

COMPONENTS REMOVAL IN FLOTATION DEINKING

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ABSTRACT

In addition to ink removal in flotation deinking, valuable material, such as fibres and minerals, is lost which lowers yield and thus decreases the profitability of the processing. By studying component removal in flotation, a better understanding of the selectivity of the flotation can be gained. In the present study, removal of ink, ash, long and short fibres and fibre fines was studied by calculating their removal efficiencies as a function of yield. Operational parameters, such as rotor speed, soap addition, and flotation consistency were also studied to see their influence on the removal selectivity of each component.

The removal selectivity of ink was very good, and by adding soap just before flotation, the removal selectivity could even be improved. The removal selectivity of ash, long and short fibres and fibre fines were considerably lower than that of ink. The main yield losses were due to ash and partly to fibre fines removal.

INTRODUCTION

Flotation is used to remove ink and other contaminants in the paper recycling processes. Besides removal of ink and other impurities, flotation removes some valuable material such as ash, fibres, and fibre fines. This lowers the yield and decreasing the profitability of the processing.

Mechanistically, particle removal by flotation can be divided into true flotation and entrainment [1]. In true flotation, hydrophobic particles attach to air bubbles that transport the material to the froth layer. Entrainment, on the other hand, removes hydrophilic particles that have no tendency to attach to the bubbles. In this case, particles are mechanically transported with the bubble upward flow, to the froth. Drainage of components with water from the froth back to the pulp from the froth also takes place, especially of hydrophilic and heavy particles.

Several studies have been undertaken in order to understand the removal of individual paper components and model substances in flotation [2, 3, 4]. Keeping in mind the whole process yield, misleading estimations can be made based on component removal studies using only clean model compounds. This is especially the case with ash, because its properties may change during the papermaking process and recycling both in size and surface chemistry [3]. Substances, like dispersing agents, used in coatings colours have an effect on the frothing tendency and froth stability of flotation [5, 6]. Fines have also been shown to stabilize froth [7]. However, there is little published data on component removal in flotation deinking with real pulp and there is a need for a better understanding of the removal of separate furnish components. In this article, we present results of ink, ash, long and short fibres and fibre fines removal efficiencies as a function of the mass reject rate (RR_m) or inversely yield to better understand the nature behind process yield losses. Some operation parameters (rotor speed, soap addition, and flotation consistency) were studied and compared to reference situations to see their influence on component removal selectivity.

MATERIAL AND METHODS

Pulping and flotation

In this study, carefully mixed old western European pre-consumer old newspapers and old magazines (ONP/OMG) (50/50) paper was pulped in a pilot-plant drum pulper at 16% consistency. The pulping chemical dosages were kept constant as follows: sodium hydroxide 10 kg/t, sodium silicate 18.6 kg/t (as product, mole ratio 2.5), soap 6 kg/t and hydrogen peroxide 10 kg/t. Process water hardness was adjusted to 20°dH with calcium chloride. After pulping, the pulp was diluted to around 2% consistency for coarse screening (perforated screen 1.5 mm). Flotation was performed with the continuous Metso OptiBright MC™ primary flotation cell of 1 m³ volume which is divided into four equal size sectors lined in sequence. In the study, secondary flotation was not used for reject.

During reference conditions, coarse screened pulp was fed into the flotation cell at a flow of 1 L/s at 1% consistency. In the Metso cell, air is fed to the bottom of cell and the bubble size was controlled by rotor speed. The total air flow rate of 80 L/min and rotor speed of 70% were kept constant in the reference trial. All chemicals were introduced to the pulper.

Additional tests were done to understand the effect of rotor speed, soap addition to the flotation cell, flotation consistency at low and high volumetric capacities. The tests were made in two different trials.

The effect of rotor speed and soap addition

The influence of decreased rotor speed and soap addition to the flotation feed was studied first. In this particular case, the rotor speed was lowered to 50% and an additional soap dosage of 1 kg/t was fed into the flotation feed. All other parameters were kept constant, as seen in Table I.

Table I. Parameters during flotation trial (FFE is flotation feed).

Parameter	Rotor 70%, ref.	Rotor 50%	Soap to FFE
Flow [L/s]	1.0	1.0	1.0
Consistency [%]	1.0	1.0	1.0
Air flow [L/min]	80	80	80
Rotor [%]	70	50	70
Soap to FFE [kg/t]	0	0	1.0

The effect of flotation consistency

The effect of flotation consistency was also studied; at first, by having constant production of dry pulp (Table II), and secondly by having a constant volumetric feed rate (Table III). When the volumetric flow was kept constant, the air flow was adjusted according to the flotation consistency. All other parameters were kept constant.

Table II. Parameters during flotation with constant production 0.6 o.d. kg/min (FFE is flotation feed).

Parameter	Cs 1%	Cs 1.4%	Cs 1.8%
Flow [L/min]	60	43	34
Consistency [%]	1.0	1.4	1.8
Air flow [L/min]	80	80	80
Rotor [%]	70	70	70
Soap to FFE [kg/t]	0	0	0

Table III. Parameters during flotation with constant volumetric feed rate 60 L/min (FFE is flotation feed).

Parameter	Cs 1%	Cs 1.4%	Cs 1.8%
Flow [L/min]	60	60	60
Consistency [%]	1.0	1.4	1.8
Air flow [L/min]	80	112	144
Rotor [%]	70	70	70
Soap to FFE [kg/t]	0	0	0

Sampling and analyses

The analysed pulp sample consisted of a mixture of pulp collected from four pulp sampling rounds sampled during a 30 min stable processing period. Samples were taken from the flotation feed and flotation reject, as well as the individual accept and reject from each of the four flotation sectors. Additionally, online data on the volumetric flow rate was collected during the sampling period.

Residual ink (RI) values in the flotation feed and flotation sectors were analysed. Consistency, ash and fractional mass proportions were determined on flotation feed, final accept (i.e. last sector) and reject samples. In addition, usable fibres in the reject were analysed by hyperwashing the reject.

RI was analysed on pulp pads prepared according to INGEDE Method 1 and measured with L&W Elrepho spectrophotometer using a wavelength of 700 nm. The amount of free ink was calculated by subtracting the amount of attached ink from the RI value of the flotation feed and accepts samples. The attached ink was determined by measuring the RI of the accept pulp after hyperwashing on a 150 mesh screen. Consistency and ash were measured from the same sample by firstly drying the pulp at 105°C and then burning the dry sample in a furnace at 525°C (ISO 638 and 1762, respectively). Classification of the fibre mass proportions and fines content was conducted by tube flow fractionation which is correlated to Bauer McNett classification [8]. Fractions were classified as flakes (R12), long fibres (P12R48), short fibres (P48R200) and fines (P200). Usable fibres in the reject were analysed by washing out fines through a 100 mesh wire, and by drying and weighing the remaining fibres. The fibre fines proportion was calculated by subtracting the fines ash content from total content of fines. The fines ash content was achieved by subtracting 6% from the total ash content, because experimental tests have shown 6% of ash being in other fractions than fines fractions.

Calculations and curve fitting

Flotation feed flow by weight of dry pulp was calculated by multiplying flow and consistency. The dry reject flow was calculated by multiplying flow (manual measurement) and consistency. The dry accept flow was then calculated by subtracting reject flow from feed flow. The individual component flows were calculated by multiplying the proportion of the studied component by the mass flow. Cumulative sector mass reject rates were calculated from cumulative reject dry flows divided by flotation feed flow.

The free ink removal efficiency (E_r) calculation was based on free ink RI-values in accept and feed. Feed, accept and reject are abbreviated as F, A and R, respectively. Removal efficiency was calculated as follows:

$$E_r = \left[1 - \left(1 - \frac{RR_m}{100} \right) \cdot \frac{RI_A}{RI_F} \right] \cdot 100\% \quad (1)$$

Where RR_m is mass reject rate
 RI is free residual ink

The component removal efficiency was based on the reject and feed flows of the component. Removal efficiency can be calculated as follows:

$$E_r = \frac{\dot{m}_R \cdot C_R}{\dot{m}_F \cdot C_F} \cdot 100 \quad (2)$$

Where $\dot{m}$ is flow by weight (kg/min)
 C is content of studied component (%)

Selectivity is estimated in screening and cleaning commonly by a so called Q-index. Here the Q-index was also used by fitting a curve to the experimental data, calculated as follows [9]:

$$E_r = \frac{RR_m}{1 - Q + Q \cdot RR_m} \quad (3)$$

Where Q is selectivity

RESULTS

The effect of rotor speed and soap addition

Free ink removal efficiency as a function of mass reject rate is shown in Figure 1. Four different mass reject rates and removal efficiencies (i.e. the results from each sector in the flotation cell) from the same sampling period are indicated by a cumulative curve. A trend line was fitted by adjusting the Q-index (i.e. component selectivity value) according to Equation 3.

At reference conditions, free ink selectivity in removal was 0.972. Free ink Q-index was slightly lower, 0.968, with a lower rotor speed. Soap addition enhanced free ink removal, as the Q-index, was 0.990.

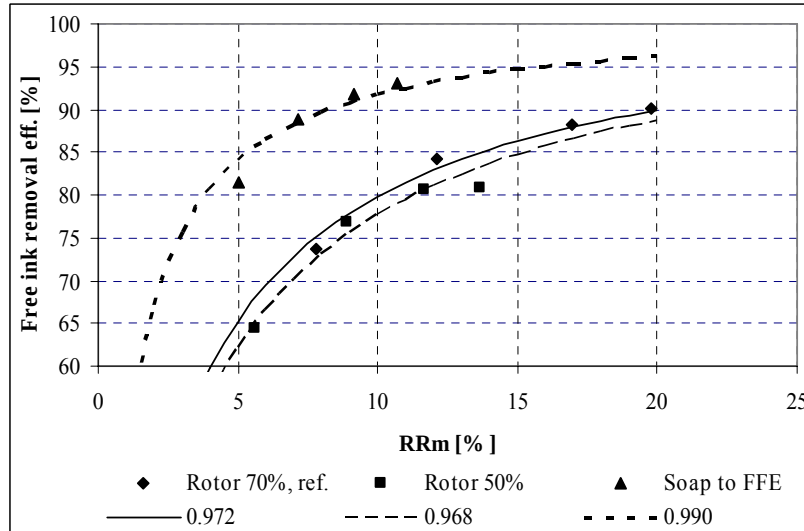


Figure 1. Free ink (detached) removal with two different rotor speeds and soap addition. Numbers on the legend shows selectivity index Q .

Ash removal efficiency as a function of mass reject rate is shown in Figure 2. The ash selectivity in removal was 0.53 for the reference conditions, and 0.51 for the lower rotor speed and soap addition. As the figure shows, the selectivity difference is only marginal.

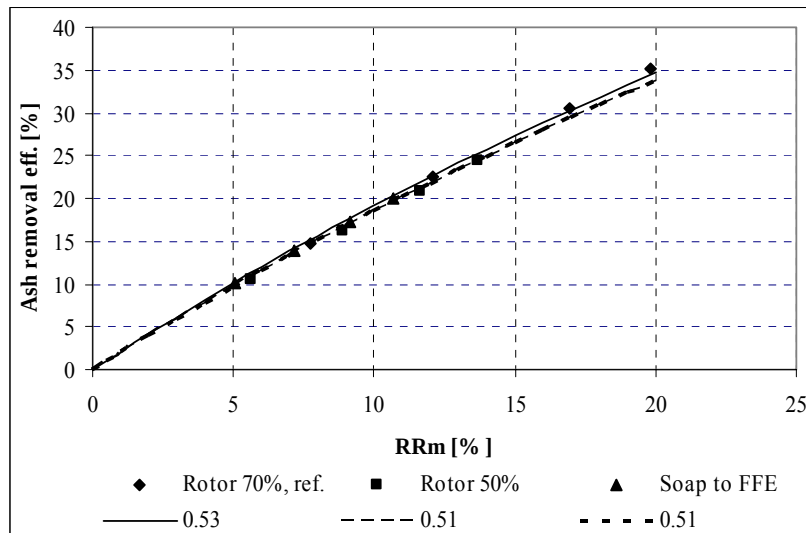


Figure 2. Ash removal with two different rotor speeds and soap addition to the flotation feed. Numbers in the legend show the selectivity index Q .

Long fibres removal efficiency as a function of mass reject rate is shown in Figure 3. For the studied parameters, long fibres selectivity in removal was -7.8 for the reference and for lower rotor and soap addition, -7.0. Negative selectivity index indicate that the content of a component in the reject is lower than in accept.

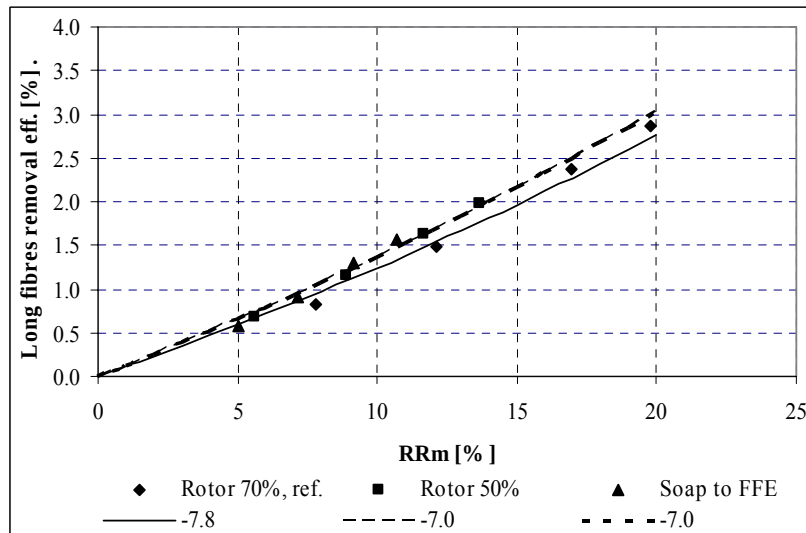


Figure 3. Long fibres removal with two different rotor speeds and soap addition. Numbers in the legend shows the selectivity index Q .

Short fibres removal efficiency as a function of mass reject rate is shown in Figure 4. Q-indexes for the reference, lower rotor and soap addition was -0.68, -0.76 and -0.62, respectively.

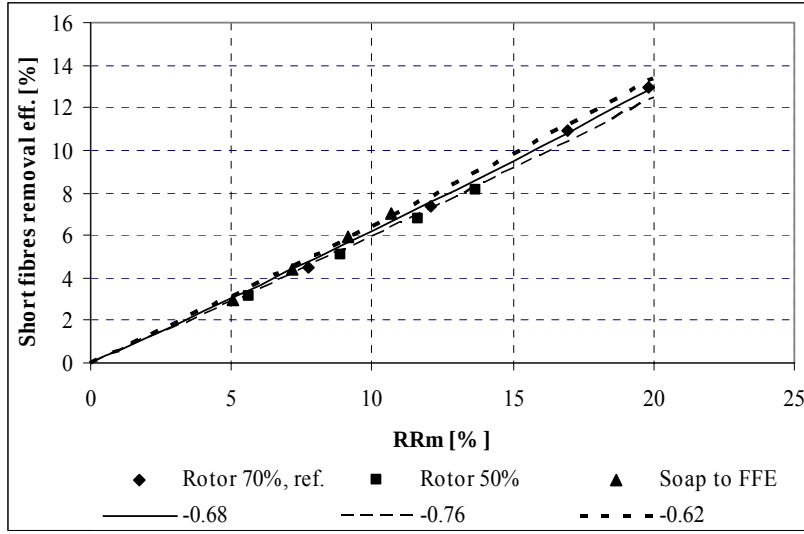


Figure 4. Short fibres removal with two different rotor speeds and soap addition. Numbers in the legend shows the selectivity index Q.

Fibre fines removal efficiency as a function of mass reject rate is shown in Figure 5. Selectivity curve fitting gave Q-index for the reference, lower rotor speed and soap addition of 0.60, 0.69 and 0.64, respectively.

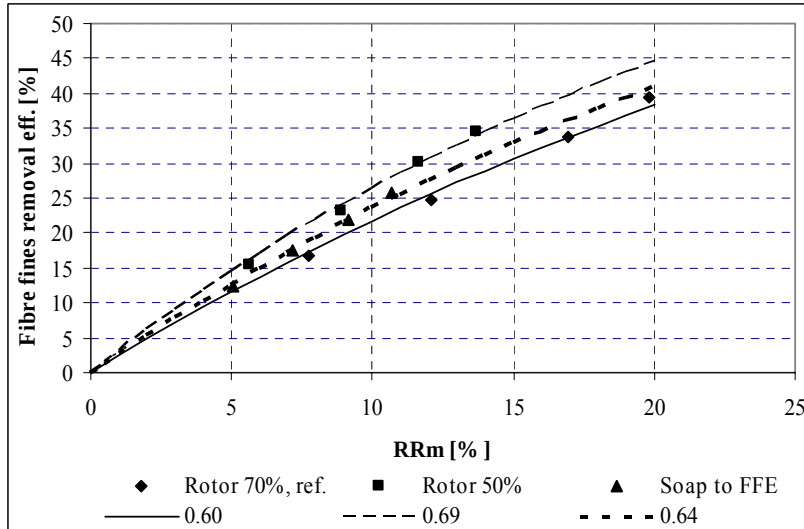


Figure 5. Fibre fines removal with two different rotor speed and soap addition. Numbers on the legend shows selectivity index Q.

The Q-index estimated for the experiments are summarized in Table IV. It can be seen that in case of lower rotor speed, decreased removal of ink and increased losses of long fibres and fibre fines were found. Soap addition to the flotation feed increased ink and long fibres removal.

Table IV. Summary of selectivity indexes from rotor/soap addition.

Component	Rotor 70%, ref.	Rotor 50%	Soap to FFE
Ink	0.972	0.968	0.990
Ash	0.53	0.51	0.51
Long fibres	-7.8	-7.0	-7.0
Short fibres	-0.68	-0.76	-0.62
Fibre fines	0.60	0.69	0.64

The effect of flotation consistency

At constant (dry) pulp production, the Q-indexes for different flotation consistencies are shown in Table V. Ink removal was similar at flotation consistencies of 1.0% and 1.4% (Q-index was 0.988), but lower at 1.8% consistency (0.979). Ash removal increased with increasing flotation consistency. Long fibres losses was lowest at 1.4% and 1.8% consistencies (-10.6 and -8.4) and highest at the lowest consistency (-4.1). Short fibres losses were lowest at 1.4% consistency and highest at 1.8% consistency. Fibres fines losses decreased with increasing flotation consistencies.

Table V. Selectivity indexes for different flotation consistencies with constant production 0.6 bd kg/min.

Component	Cs 1%	Cs 1.4%	Cs 1.8%
Ink	0.988	0.988	0.979
Ash	0.41	0.53	0.55
Long fibres	-4.1	-10.6	-8.4
Short fibres	0.12	-1.1	0.42
Fibre fines	0.85	0.69	0.37

At a constant volumetric flow rate, Q-indexes for flotation consistencies are shown in Table VI. Free ink removal increased with decreasing consistencies. The highest ash removal was obtained at 1.4% consistency and the lowest at 1.0% consistency. Long fibres losses were lowest at 1.4% and 1.8% consistencies and the highest at the lowest consistency. Short fibres losses decreased with increasing flotation consistencies. The lowest fibre fines losses were achieved with 1.4% consistency and the highest with the lowest consistency.

Table VI. Selectivity indexes for different flotation consistencies with a constant volumetric feed rate of 60 L/min.

Component	Cs 1%	Cs 1.4%	Cs 1.8%
Ink	0.988	0.982	0.966
Ash	0.41	0.56	0.53
Long fibres	-4.1	-12.6	-10.5
Short fibres	0.12	-0.52	-1.6
Fibre fines	0.85	-0.60	0.40

At reference conditions and higher consistency (1.4%) free ink selectivity in removal was same 0.988. On the higher consistency ink removal was lower 0.979 as can be seen in figure. Ink removal is shown as an example for clarifying the selectivity difference shown in table; same figures can be drawn from all other components too.

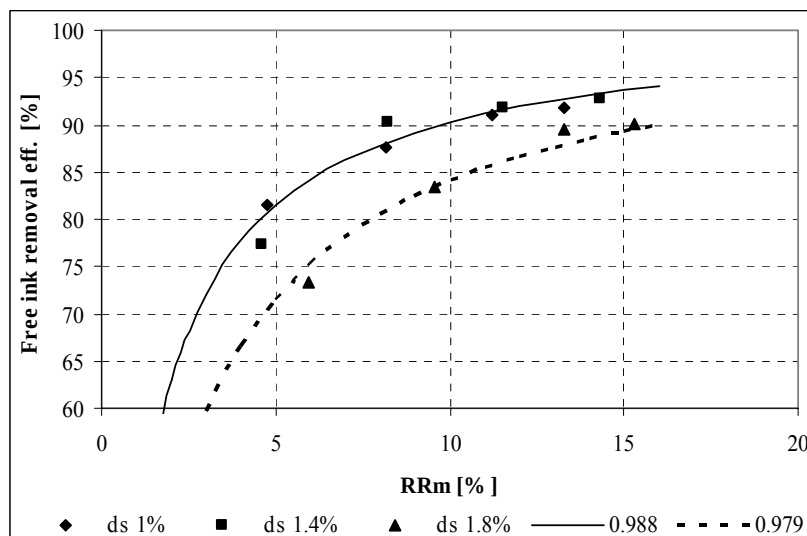


Figure 6. Free ink removal with three different flotation consistencies. Numbers on the legend shows selectivity index Q .

DISCUSSIONS

The effect of operation parameters and deinking chemicals on individual component removal in flotation has not been widely studied. However, some work with regards to ash has been done on a laboratory scale [3, 4, 5, 6, 10, 11, 12]. Some studies on brightness and residual ink have also been performed by analysing flotation samples from pilot-plants and mills [13, 14, 15, 16]. In addition, a few froth characterization studies of mill samples have been done to estimate component removal [17, 18]. We have not found solid published information on different component removal in continuous flotation in large scale. Thus, this study was carried out to better understand why yield losses take place in flotation and to study the effect of some process parameters on flotation selectivity.

The effect of rotor speed and soap addition

High ink selectivity is very important, because better ink removal can be achieved with lower yield losses. Lower rotor speed decreased the ink selectivity. To achieve the same removal efficiency with the tested lower speed, more than 1% higher mass reject rate was needed to achieve the same ink removal. Lower rotor speed probably increases the bubble size and an increase in bubble size lowers the amount of small bubbles and also the total amount of bubbles which would explain the results. The results are in accordance with a previous study where the deinkability factor was measured [11].

Soap addition clearly improved ink removal and the same ink removal efficiency could be achieved with 10% lower yield losses when 1 kg/t soap was added to the flotation cell. As the surface level in cell was constant, froth suppression was observed and it lowered the mass reject rate and led to lower solids removal with water without sacrificing ink removal.

Ash selectivity in removal was practically unaffected by bubble size or soap addition and meant that ash was removed with a similar removal efficiency at constant mass reject rate. On the other hand, the increase of rotor speed improves frothing, i.e. RR_m , so ash removal is enhanced. It seems that there is no true flotation of ash, and that ash losses take place through other mechanisms. It has been reported that pure PCC (precipitated calcium carbonate) deposits at the air-water interface even without chemicals in pure waters [2]. However, dispersion agents and coating components of real recycled pulps may turn ash surfaces more hydrophilic [3, 5, 6], which may be the reason why the effect was not seen in our study.

Long fibres loss was slightly higher at a lower rotor speed and with soap addition. Soap addition only slightly increased short fibres loss. Short fibres losses were higher than that of long fibres. Fibres are hydrophilic in nature, and it is widely believed that they are removed only by entrainment. However, it has been suggested that sticky calcium particles can precipitate on fibre material and assist in the removal, especially of fine particles [2]. That is in accordance with our findings where short fibres removal was higher than long fibres removal.

Fibre fines loss in flotation was higher with lower rotor speed. When targeting the same ink removal as in the reference conditions, more fibre fines were lost with bigger bubbles. Fibre fines losses were only slightly affected by soap addition. It has been calculated that eddies behind rising bubbles are able to transport small light particles ($<100\text{ }\mu\text{m}$ in diameter, having a density close to that of fibres) to the surface [19]. This might explain its high losses when fines rich water on the surface of cell moves to froth lamellas leading to rejection of fibre fines. On the other hand, fines, especially mechanical pulp fines, are usually covered by a larger proportion of hydrophobic substances probably due to their larger surface area compared to long fibres. Therefore fines are more likely to be removed in flotation.

Component removal selectivity in descending order was: ink, fibre fines, ash, short fibres and long fibres. Selectivity of ink was clearly the highest because of its hydrophobic surface. Component mass proportions in the flotation feed stream were: 2% ink (estimate), 14% fibre fines, 29% ash, 19% short fibres, and 34% long fibres, the rest (2%) being flakes. Despite the fact that ink removal was the highest, the highest total losses were in the ash, which is in accordance with other studies [14, 17]. In addition to ash losses, also removal of fibre fines caused yield losses.

The effect of flotation consistency

Ink selectivity in removal was the same at 1.0% and 1.4% consistencies, but at 1.8% consistency, the ink selectivity was lower. It has been reported that 1.3% consistency is the highest consistency recommended to be used with traditional flotation cells [11]. Ink selectivity was lower at a higher production, due to shorter retention time. In this study, it was shown that during constant mass production, the flotation was working well up to 1.4% consistency in the pilot cell.

Ash selectivity in removal was reasonably similar at 1.4% and 1.8% consistencies and lower at 1.0% consistency. At 1.0% consistency, approximately 2% higher mass reject rate was needed for the same ash removal efficiency. A higher mass production increased ash selectivity at 1.4% consistencies and decreased at 1.8% consistency. However, the differences are small and this crossing trend was close to experimental inaccuracy.

The lowest long fibres losses were achieved at the 1.4% consistency. Higher production even decreased the long fibres losses. At higher consistencies, the fibre network is stronger which prevents excess fibre removal. However, too tight of a fibre network prevents bubble rising by causing channelling and a subsequent decrease in ink removal. At the same time, ash removal was higher when long fibres losses were decreasing (due to mass balance).

The highest short fibres losses were found at the highest consistency probably due to a higher amount of short fibres in the water phase flowing to the reject. On the other hand, it could be that the high long fibre yield could be the reason. Increased production changed the situation so that highest short fibres losses were with the lowest consistency.

Fibre fines losses were the highest at the lowest consistency, which is the same trend as with long fibres. At a higher production, minimum losses were achieved with 1.4% consistency. This is probably due to the fibre network that prevents excess fibre fines losses.

Generally, it was seen that at a constant production at low consistency, more of the yield losses were due to fibre fines rejection but at higher consistencies, due to ash losses. From a practical point of view, the same ink removal selectivity could be achieved at a moderate consistency of 1.4% with lower fibre fines losses. On higher production (at 1.4% consistency) a higher mass reject rate would be needed for the same ink removal, but the increased yield losses would be more likely due to ash removal not due to fibre fines removal.

Table VII. Influence of some operational parameters on selectivity of components.

Component	Rotor 70→50%	Soap to FFE	Cs 1.0%→1.4%
Ink	Decreased	Increased	Unaffected
Ash	Unaffected	Unaffected	Increased
Long fibres	Slightly increased	Slightly increased	Decreased
Short fibres	Unaffected	Unaffected	Decreased
Fibre fines	Increased	Slightly increased	Decreased

CONCLUSIONS

The removal selectivity of ink in a pilot flotation cell was very good. The addition of soap just before the flotation cell clearly improved the selectivity. The removal selectivity of ash, long and short fibres and fibre fines were considerably lower than that of ink. Because of the high amount and density of ash, losses of ash mainly explain the total yield losses of the process. Because ash and hydrophilic material tend to follow the water draining back from the froth to the pulp, a high consistency of the reject is recommended as long as it will not lead to loss in ink selectivity.

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