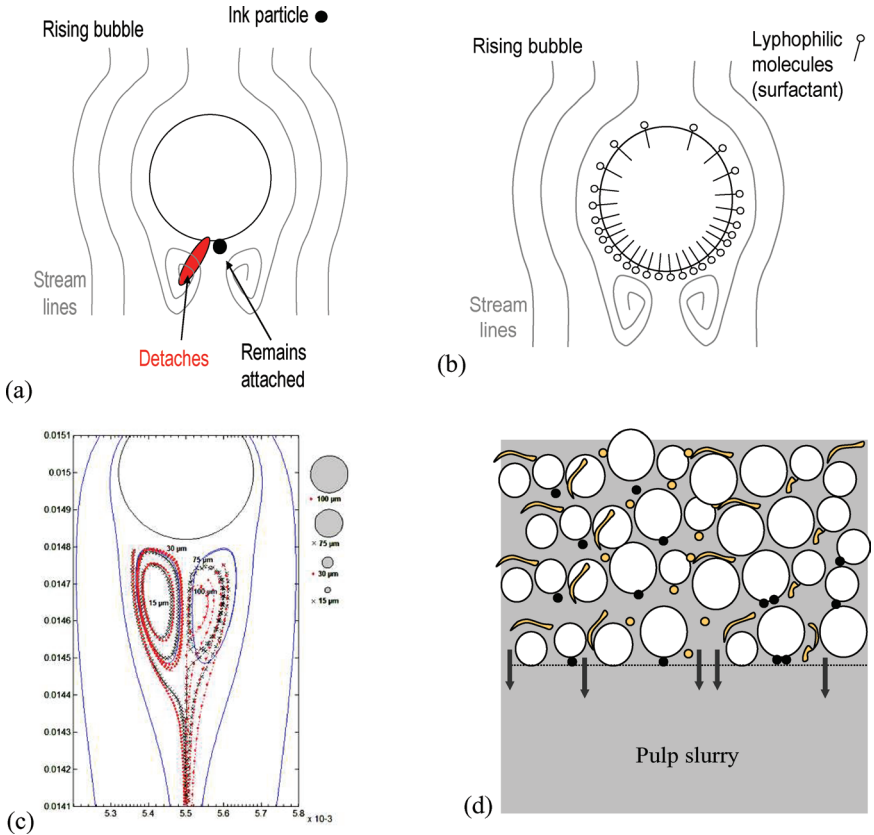


Figure 1. Scheme of mass transport mechanisms acting during the flotation deinking process. (a) Hydrophobic particle attachment and flotation, (b) lypophilic molecules adsorption, (c) cellulose particle path in the wake of an air bubble, (d) water and particle drainage in the froth.

experimentally determined parameter including particle/bubble collision dynamics and physicochemical factors affecting particle adhesion to the bubble surface [26].

Entrainment

During the rising motion of an air bubble in water (pulp) a low pressure area is formed in the bubble wake inducing the formation of eddies, whose size

and stability depend on bubble size and rising velocity. Both hydrophobic and hydrophilic particles can remain trapped in eddies streamlines (Fig. 1.c) with their subsequent entrainment by air bubbles.

Particles and solutes entrainment was correlated to their concentration in the pulp slurry and to the water upward flow in the froth. The variation in concentration due to entrainment, $\frac{dc_n^e}{dt}$, was given by the equation

$$\frac{dc_n^e}{dt} = -\frac{\phi \cdot Q_f^0}{V} c_n \quad (3)$$

where $\phi = c_{of}/c_n$ is the entrainment coefficient Q_f^0 , is the water upward flow in the froth in the absence of drainage, c_{of} is particle concentration at the pulp/froth interface and V is the pulp volume in the flotation cell. The total variation of particles/solutes concentration due to both flotation and entrainment was given by the sum of the two contributions, i.e. $dc_n/dt = dc_n^f/dt + dc_n^e/dt$.

Water and particle drainage in the froth

When air bubbles reach the surface of the pulp slurry, froth is formed with water films dividing neighbouring bubbles and solid particles dispersed in the liquid phase (in general hydrophilic or detached particles) or attached to the surface of froth bubbles (hydrophobic attached particles), Fig. 1.d. Froth systems display complex and unstable dynamics, however, water and particle drainage induced by gravitational forces can be considered as the two main phenomena governing mass transfers in the froth.

Water drainage through the froth was described using water hold-up in the froth, ε , and froth retention time (FRT) in the flotation cell as main parameters,

$$\varepsilon = \frac{Q_f}{Q_f + Q_g} \quad (4)$$

$$FRT = \frac{h}{J_g + J_f} \quad (5)$$

where Q_g and Q_f are the gas and the froth reject flows, h is the froth thickness and J_g, J_f are the gas and water superficial velocities in the froth. In order to select the best equation describing water drainage in the froth, namely the

decrease of water hold-up versus time, experimental data were fitted by using both an exponential decay [26,34,35]

$$\frac{\varepsilon}{\varepsilon_0} = e^{-L_d \cdot FRT} \quad (6)$$

and the usual inverse relationship [25, 36]

$$\frac{\varepsilon}{\varepsilon_0} = \frac{1}{1 + k \cdot FRT} \quad (7)$$

where ε_0 is the water volume fraction at the froth/pulp interface and L_d and k are the water drainage rate constants.

The mass drainage flow of particles/solutes dispersed in the froth, dM_f/dt , was given by the equation

$$\frac{dM_f}{dt} = -\delta \cdot c_{nf} \cdot Q_d \quad (8)$$

where Q_d is the water drainage flow, $\delta = c_d/c_{nf}$ is particle drainage coefficient, c_{nf} and c_d are particle concentration in the froth and in the water drainage stream, respectively.

Perfect mixing and piston flow were assumed to occur in the aerated pulp and in the froth in order to close-up Eqs. (1–8).

Influence of surfactant on mass transfer

The effect of non-ionic surfactant concentration and distribution on ink removal selectivity was simulated for the conventional multistage flotation system shown in Fig. 2. Transport coefficients obtained in previous laboratory experiments by fitting experimental data with Eqs. (1–8) [37] (using finite difference forward explicit method programmed on Excel worksheet) were used to run simulations. The composition of the model pulp feed is given in Table 1.

Fig. 3 shows that flotation rates, entrainment/drainage coefficients and pulp frothing are strongly affected by the surfactant concentration. Correlations shown in Fig. 3 and Eqs. (1–7) were implemented in process simulation software and transport coefficients in each flotation cell composing the multi-stage system were calculated from the surfactant concentration at the inlet of each unit.

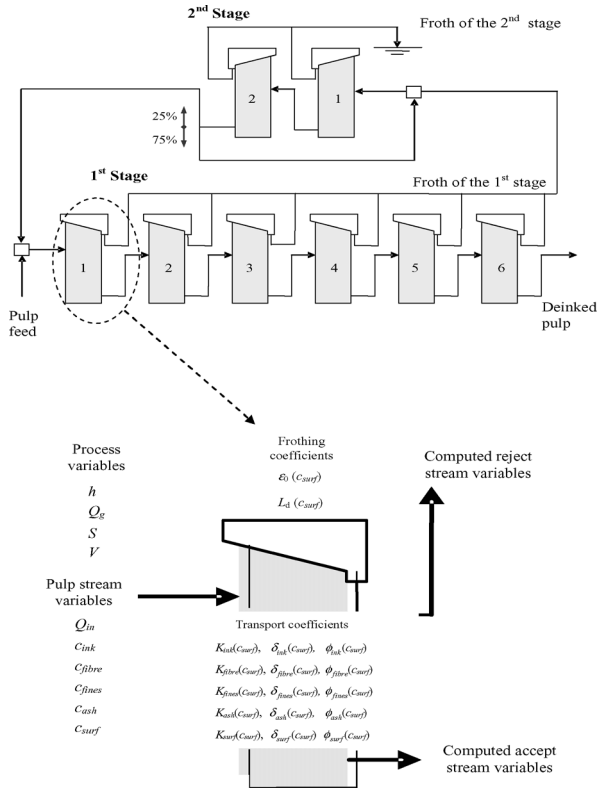


Figure 2. Scheme of the conventional multistage deinking line simulated in this study and of relevant pulp stream, flotation process and particle transport variables used to simulate each flotation unit.

Table 1. Composition of the pulp slurry at the inlet of the deinking line. Model is the pulp composition used to run simulations and Mill is the pulp composition in the deinking mill.* Calculated using Eq. (9).

Pulp type	Ash (%)	Fines (%)	Fibres (%)	ERIC (ppm)	Ink* (%)
Model	20.1	22.3	57.6	827	2.1
Mill	27	19	54	686	1.8

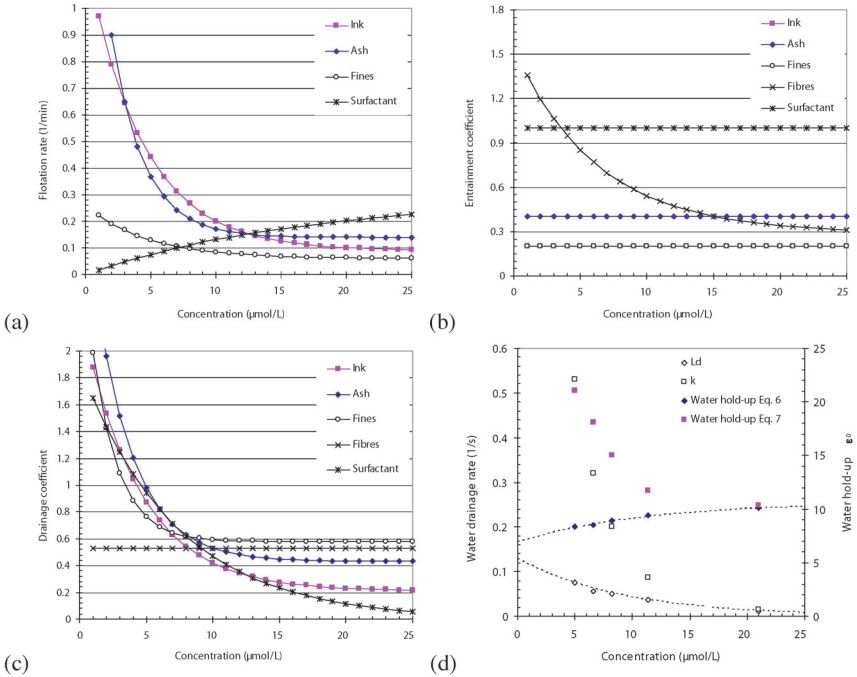


Figure 3. Effect of non ionic surfactant concentration (nonyl phenol ethoxylate 20EO) on pulp components transport during flotation. (a) flotation rate constants, (b) entrainment coefficients, (c) drainage coefficients in the froth, (d) water hold-up and water drainage coefficient obtained by using Eq. 6 and Eq. 7. Curves were obtained from the interpolation of experimental data given in [37].

Layout of the simulated deinking line

In the simulated system (Fig. 2), a pulp stream of 32000 L/min is processed in a first stage composed by six flotation cells in series. The outlet pulp of the sixth cell is considered as the outlet of the entire system, whereas, froths generated in the first stage are mixed and further processed in a second stage made of a series of two flotation cells. The froth of the second stage is the reject of the entire system. In order to insure a froth flow sufficient to feed the second stage and to avoid ink drainage, the froth retention time in the first stage never exceeds 3–4 s and 75% of the pulp stream processed in the second stage is circulated at the inlet of the second stage. The remaining 25% is cascaded back at the inlet of the first stage. The froth retention time in the second stage ranges between 10 s and 4 min to stabilize the water reject to 5%

Table 2. Characteristics of each flotation cell in the simulated de-inking line.

<i>Volume (L)</i>	<i>Feed flow (L/min)</i>	<i>Aeration rate per cell (%)</i>	<i>Cross section (m²)</i>	<i>Feed consistency (g/L)</i>	<i>Line capacity (T/day)</i>
20000	40000	50	12	10	580

(i.e. 1600 L/min). Main characteristics of the flotation line used to run simulations are given in Table 2.

Overall mass balance calculations involving multi stage systems were resolved using a process simulation software (CadSim Plus 2.4).

Industrial deinking line characterization

The operating conditions of an industrial pre-flotation line with layout, pulp processing capacity, deinking chemistry and nominal pulp stock composition similar to those used to run simulations and to extract transport coefficients [37] were determined by a complete mass balance around each flotation unit.

The distribution of surface active substances along the line was evaluated from surface tension measurements. A maximum bubble pressure tensiometer (Sita, T60) with a bubble lifetime triggered to 15 s was used to measure the surface tension at the inlet, outlet and reject of each flotation unit. In order to correlate surface tension variations to a corresponding change in surfactant concentration, the froth of the second stage was centrifuged and the surface tension was measured after the dilution of the supernatant 1 to 100 times with tap water. The surface tension versus dilution plot was used as calibration curve to convert surface tension into a corresponding surfactant relative concentration and to calculate surfactant removal during flotation [38].

Dry pulp pads (~400 g/m²) were prepared by filtrating the pulp slurry on a Büchner funnel (Whatman grade 2 paper filter) after the addition of aluminium sulphate and cationic polyacrylamide in order to lower pH to 7 and to prevent ink washing during filtration by coagulating ink particles on fibres [39]. The residual ink content in pulp pads (ERIC) [40] was determined by measuring light reflectance at 950 nm (Technidyne, Color Touch) and the ink concentration in the pulp slurry was estimated by using the equation

$$c_{ink} = ERIC \cdot c_{pulp} \frac{r_{ink}}{r_{flexo}} \quad (9)$$

where c_{pulp} is the pulp concentration, r_{ink} is the average diameter of ink particle and r_{flexo} is the average diameter of reference ink particles, viz. ~ 13 and 0.5 μm , respectively [26].

The fibre fraction in pulp samples was determined by weighing long fibres remaining on a 200 mesh wire screen after abundant washing, whereas, the ash fraction was determined by weighing residual inorganic material after dry pulp ignition and overnight storage in an oven at 425 $^{\circ}\text{C}$. The industrial pulp composition is given in Table 1.

SIMULATION OF A TWO-STAGE FLOTATION DEINKING LINE

Surfactant removal

Fig. 3 shows that the flotation rate and the drainage coefficient of surfactant molecules is strongly affected by the surfactant concentration itself. The increase in the flotation rate and the sharp lowering of the drainage coefficient are ascribed to the inhibition of bubble coalescence and to the stabilization of froth liquid films associated to the presence of surface active molecules [41,42]. As expected, pulp frothing progressively increased with the surfactant concentration and both Eq. (6) and (7) fitted with good accuracy experimental data. Fig. 3d shows that surfactant molecules stabilized foam bubbles inducing a decrease in the water drainage rates calculated using Eqs. (6, 7). The drop in water hold-up at the froth/pulp interface (ε_0) calculated by using Eq. (7) deviated from the physical behaviour of the froth. Whereas, the progressive increase in water hold-up calculated using Eq. (6) was associated to the typical decrease in bubble size and froth liquid film drainage observed in presence of surfactants [43,44]. Consequently, Eq. (6) was used to describe water drainage in the froth.

As shown in Fig. 4a, for a constant surfactant concentration in the pulp feed flow, the surfactant load progressively decreases when the pulp is processed all along the first and the second stage. However, within the range of simulated conditions, the surfactant concentration in the second stage is ~ 1.5 times higher than in the first stage indicating the low capacity of the first line to concentrate surfactants in the froth phase. Surfactant removal efficiencies illustrated in Fig. 4b show that flotation units in the first stage had similar yield which asymptotically increased from $\sim 6\%$ to $\sim 15\%$ when the surfactant concentration in the pulp feed flow increased from 2 to 25 $\mu\text{mol/L}$. This trend was associated to the influence of surfactant concentration on the flotation rate and on pulp frothing (Fig. 3). With a low surfactant concentration in the feed flow, surfactant removal in flotation cells of the second stage was lower than in the first stage. Similar yields were obtained with extremely high surfactant concentrations, i.e. >15 $\mu\text{mol/L}$.

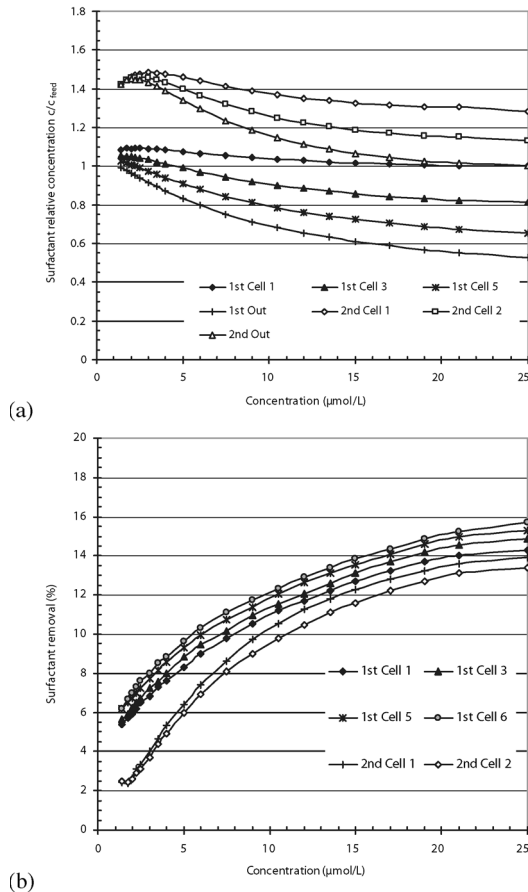


Figure 4. Effect of surfactant concentration in the pulp feed flow on surfactant distribution and removal. Surfactant concentration (a) and removal (b) in each flotation unit composing the multistage system.

The different froth retention time in the first and in the second stage was at the origin of this trend. Indeed, in the first stage the froth is removed with no retention and surfactant molecules are subjected only to flotation and entrainment. Whereas, in the second stage the froth retention time ranges between 10 s and 4 min in order to promote water drainage and to stabilize the froth flow at 1600 L/min. Surfactant transport takes place by flotation, entrainment and drainage in the froth. The low surfactant removal in the

second stage shown in Fig 4b is therefore associated to froth bubbles instability and to the ensuing intense surfactant drainage (Fig. 3) from the froth to the aerated pulp.

Ink removal

Fig. 5a shows that for all simulated concentrations, mixing the feed pulp with the pulp flow cascaded back from the second stage gives an increase in the ink concentration at the inlet of the first stage. In general, ink concentration

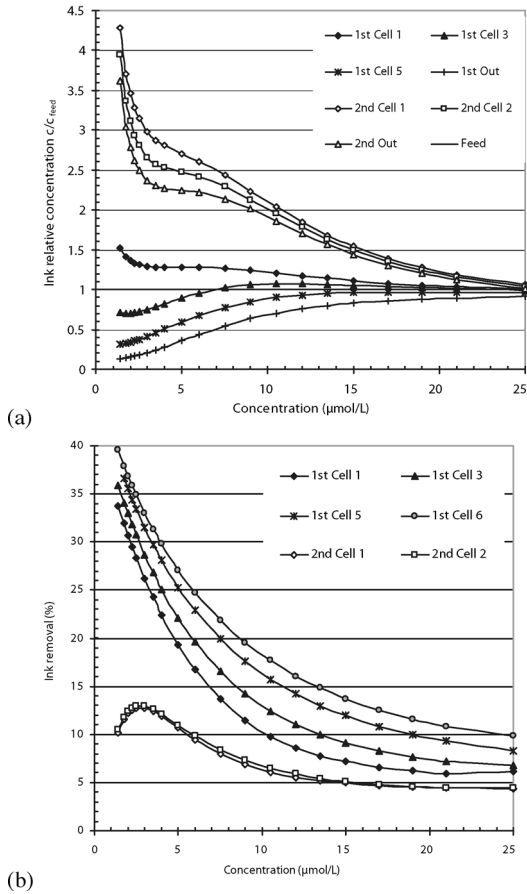


Figure 5. Ink distribution and removal in the flotation line at increasing surfactant concentration in the pulp feed flow. (a) Ink concentration, (b) ink removal.

progressively decreased all along the first and the second stage, however, ink distribution in the deinking line was strongly affected by the surfactant concentration. Fig. 5a shows that ink concentration along the deinking line progressively converges to the ink concentration in the feed flow.

At high surfactant concentration, densely packed surfactant monolayers form at air/water and ink/water interfaces inducing a drop in the bubble/ink adhesion energy [45], in air bubbles coalescence [46], and dispersing ink particles/calcium soap aggregates [45]. In this condition, the collision and the attachment of ink particles to air bubbles is disfavoured, flotation is depressed (Fig. 3a) and ink removal is due to the hydraulic partitioning of the pulp flow into the reject and the floated pulp streams. Ink removal versus surfactant concentration plots illustrated in Fig. 5b show that in all flotation cells of the first stage ink removal monotonically decreases, while in the second stage a peak in ink removal appears at 3 $\mu\text{mol/L}$. For all simulated conditions, ink removal in the second stage is lower than in the first stage. This behaviour was associated to different froth retention time and surfactant concentration in the two stages. In the first stage surfactant concentration is ~ 1.5 times lower than in the second stage and the froth is removed with no retention. Ink removal is therefore directly correlated to the flotation rate which, according to the lower surfactant concentration, is higher than in the second stage. The peak in ink removal in the second stage reflected the progressive depression of ink upward transfer from the pulp to the froth by flotation and of ink drop back from the froth to the pulp by drainage [37,47]. At low surfactant concentration, $< 3 \mu\text{mol/L}$, ink removal is governed by particle transport in the froth. The froth is unstable and bubble burst and water drainage induce ink to drop back into the pulp with an ensuing decrease in ink removal. At high surfactant concentration, $> 3 \mu\text{mol/L}$, froth bubbles are progressively stabilized and ink drainage is reduced (Fig. 3c, 3d). Nevertheless, ink floatability is depressed (Fig. 3a) and the overall ink removal decreases. The presence of a maximum in the ink removal vs. surfactant concentration curve corresponds to the best compromise between froth stabilization and ink floatability depression. In the first stage the peak in ink removal is absent because the froth is removed without froth formation and ink removal is due only to flotation and entrainment.

The variation of the ink mass flow in the two flotation stages is shown in Fig. 6b. As anticipated by ink removal plots shown in Fig. 5b, the increase of surfactant concentration decreases the ink flow eliminated in the froth of the first stage and increases the ink flow at the outlet of the deinking line. Ink flow variations in the second stage appear more complex since a sharp decrease at the inlet of the second stage is followed by a plateau for surfactant concentrations below 6 $\mu\text{mol/L}$. Above 6 $\mu\text{mol/L}$ the ink flow decreases

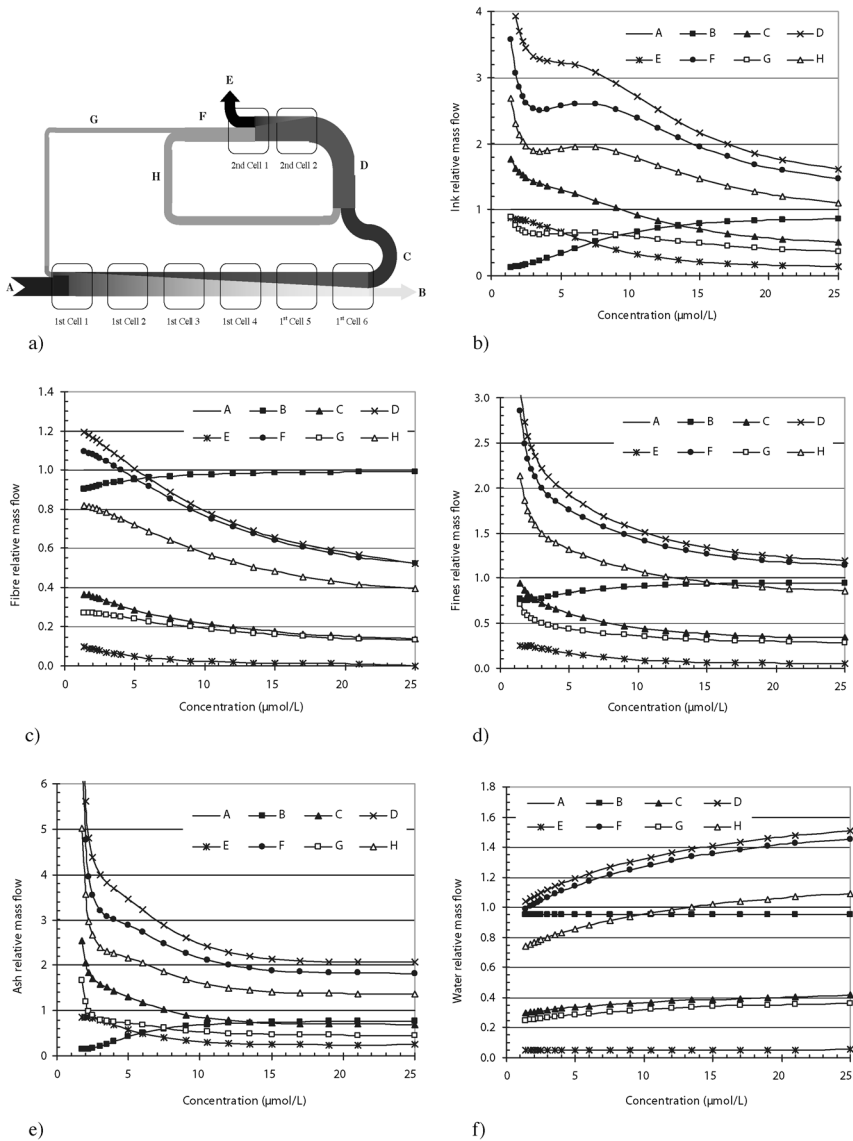


Figure 6. Influence of surfactant concentration on relative mass flows, $(Q_{in}c_{in})/(Q_{feed}c_{feed})$, across the multistage deinking line. (a) Mass flow diagram of the multistage line shown in Figure 1, (b) ink mass flow, (c) fibre mass flow, (d) fines mass flow, (e) ash mass flow, (f) water mass flow. $G = 0.25 F$, $H = 0.75 F$.

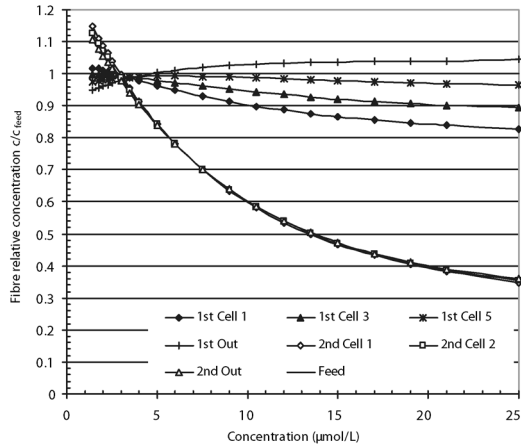
monotonically. Between 2 and 6 $\mu\text{mol/L}$ the ink flow in the second stage is mainly governed by the ink removal in flotation cells and the ink flow at the outlet of the second stage displays a minimum which is associated to the peak ink removal shown in Fig. 5b. Above 6 $\mu\text{mol/L}$ ink removal has a nearly stable value and the ink mass flow in the second stage is directly correlated to the ink stream from the first to the second stage.

Fibre removal

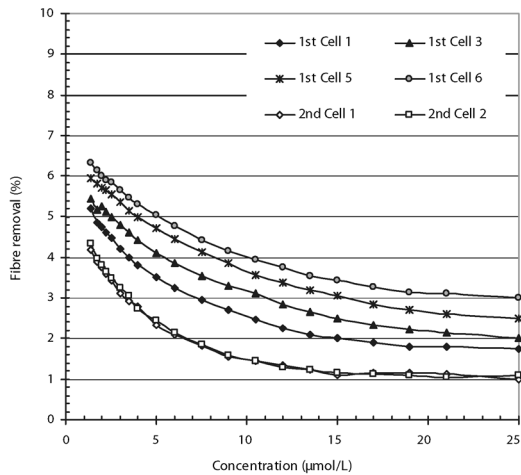
Curves illustrating fibre versus surfactant concentration along the deinking line (Fig. 7a) display different profiles than ink versus surfactant concentration plots shown in Fig. 5a. At surfactant concentrations lower than 4 $\mu\text{mol/L}$, the fibre concentration progressively increases all along the first stage. Above 4 $\mu\text{mol/L}$ the trend is reversed and, when the pulp is processed in subsequent flotation cells, the fibre concentration increases. According to Eq. (3), fibre transport during flotation is associated to the intensity of entrainment phenomena and to the water upward flow from the aerated pulp to the froth. The specific shape of concentration plots shown in Fig. 7a can be correlated to the influence of surfactant on fibre entrainment (Fig. 3b) and pulp frothing (Fig. 3d). At surfactant concentrations below 4 $\mu\text{mol/L}$ the pulp is flocculated by the calcium soap and cellulose fibres are entrained by air bubbles, while froth bubbles are unstable and water hold-up in the froth is fairly low. Fibres are concentrated in the froth. Above 4 $\mu\text{mol/L}$, increasing surfactant concentration depresses fibre entrainment and water hold-up is boosted by the presence of high surfactant concentrations. This can be explained by pulp deflocculation though this effect is controversial in literature [48]. In these conditions, water removal from the aerated pulp is favoured and causes an increase in fibre concentration.

In the second stage, fibre concentration progressively decreases, however, for surfactant concentrations lower than ~ 3.5 $\mu\text{mol/L}$ fibre concentration in the second stage is higher than in the first stage indicating that in this range of surfactant concentrations the intense fibre entrainment in first stage cells favours fibre accumulation in the froth.

Fig. 7b shows that fibre removal monotonically decreases when increasing surfactant concentration indicating that the increase in the water upward flow in the froth is not sufficient to counteract the decrease in fibre entrainment. As observed for ink, fibre removal in the second stage is lower than in the first stage and in line with the presence of a high surfactant concentration and of a thick froth layer in second-stage cells.



(a)



(b)

Figure 7. Influence of surfactant concentration on fibre distribution and removal. (a) Fibre concentration, (b) fibre removal.

Fines and ash removal

Fines and ash transport display an intermediate behaviour between ink and fibres. Mineral fillers (ash) have flotation rate constant similar to that of ink particles (Fig. 3a) and flotation is the dominant transport mechanism. Organic fine elements (fines) are poorly floatable particles and their transport

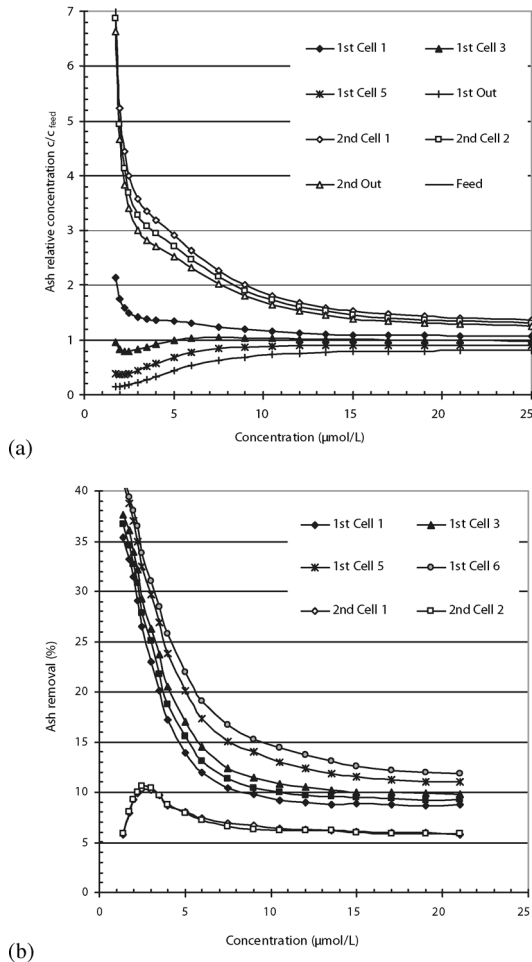


Figure 8. Effect of surfactant concentration on ash distribution (a) and removal (b).

is governed by flotation and entrainment. The shape of ash concentration and removal curves shown in Fig. 8 is similar to those obtained for ink particles. The ash concentration in both the first and second stage monotonically converges to the concentration in the pulp feed flow indicating the depression of ash removal by flotation. As obtained for ink, a peak in ash removal in the second stage is present at 3 $\mu\text{mol/L}$. Fines concentration profiles illustrated in Fig. 9a display an intermediate shape between ink and fibre

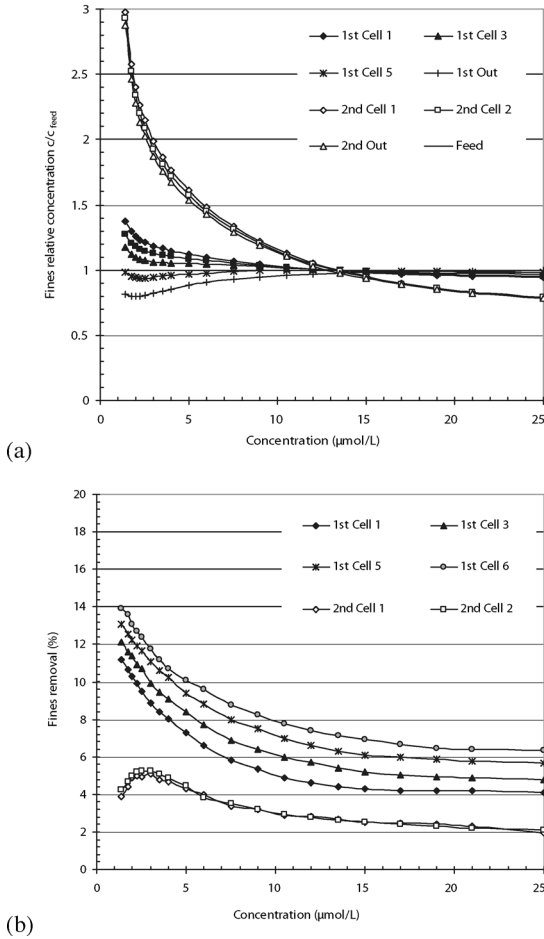


Figure 9. Fine elements concentration (a) and removal (b) in the flotation line at increasing surfactant concentration in the pulp feed flow.

concentration plots shown in Figs. 5a and 7a. Below 14 $\mu\text{mol/L}$ fines concentration decreases all along the deinking line and concentration values converge to the feed concentration. Furthermore, in the second stage fines load is higher than in the first one and their removal displays a peak at 3 $\mu\text{mol/L}$. All these features point out that, within this range of surfactant concentrations, flotation is the dominant transport mechanism. Above 14 $\mu\text{mol/L}$ fines

concentration slightly decreases along the flotation line and fines load in the second stage is lower than in the first one. As stated for fibres, this inversion was associated to the slight contribution of flotation and entrainment to particle transport and to the high water hold-up in the froth. Ash and fines mass balance along the deinking line is shown in Fig. 6d,e.

Process yield

Simulation results show that both the variation of surfactant load in the pulp feed flow and its distribution in the two flotation stages affect the yield of the deinking line. Except for a peak in ink removal in the second stage at 3 $\mu\text{mol/L}$, Fig 10a shows that the ink removal efficiency of the entire deinking line progressively decreases when increasing surfactant concentration.

Similar trends were obtained for fibre, fines and ash (Fig. 10b) and only surfactant removal increased when increasing the surfactant load in the pulp feed flow.

Fig. 10 shows that with a surfactant load in the pulp flow comparable with the amount released by a standard pulp stock composition, i.e. $\sim 4 \mu\text{mol/L}$ [37], ink is efficiently removed ($\sim 70\%$), fibre, fines and ash loss have realistic values for a deinking line, i.e. 5, 19 and 65% respectively, and surfactant removal does not exceed 17%.

The high sensitivity of the process yield to the surfactant load in the pulp stream and the low surfactant removal efficiency lead to assume that a conventional deinking line weakly attenuates fluctuations in the amount of surface active agents released by recovered papers with a direct effect on the stability of the process yield and on surfactant accumulation in process waters.

COMPARISON OF SIMULATION RESULTS WITH MILL DATA

Fig. 11a shows that the residual ink content obtained by simulation with a surfactant load of 4 $\mu\text{mol/L}$ was in good agreement with data collected during mill trial. In the first stage, residual ink obtained from simulation displayed higher values than experimental data. This mismatch was due to the different ink load in the pulp feed flow. The ERIC of the industrial pulp (690 ppm) was lower than that of the model pulp used in laboratory experiments [37] and to run simulations (830 ppm). When using the industrial pulp composition to run simulations this discrepancy was strongly attenuated. The variation of the surfactant concentration in the deinking mill was in good agreement with simulation results.

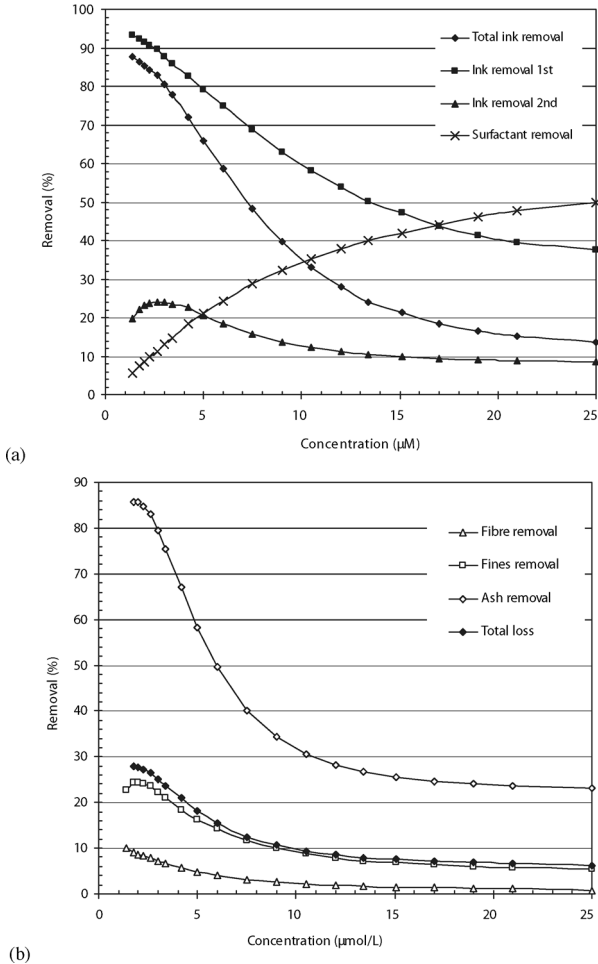


Figure 10. Total ink and surfactant removal (a) and fibres, fines, ash loss (b) plotted as a function of surfactant concentration in the pulp feed flow.

Fig. 11b shows that surfactant concentration in the first stage was nearly constant and the decrease predicted by process simulation can not be observed since it is within the experimental error. As predicted by the simulation, the surfactant concentration in the second stage was 1.4–1.5 times higher than in the first stage and it progressively decreased all along the line.

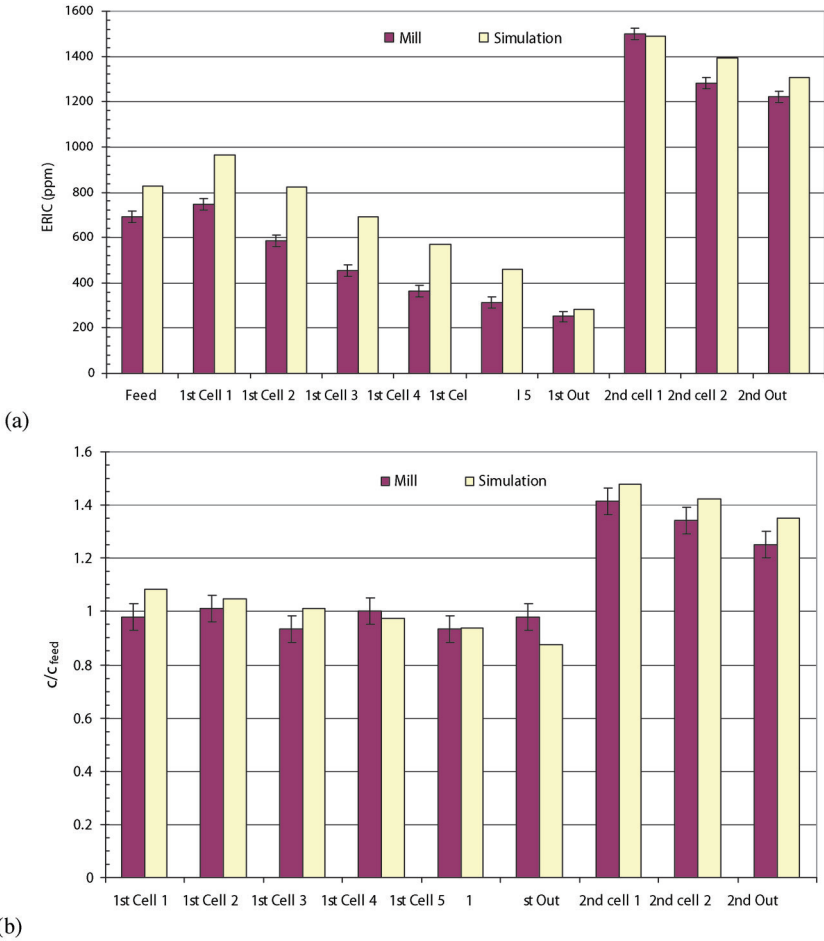


Figure 11. Comparison of residual ink concentration (a) and surfactant relative concentration (b) obtained from process simulation with mill data.

Ink and surfactant removal determined for the industrial deinking line in the first and second stages matched with quite good accuracy with the yield predicted by process simulation (Fig. 12). Furthermore, Fig. 13 shows that, when accounting for the slight deviation due to different composition of industrial and model pulps (Table 1), the pulp composition determined in the

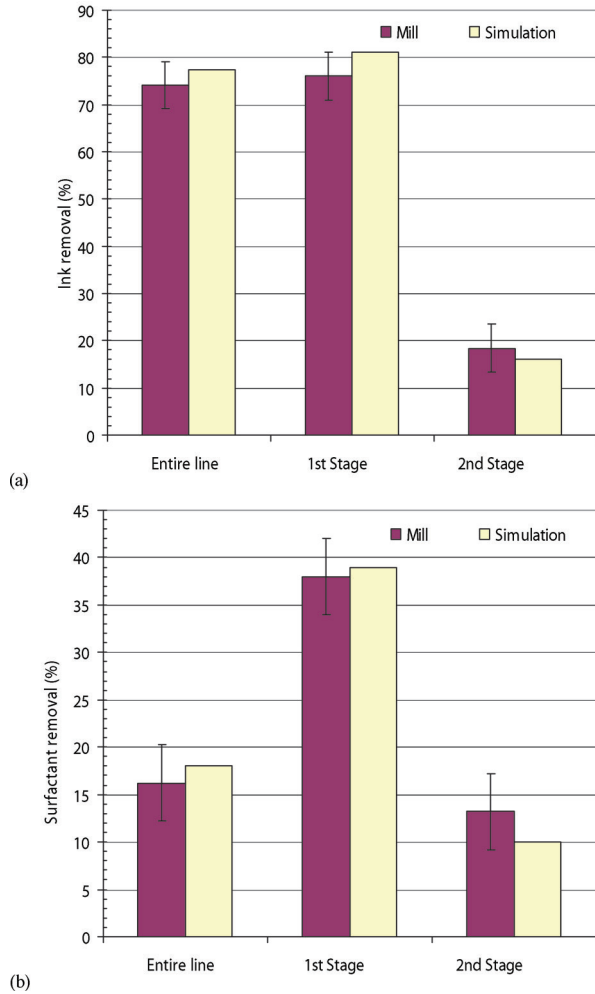


Figure 12. Comparison of ink (a) and surfactant removal (b) obtained at the industrial scale with simulation results.

mill and by simulation matched, thus indicating that particle and water transport mechanisms used for the simulation of the industrial line describe with reasonable accuracy the deinking process.

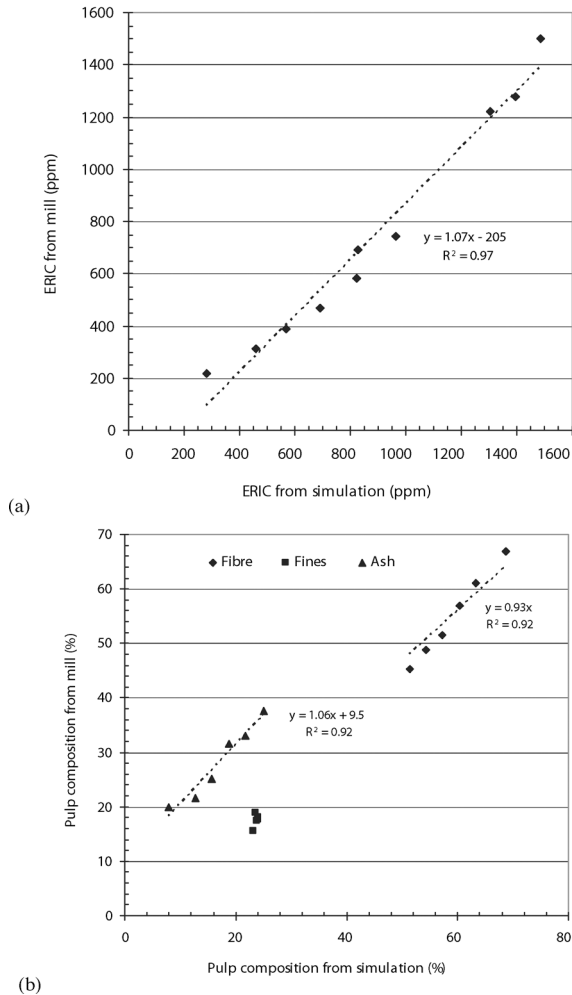


Figure 13. Comparison of pulp composition obtained from simulation and during mill trials.

CONCLUSIONS

The following general conclusions can be drawn from this investigation:

- Particle, water and surfactant transport coefficients and their dependence from surfactant concentration obtained in a previous study were used to

simulate the impact of surfactant load in the pulp stock on the operating conditions of a conventional two-stage flotation deinking line.

- Surfactants are slightly removed from the pulp in the first stage and concentrated in the froth which are further processed in the second stage. The high surfactant concentration in the second stage leads to an increase in water hold-up in the froth and to a drop in the ink flotation rate and in the ink removal efficiency of the deinking line.
- When the water reject flow was stabilized to 5% by adjusting the froth retention time, the increase in surfactant concentration in the pulp feed flow gave a drop in suspended solids removal showing the high sensitivity of conventional flotation deinking lines to surfactant contamination in the pulp stock.
- Pulp composition, ink and surfactant distribution all along the deinking line and their corresponding removal efficiency obtained by simulation were in reasonable agreement with data collected in an industrial line bearing similar layout and processing a pulp stock with same nominal composition.

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LIST OF SYMBOLS

c_n	is the concentration of the considered particle class in the flotation cell (g/L)
c_{nf}	is the concentration of particle class n in the froth (g/L)
c_{of}	is the concentration of particle class n at the pulp/froth interface (g/L)
c_{pulp}	is the pulp slurry concentration (g/L)
dM_f/dt	is the particle downward flow from the froth in the pulp due to drainage (g/min)
ERIC	residual equivalent flexo ink in the pulp (ppm)
FRT	is the froth retention time (s)
h	is the froth thickness (cm)
k_n	is the flotation rate constant of particle class n (1/min)
K_n	is the experimental flotation coefficient of particle class n (1/m)
J_g	is the gas superficial velocity (cm/s)

J_f	is the water superficial velocity in the froth (cm/s)
L_d	is the water drainage rate constant (1/s)
Q_d	is the water drainage flow (m ³ /h)
Q_f	is the water upward flow in the froth (m ³ /h)
Q_f^0	is the water upward flow in the froth in the absence of drainage (m ³ /h)
Q_g	is the gas flow (m ³ /h)
Q_{in}	is the water flow at the inlet of the flotation unit (m ³ /h)
Q_{out}	is the water flow at the outlet of the flotation unit (m ³ /h)
r_{flexo}	is the average diameter of the reference flexo ink particles (0.5 μm)
r_{ink}	is the average diameter of ink particle (μm)
S	is the cross sectional area of the flotation column (m ²)
t	is the flotation time (min)
V	is the flotation cell capacity (m ³)

Greek letters

a	correction coefficient used in Eq. (7)
δ	is the particle drainage coefficient
ϕ	is the particle entrainment coefficient
ε	is the water volume fraction in the froth
ε_0	is the water volume fraction at the froth/pulp slurry interface

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Transcription of Discussion

SIMULATION OF SURFACTANT CONTRIBUTION TO INK REMOVAL SELECTIVITY IN FLOTATION DEINKING LINES

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Richard Bown Retired

Did you look at the adsorption of the surfactant by the particles? I mean are you using a surfactant which is not attached to particles or one which is? And if it is not attached, have you tried any experiments where you have selective adsorption as in, say, a conventional mineral flotation process?

Davide Beneventi

The problem is that when we do adsorption studies, we have to work with model systems. We did some trials with model ink particles and this kind of nonionic surfactant. There was adsorption of course. There was an increase in the dispersion ability of the ink in water. The main point is that when we consider a real system, pulp slurries which are generated from the re-pulping of recovered papers, the adsorption studies make no sense. It is really not possible to do adsorption studies because, in the original pulp slurry, we have already added some surfactants, fatty acids and a wide variety of other molecules. When we add our surfactant in this case we just cannot observe, at the macroscopic level, what the effect is. We tried to understand what was the

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effect of the surfactant adsorption on the air bubbles, so we investigated the effect of this surfactant on the size of bubbles. With the model system, everything is nice, it's clear and produces nice trends. In a real system, it is chaotic: there are effects from particles and dissolved substance which mask the effect of the surfactant.

John Roberts University of Manchester

How did you measure the surfactant concentrations, particularly in the industrial simulation?

Davide Beneventi

That is tricky, it is not a direct measurement, for which we would need to use analytical techniques. We did not use these because in the industry we have a sort of soup as a mixture, so we tried to evaluate adsorption at the macroscopic level using the surface tension of our system and a reference curve. In this case, the reference curve was the surface tension versus concentration curve of our model surfactant. We know that this is just an approximation but, from the effect of this surfactant mixture on the surface tension, it is possible to obtain an equivalent surfactant concentration.

John Roberts

So, are you comfortable with that, I know you cannot do any better, but are you comfortable with that as a method?

Davide Beneventi

Now, we have some experimental cases, and it seems to work; but we know that from the academic point of view it is not really correct because we can have the same value of the surface tension obtained using different concentrations of different surfactants. We are trying to find the optimal solution because chemical analysis is not viable – at least for us.

Agne Swerin YKI – Institute for Surface Chemistry

Perhaps I missed this point but what was your starting point? Was it already dispersed ink particles, because your simulation indicates that the best situation with the flotation rate removal is to have no surfactant at all in the system?

Davide Beneventi

The best results in terms of interaction between the air bubble and the ink particles are predicted when we do not add surfactant. The problem is the froth generation: if we do not have any surfactant, we do not have any stabilization of the froth. So no froth means no separation. At the zero concentration we should not use the model because with no surfactant we are not able to predict the behaviour of the system. For example, we can have an agglomeration or coalescence of air bubbles with very large bubbles. We have too many variables which are affecting the ink and surfactant removal. In any case, the real curve is this one in the second stage, because in this case we have the effect of the surfactant on entrainment, on flotation but also on ink transport in the froth.

Agne Swerin

So in your simulation, did you start with dispersed ink particles?

Davide Beneventi

Yes, it was a mixture of 50% old magazines and 50% old newsprint re-pulped with a conventional chemistry containing soap. Then later we add the nonionic surfactant to simulate surfactant effect.

Bob Pelton McMaster University,

One would expect that the surfactant concentration will influence the bubble size distribution. Is that true and how do you account for that in your model?

Davide Beneventi

We did not consider it directly. We did the measurement and we observed a variation in the bubble size. However, since we are working with a semi-empirical model; everything is accounted in the flotation rate constant which is correlated to the gas flow, to the cross-sectional area and to a coefficient which is the experimental factor that we extract from lab experiment. It is possible to have a mathematical equation for this coefficient. Within this coefficient, we have the effect of the air bubble size, the surface energy of ink, the surface tension of the air bubbles. The problem is that these parameters are not measured during our mill trials. So we decided to use this general parameter which is obtained from lab experiments to account for the effect of

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air bubble size, air-bubble surface tension, ink-water interfacial energy and all these factors which we are not able to measure.

Bob Pelton

So that term is a variable? It depends on surfactant concentration?

Davide Beneventi

Yes.

Roger Gaudreault Cascades R&D

Can you comment on the way you validate your water drainage parameters? It is not clear to me how you managed this.

David Beneventi

We ran different lab trials and, at steady state for different froth removal heights or different froth retention times, we measured the reject flow in the froth. So we could plot a profile of the water hold-up in the froth as a function of the froth retention time, obtaining an exponential decay. So, this is an experimental correlation, which is also used in minerals flotation to describe the drainage of the froth and, by extrapolation, we decided to use this correlation. We did several trials varying the froth retention time in the flotation cell and the gas flow and we criss-crossed these two parameters to obtain different water removal – we had an exponential decay.