STUDY OF NON-IONIC SURFACTANT AND FOAMING AGENT CHARGE IMPACT ON FLOTATION DEINKING OF LASER-PRINTED WASTE PAPER

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The present contribution deals with the impact of acharge of a non-ionic surfactant and soft soap on the efficiency of printing ink removal from a suspension of recycled fibres at various flotation times. To determine the optimum conditions, a 3-factor experimental design using aStatgraphics software was used. The efficiency was evaluated by the image analysis using a Motic Images 2.0 software.An equation relating the flotation efficiency and variables (such assurfactant, soap, time), influencing significantly the flotation efficiency, was derived. A flotation efficiency of up to 96% can be attained via 5% surfactant addition, and 2% soap addition to oven-dry pulp for a flotation time of 25 minutes.

Keywords: recycling, flotation, surfactant, statistical modelling

INTRODUCTION

In general, wastes represent athreat to the environment at the time being. Waste paper is one of the waste types. It may be upgraded through its combustion and exploitation of its energy potential. This mode is put forth by a part of the academic community. On the other hand,the idea of recycling and exploiting the waste paper via further chemical processing, leading to the formation of fibres or feed stock for the preparation of chemicals and materials able to replace those prepared from fossil fuels, has been offered. Mostly, the proposals concern recycled printed paper. In both modes of waste paper utilization, the printing ink must be detached from the fibres. The fibres thus purified can be used for replacing virgin fibres in paper production or as raw material for other kinds of utilization.

The separation of printing inks is arather extensive issue. It is usually performed by flotation-type cleaning, which improves the optical properties with minimum changes of other properties, mainly the strength related ones.

Flotation deinking is anecessary brightening process used to remove printing inks, fillers, stickies and impurities from waste paper. The process is aimed at obtaining raw material of the highest quality, preserving the fibre mass and mechanical strength, and improving optical parameters. The obtained raw material can be used as anadmixture in high-grade graphical paper production. Gottsching[1] dealt with increasing the efficiency in waste paper deinking by optimizing the process of flotation. Several other authors have dealt with the issue of deinking from the viewpoint of the flotation process, additives influence etc.

Foam flotation deinking is the industrial process in which solid particles suspended in water are lifted by fine air bubbles to the surface. There acompact foam layer is formed, and subsequently removed by, e.g. skimming off or sucking.[2,3]

The method is based on separation of solid particles differing in wettability. The suspension contains hydrophobic particles (with low wettability) adhering to bubbles and forming thus particle-bubble aggregates. The process of the aggregate development occurs at interfaces of three phases (particle – air – water). The stability of the formed complex system depends on the particle and bubble sizes, physico-chemical properties (hydrophobicity, interfacial tension) andhydrodynamic conditions.[4] The most important separation criterion in flotation is the different surface wettability of the particles being removed from the suspension (printing ink) and those remaining in the suspension (recycled fibres).[5,6]

The particles having hydrophobic surface or being hydrophobized by additives may undergo flotation in acertain range of their size.[7] By means of deinking, particles from 10 to 250 μm are removed with high efficiency and high yield of fine particles and fillers. There are also systems able to remove larger particles (up to 500 μm) with corresponding efficiency.[8]

The efficiency of printing inks removal in waste paper processing can be improved by applying surfactants. Surfactants form anecessary component in the pre-treatment of pulped paper. In soaping by sodium hydroxide, filler and printing ink carrier undergo decomposition. The printing ink thus detached must be stabilized and impeded torebond to pulp fibres. To accomplish this target, surfactants are mostly used.[9,10]

Surfactants are substances changing reaction conditions at phase interfaces, even in low concentration. Based on the mode of their dissociation in aqueous media, they are classified as ionic (anionic, cationic andampholytic) andnon-ionic. In paper production, all types of surfactants are applied in a wide range.[11]

Based on the results obtained by Botková*et al.*[12] devoted to the selection of asuitable surfactant to improve the removal of printing ink from suspension, this work is focused on the investigation of recycled fibre wettability within the impact of anon-ionic surfactant in combination with soft soap.

EXPERIMENTAL

Materials

Waste paper brightening by flotation indeinking technology is carried out due to the different wettability of the particles present in the suspension. To verify the influence of surfactant and/or soap charge in the waste paper brighteningby flotation, recycled laser printed paper was used. The toner composition is given in Table 1.

Chemicals

Non-ionic surfactant PEDISOL® N 121,polyethylene dispersion in water functioning as a softening agent intended primarily for textile industry provided by company Chemotex, Děčín, ČR, was used (relative density (20°C)= 1000 kg.m^{-3}, dynamic viscosity (20°C) <100 mPa.s, dry matter content= 24-26%, content of an ethoxylated fatty alcohol C_{12}-C_{15}<5%, biodegradable). Soft soap was used as foam-forming substance.

Flotation procedure

Laboratory-scale flotation was performed in an acrylate flotation cell (total volume = 12.6 L).

Waste paper was allowed to soak for 24 hours in tap water with added 1wt% sodium hydroxide (standard conditions) and an exact surfactant amount. Subsequently to soaking, the sample was pulped according to STN ISO 5263-1 (0.5% consistency, 21°C). Asample withdrawn from the pulped slurry was washed and put aside for further analyses. The remaining pulp was transferred to aflotation cell. Air was blown to the flotation cell bottom and stirrer rotations were adjusted to arequired value. After the mixing, soap was added to the slurry. The foam formed during flotation and containing (dispersed) particles of printing ink was removed through the flotation cell discharge hole. After terminating the flotation, the paperpulp was washed with tap water and put aside for further analyses (Fig. 1)

Table 1
General composition of powdered toner for laser print

Binding agent* (wt%)	Colour forming component** (wt%)	Additives (wt%)	Size of components (μm)	Fixation
80-90	5-15	1-3	5-15	pressure + temperature

*Polystyrene-metacrylate copolymer, polyesters; **Pigment

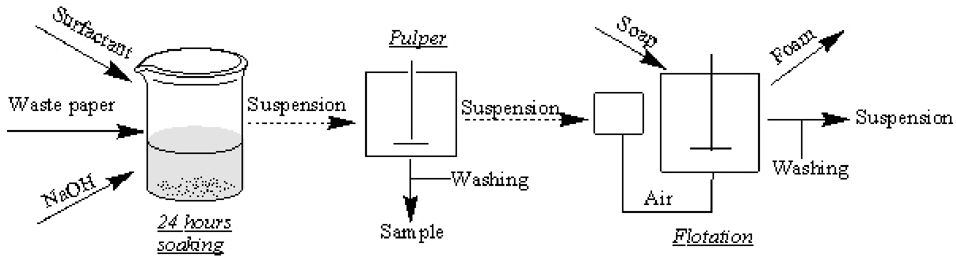

Figure 1: Schematic representation of the flotation procedure

Image analysis

To evaluate the flotation process efficiency, the method of image analysis was applied. Test sheets were prepared from the paperpulp originating from flotation and from pulped waste paper, and analysed using the image analysis technique, provided by the Motic Image Plus 2.0 software. The obtained values were processed according to the relation (1):

$$\text{ink removal efficiency (\%)} = \left(1 - \left(\frac{\text{printing ink total area after flotation}}{\text{printing ink total area before flotation}}\right) \times 100\%\right)$$

Conditions of flotation

For laboratory-scale verification of the influence of surfactant and/or soap charge in waste paper bleaching, the method of statistical design of experiment, developed by Box, Wilson[13] and Box,Hunter,[14] was used. In this experiment, a 3-factor experimental design (2^3 + star design), in which the impact of three factors, namely the surfactant charge (in % to oven-dry pulp, X_1), soap charge (in % to oven-dry pulp, (o.d.p.) X_2) and flotation time (min, X_3), was applied. The monitored flotation parameters reached the following values (in coded expression): -1.682, -1, 0, 1, and 1.682. The range of actual parameters is given in Table 2.

Flotation experiments were performed under the conditions defined in Table 3. The other flotation parameters were kept constant: sodium hydroxide charge 1 wt%, 0.5% consistency, air flow rate through the flotation cell 5.5 L/min, andstirrer revolutions 4400 rpm at 21°C.To calculate dependences, statistical software Statgraphics[15] was used.

Table 2
Coded and actual levels of the quantities in 3-factor and 5-level experimental design

Factor	Mark	Range and level of factors				
		-1.682	-1	0	1	1.682
Surfactant charge (% o.d.p.)	X_1	0	1	2.5	4	5
Soap charge(% o.d.p.)	X_2	2	3	5	7	8
Flotation time (min)	X_3	1	7	15.5	24	30

Table 3
Conditions and results of flotation

N	Factors			Variables			Efficiency, %
	X_1	X_2	X_3	X_1 Surfactant charge, % o.d.p.	X_2 Soap charge, % o.d.p.	X_3 Flotation time, min	
1	-1	-1	-1	1	3	7	72
2	1	-1	-1	4	3	7	71
3	-1	1	-1	1	7	7	77
4	1	1	-1	4	7	7	71
5	-1	-1	1	1	3	24	73
6	1	-1	1	4	3	24	88
7	-1	1	1	1	7	24	85
8	1	1	1	4	7	24	74
9	-1.682	0	0	0	5	15.5	81
10	1.682	0	0	5	5	15.5	78
11	0	-1.682	0	2.5	2	15.5	86
12	0	1.682	0	2.5	8	15.5	80

13	0	0	-1.682	2.5	5	1	55
14	0	0	1.682	2.5	5	30	82
15	0	0	0	2.5	5	15.5	81
16	0	0	0	2.5	5	15.5	76
17	0	0	0	2.5	5	15.5	78
18	0	0	0	2.5	5	15.5	83
19	0	0	0	2.5	5	15.5	82
20	0	0	0	2.5	5	15.5	79

RESULTS AND DISCUSSION

The efficiency values for the three followed parameters influencing the flotation process are listed in Table 3.

The variance analysis leads to the conclusion that the flotation efficiency of95% probability is influenced by the flotation time ($p = 0.0006$), the quadratic member of the flotation time ($p = 0.0033$) and the interaction of the surfactant and soap charges ($p = 0.0243$) (Table 4). On the contrary, the surfactant and soap charges and their quadratic values do not influence significantly the resultant efficiency of printing ink removing by flotation, their $p > 0.05$.

The impact of added surfactant and soap into the suspension of printed waste paper on their deinking efficiency can be described by the following regression equation:

$$\begin{aligned} \textit{Efficiency}\ (\%) = {} & 49.028 + 5.057*(X_1) + 0.933*(X_2) + 2.368*(X_3) - 0.133*(X_1)^2 \\ & - 1.292*(X_1*X_2) + 0.108*(X_1*X_3) + 0.285*(X_2)^2 - 0.051*(X_2*X_3) \\ & - 0.056*(X_3)^2 \end{aligned} \qquad (2)$$

The optimum values for reaching the maximumefficiency, i.e. 96%, were obtained for the suspension containing 5% of surfactant and 2% of soap to oven dried pulp (o.d.p.).

Table 4
Variance values for flotation efficiency of 3-factor experimental design

Source	Variance p-value
X_1: surfactant charge	0.6109
X_2: soap charge	0.6903
X_3: flotation time	**0.0006**
$(X_1)^2$	0.7919
X_1X_2	**0.0243**
X_1X_3	0.3693
$(X_2)^2$	0.3974
X_2X_3	0.5630
$(X_3)^2$	**0.0033**

Table 5
Optimum values of the monitored factors for maximum 96% efficiency

Factor	Unit	Min. value	Max. value	Optimum value
X_1: surfactant charge	% o.d.p.	0	5	5
X_2: soap charge	% o.d.p.	2	8	2
X_3: flotation time	min	1	30	25

Flotation time was 25 minutes (Table 5). Fig. 2 presents the impact of surfactant and soap charges on the flotation efficiency at the optimum flotation time of 25 minutes. It is obvious that the efficiency rises up to 88% withincreasing soap charge and zero surfactant content. On the other hand, increasing the surfactant charge during flotation at 2% soap charge to o.d.p., the efficiency reached its maximum value (96%). It can be also noted from Figure 2 that increasing the surfactant charge simultaneously with decreasing the soap charge increasestheefficiency. The reason is that the strength of the non-ionic surfactant predominates over the soft soap ionic strength, leading to foaming and may include increasing flotation efficiency. This finding has apositive effect on the removal of printing ink from the suspension. Combining these two parameters, only 84% efficiency is reached. Increasing soap charge, which is cheaper, led to an efficiency increase, but not to the value used as surfactant charge.

Fig. 3 describes the dependence of flotation efficiency on the soap charge and flotation time. Flotation time exhibits apositive effect on the efficiency, the longer the time, the higher efficiency. It, however, does not concern the soap charge. An increase in the soap charge led to anefficiency decrease down to 72% at the optimum flotation time of 25 min. The optimum values were obtained on the basis of the regression equation for the range defined at the start of the experiment. Marginal values are loaded by error and an extension of time can be assumed to stabilize the efficiency.

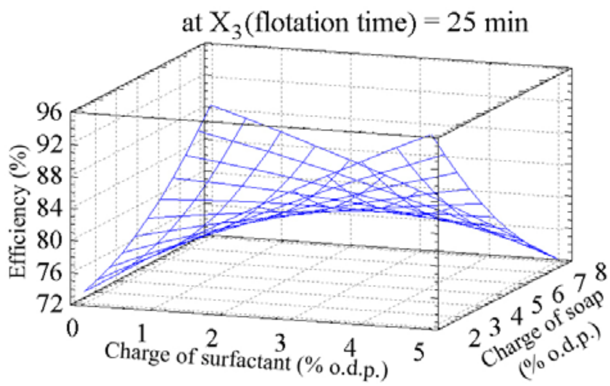

Figure 2: Impact of surfactant and soap charge on flotation efficiency at the optimum constant flotation time of 25 min

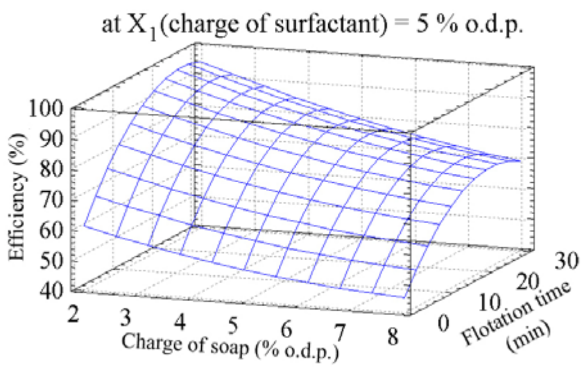

Figure 3: Impact of soap charge on flotation efficiency at the optimum constant surfactant charge of 5% o.d.p.

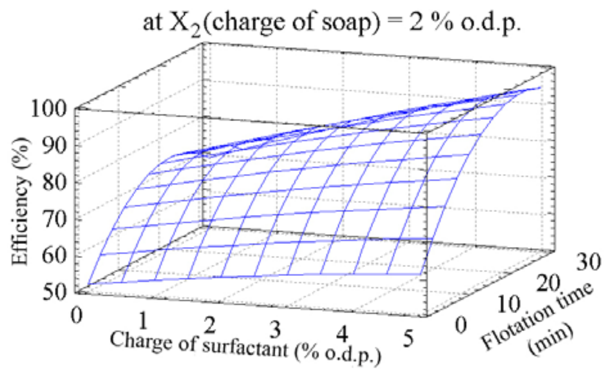

Figure 4: Impact of surfactant charge on flotation efficiency at the optimum constant soap charge of 2% o.d.p.

Table 6
Calculated values of the monitored factors for 99% efficiency

Factor	Unit	Min. value	Max. value	Optimum value
X_1: surfactant charge	% o.d.p.	0	5	5
X_2: soap charge	% o.d.p.	2	8	0
X_3: flotation time	min	1	30	13

The influence of all three parametersinvolved, i.e. surfactant charge, soap charge and flotation time, is clearly demonstrated in Fig. 4. At the optimum soap charge (2% o.d.p.), an increase of the efficiency with increasing surfactant charge is observed. At 25 min flotation time and zero surfactant charge, the efficiency approached 75%, while at maximum 5% o.d.p. charge, it reached 96%.

With the aim to minimize the amount of chemicals added to the flotation process and to reach anas high as possibleefficiency, flotation in the absence of soap was verified. This step could be done as the used surfactant created asufficient amount of foam. No synergy was observed when adding both chemicals, on the contrary, the efficiency gradually decreased.

Applying the above regression equation, the maximum efficiency was calculated and taking the followed parameters into account, the parameters of flotation allowing to exceed 99% flotation efficiencywere obtained(Table 6).

The attained flotation efficiency exceeds commonly reached values. As a result, a reduced amount of bleaching agents to bleach waste paper is needed.

CONCLUSION

The presented experiment was aimed at finding out the effect of adding surfactant and soap to a suspension of printed waste paper on the efficiency in removing printing ink.

The obtained results lead to the finding that with 95% probability, the flotation efficiency is influenced by flotation time, quadratic member of time, and interaction of soap and surfactant charges. The optimum values for reaching maximum efficiency were obtained:96% efficiency can be obtained by 5% surfactant and 2% soap charges to oven-dried pulp during 25 min of flotation. It was observed that the simultaneous addition of soap caused the breaking of the foam formed due to non-ionic surfactant addition, which, in turn, led to adecrease in the removal of printing ink from the suspension in the form of foam.

By altering the starting flotation conditions and excluding soap as an additive, the flotation efficiency can rise up to 99% (5% surfactant charge to oven-dry pulp during 13 min of flotation). It may allow to minimize the concentration of chemicals used in the deinking process and, at the same time, to decrease the amount of required bleaching agents in the subsequent waste paper bleaching. The detrimental impact on the environment is thus reduced.

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