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Separation of cellulose fibres from pulp suspension by froth flotation fractionation

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ABSTRACT

Flotation of cellulose pulp suspension in paper industry is primarily used for separation of ink particles from cellulose fibres. Entrainment, an unwanted phenomena well described in the field of mineral flotation, also leads to a removal of fibres with the flotation froth. We find that the entrainment phenomena can be used for the separation of long fibres from a fibre pulp suspension, and hence for pulp fractionation. Specifically, we use a 2D bubble column to investigate the influence of (i) bubble size, (ii) wash rate and (iii) stirring on the separation of long fibres from cellulose pulp suspension. Separation of fibres from fibre pulp suspension is tested for mechanical pulp and chemical pulp. We find that size selective recovery yields best result for (i) large bubbles, and (ii) additional washing due to the increase of small particle drainage. However, both strategies lead to a reduction of the total recovery rate. Stirring significantly improved the total recovery and benefited the selective separation. Best results are achieved with small bubbles for chemical pulp. For mechanical pulp, fractionation is more challenging due to lower froth stability, but still fibres with a reduced amount of smaller fraction can be recovered.

1. Introduction

In paper and pulp production, effluent streams containing cellulose fibres, fibre fines, and inorganic fines accrue. Common strategy to reduce waste in paper and pulp production is to recover fibre and fibre-fines and reuse them in paper and/or paper board production [1,2]. However selectively recovered cellulose fibres could also be used as raw material for plastic compounds [3–8]. Classical separation of cellulose fibres and fibre-fines by size are mechanical screening and separation technologies [9]. Pulp is typically fed at concentration of several percent. For those obviously the process energy demand increases with decrease of concentration as more water has to be pumped. Flotation can serve as alternative process for recovering cellulose fibres, especially from thin suspension.

Flotation of cellulose fibres typically occurs as unwanted effect in de-inking of recycled paper. Along with the hydrophobic ink particles, fibres are removed with the froth. In the past decade, researcher could show, that the removal of fibres and fibre-fines which are hydrophilic, occurs rather due to entrainment than due to true flotation [10–18]. Ajersch [11] reported, that gas bubbles do not adhere or form at the fibre surface. Deng et al. [13,18] performed experiments with surface modified fibres. The amount of fibres removed by flotation did increase for modified fibres with a hydrophobic surface (contact angle of 39°). But even for hydrophobic fibres 67–75% had been removed due to entrainment than by true flotation. Untreated cellulose fibres do not adhere to the ascending gas bubbles but are removed by physical entrainment into the flotation froth. A result which was also shown experimental by Turvey [19,20], however without a mechanistic explanation.

Being entrained into the flotation froth, particles can move freely in the suspension filling the void between the bubbles. Also, they are subject to be removed with the draining suspension water. However, removal rate differ and it is found, that the fibre fraction increases in the froth [21–26].

In this study we perform experiments based on literature suggestion to exploit the capability of flotation froth fractionation on the separation of fibres from thin fibre and fibre-fine suspension. Increased knowledge on the topic will also benefit de-inking flotation where loss of organic material is to be prevented [27], recovery of fibres from effluent streams [28,29], and/or controlled to set certain sludge properties [30]. Additionally, capabilities of controlling fibre to fibre-fine ratio allows to produce paper of differing properties and qualities [31,32].

To highlight the importance of process parameters on the result of froth fractionation we first reviewed literature on entrainment of particles in mineral flotation and de-inking flotation. A special

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focus is given to the change of fibre length distribution in the flotation froth.

1.1. Particle entrainment in flotation froth

A recent review paper by Wang et al. discusses the mechanism of particle entrainment in mineral flotation, and the impact of process parameters [33]. The entrainment mechanism is characterized by particles being trapped in the froth independent on their chemical properties, i.e., wettability. In literature the following phenomena are used to explain the entrainment mechanism: (i) particle transport in the liquid film around the bubble, (ii) particle transport in the wake of rising bubbles, and (iii) bubble swarm theory. The bubble swarm theory after Smith and Warren [34] is illustrated in Fig. 1, Step 1 to Step 2. It is assumed, that particles at the suspension froth interface (Step 1) are pushed in the froth (Step 2). This might be especially important for fibrous material forming coherent networks. For such it is noticed, that small bubbles accumulate beneath the flock leading to a rise of the flock as a whole [11,17,35,36].

Due to differences in the density (and the build-up of a hydrostatic pressure gradient), liquid drains from the froth to the suspension through the plateau borders between the bubbles (Fig. 1, Step3). Collapse of bubbles results in an increased transport of liquid. Entrained particles, suspended in the liquid, are removed likewise. Thus, the rate of particle drainage is related to the rate of liquid drainage. However, the intensity of both phenomena can be different [21,37,38]. Factors influencing the recovery of hydrophilic material includes (i) solid concentration in the suspension, (ii) retention time, (iii) froth structure, and (iv) particle size [39]. Important influencing parameters will be explained in detail to understand their effect on the froth fractionation performance:

- The transfer rate of (solely) entrained particles from the suspension into the froth correlates directly with the **particle concentration** in the suspension. A higher particle concentration in the suspension results in a higher particle concentration in the froth [11].
- **Retention time** is the ratio of **froth height** to superficial **gas velocity**. Increasing the froth height results in a larger drainage time, consequently the froth will be drier, and the concentration of entrained particles decreases. For an increase in the superficial gas velocity, which describes an increase in gas flow rate, the carryover of liquid into the froth is larger. Consequently more particles are entrained in the froth. Summing up, an increase in retention time yields a reduction of entrained particles in the froth [16,21]. The limiting factor is the water content of the froth: for a froth being too dry, particle transport stops and entrained particles are permanently captured in the froth. Additional top spraying of liquid prevents the froth from drying out, and increases the drainage rate [21,40–42]. The result is the desired reduction of entrained (small) particles from the froth.
- The **froth structure** is of most importance to the froth stability and hence to the capability of froth containing solids and to the drainage. However the froth structure is complicated to describe and depends on several variables including the water content, aeration rate, bubble size, type of frother (which affect the thickness of the lamella), and the length of the plateau borders. In general, a froth of low coalescence rate consisting of small bubbles promotes high recovery of entrained particles [13].
- Differences in the effect of **particle size** are found for mineral flotation and flotation of cellulose fibres. In mineral flotation, recovery of solids by entrainment reduces with the size of the solids [37,38]. It is argued, that larger particles settle faster towards the suspension in the liquid between the plateau borders. In flotation of cellulose fibres however, an increase of fibre length with the froth height and drainage time is found [21–26]. Those findings are the basis to use flotation froth for length based fractionation of fibres from the suspension. Results of previous studies will be discussed following.

1.2. Fractionation of cellulose fibre fines in flotation froth

Eckert et al. [24,25] used lab-scale copy of a conventional flotation cell to fractionate fibre pulp suspension. Their findings of the influence of operational parameters on the fractionation performance are summarized in Table 1. They noticed a strong correlation of the average length of recovered fibres on the bubble size. However in their study, they could not control the bubble size and noted the bubble size resulting from changing the other process parameters. Zhu and Tan [21–23] looked closer on the dynamics in the fibre laden froth. They found for steady froth, that fibre length evolved with froth height and drainage time. Time evolution of length-based fibre length reached a plateau level. They concluded that a minimum of water flux is needed for fibres to be washed from the froth. For a dry froth, fibres remain permanently trapped. Results show, that mechanical pulped fibres (TMP process) needed nearly twice the time of chemical pulped fibres (Kraft process) to reach the plateau level. Both cases then showed a decrease in length-based fibre length population for fibres smaller 0.8 mm. The fibre consistency in the froth increased, due to drainage of water whilst fibres remained trapped in the froth. Fig. 1, Step 3 sketches the increase of fibre consistency and increase in fibre length. With the draining water, small fibres and fibre-fines are removed whilst the long fibres remain permanently trapped in the froth.

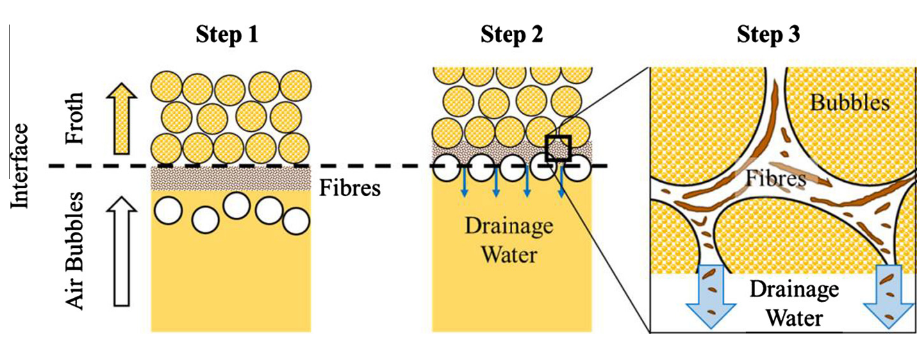

Fig. 1. Step 1 to Step 2 illustrate the entrainment of fibres after bubble swarm theory by Smith and Warren [34]. Fibres are pushed into the froth by ascending bubbles. Step 3 illustrated the reduction of fibre-fines after Eckert et al. [25]. Draining water washed fibre-fines from the froth.