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Effect of Oscillatory Rotary Motion on the Ink Removal in a Laboratory Flotation Column

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***Abstract* - In this paper the effect of oscillatory rotary motion on hp commercial ink removal by flotation was experimentally investigated. The experiments were conducted by a laboratory flotation column equipped with four vertical fins. The fins were rotationally oscillated by a reciprocating mechanism through an angle of 75^o. The tested oscillation frequencies were 0.7, 1.0 and 1.7 Hz. The bubbles were photographed by a digital camera. The flotation tests were performed at different feed ink concentrations. The photographs showed the effect of oscillatory rotary motion on the bubble behavior in the flotation column. The flotation results revealed that the oscillatory rotary motion has an adverse effect on the ink recovery.**

Keywords: flotation column, oscillatory rotary motion, concentration, ink recovery.

I. INTRODUCTION

Froth flotation is a popular separation technology for removing printing ink from paper fibers of *recycled paper*. Mechanical cells are traditionally used for this purpose. Column flotation has been proposed by Watson [1] as an alternative to mechanical cells. In his work, open and packed laboratory and pilot-scale columns were tested. The type of sparger was found to be critical for obtaining high flotation efficiencies. Fine porous stainless steel spargers gave flotation efficiencies that were equal to those of the mechanical cells.

Jones and Walmsley [2] investigated the deinking behavior of different shaped deinking cells of the same volume. The results showed that vertical injection into a rectangular cell gave stable flow patterns, non-wavy froth removal. Horizontal injection exhibited wavy froth and excessive recirculation flow patterns. The cylindrical cell with tangential injection produced stable circulatory flow and stable froth removal at low flow rates.

Beneventi et al. [3] investigated the influence of different de-inking chemistries on ink removal selectivity by using a flotation column. A surfactant-fatty acid blend and a conventional fatty acid soap were used. The surfactant/fatty acid blend gave ink removal selectivity higher than that obtained with fatty acid soap. Vashisth et al. [4] reviewed the progress made in the period (2000–2010) in deinking hydrodynamics, various measurement techniques, scale-up and design criterion.

Al-Maghrabi and Mosallem [5] evaluated the using of oscillatory baffled column for removing *hp*-ink from water. For tested frequencies, the ink recovery decreased in comparing to that of the unbaffled column. Mosallem and Ahmed [6] evaluated a flotation column equipped with two vertical rotating blades in the field of ink removal. At low feed ink concentrations and rotation speed of 60 rpm, the ink recovery increased by nearly 20% compared to that obtained in the absence of rotation.

The objective of the present work is to study the effect of oscillatory rotary motion on the ink recovery by using of flotation column equipped with four vertical oscillating fins.

II. MATERIALS AND METHODS

a) Flotation column setup

The experiments were carried out in a vertical Perspex column made with a height of 100 cm and a *square cross-section of side* 6 cm as shown in Figure 1. Four vertical fins of length 29 cm are attached to a central vertical shaft. The fins are inserted in the collection zone and they are rotationally oscillated by a reciprocating mechanism through an angle of 75^o. The mechanism was driven by a variable speed motor. The tested oscillation frequencies were 0.73, 1 and 1.65 Hz. The bubble generating device was a filter cloth covered sparger which was operated in a horizontal position at the column bottom, just above the tailing's exit. A compressed air was passed to the air sparger. The total air flow rate was measured using a flow meter. The *experiments were carried out at constant superficial gas velocity,* J_g of 3.6 cm/s. The average gas holdup was measured by the bed expansion method, [7]. An anionic surfactant, sodium dodecyl sulfate, SDS (chemical formula: $C_{12}H_{25}NaO_4$) was used as a collector. The used surfactant concentration,

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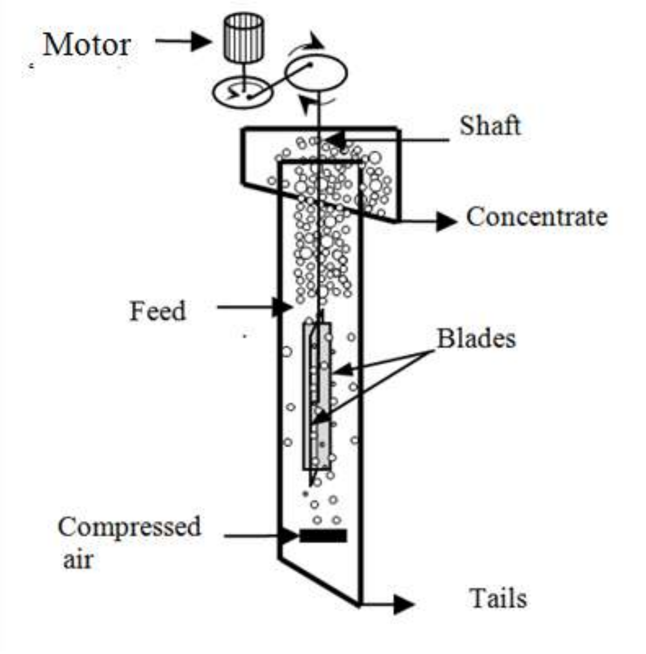

Figure 1: Schematic of the froth flotation apparatus

b) Photography experiments

The proper distribution of gas bubbles over the cross-sectional area of the flotation column and the bubbles behavior are important factors that affecting the separation efficiency of the flotation unit. In order to understand the effect of rotational oscillation frequency on bubbles behavior, a series of bubble photography experiments were performed for a swarm of bubbles in a clear water (without SDS) at a feed flow rate of 222 mL/min corresponding to superficial feed velocity, $J_f = 0.1$ cm/s The bubbles were illuminated *using* fluorescence light, that is projected onto the column. The bubbles were photographed by both still and video digital camera. The photos were later computer processed.

c) Flotation tests

Prior to flotation tests, the *hp*-ink (particle size 50-150 μm) pulp was prepared in a conditioning tank where the feed concentration was adjusted to the desired values. While the pulp was being conditioned, the column was filled with tap water to a few centimeters below the feed point. The air was switched on and adjusted to the desired rate. Then the fins oscillation frequency was adjusted to the desired value. The pulp was then pumped into the column at a height approximately 65 cm from the bottom of the column. The tailing pulp is extracted out the bottom through a valve that controls pulp level, whereas the froth freely overflowed from the column top. *The froth depth was maintained at* 40 cm. After sufficient time allowing, samples from feed, and concentrate streams were collected. The Ink recovery was evaluated by comparing the ink concentration present in the concentrate with that in the feed. To measure the ink concentration a similar technique to that followed by Leichtle [8] was used:

1. An appropriately sample of the stream was taken (100 mL).
2. The sample was thoroughly mixed prior to filtering with pre-weighted filter paper.
3. The filter paper was removed and then dried using a conventional fan.
4. After drying, the filter papers were weighed on an electronic balance and `the ink concentration was calculated.
5. Once the ink concentration was measured, a flotation recovery was calculated which is defined as the amount of ink removed relative to ink in the feed.

III. RESULTS AND DISCUSSIONS

a) Photography Results

The obtained pictures *showed* the behavior of bubbles in the column for the three rotational oscillation frequencies of the fins. For frequency of 0.7 Hz, the pictures in Figure 2 show that some bubbles (e.g. bubble No. 1) rise upward along the column centre. Other bubbles (e.g. bubbles No. 2 and 3) rise upward along the wall and hit the column sidewall several time during their rising as indicated by the arrows in the Figure.

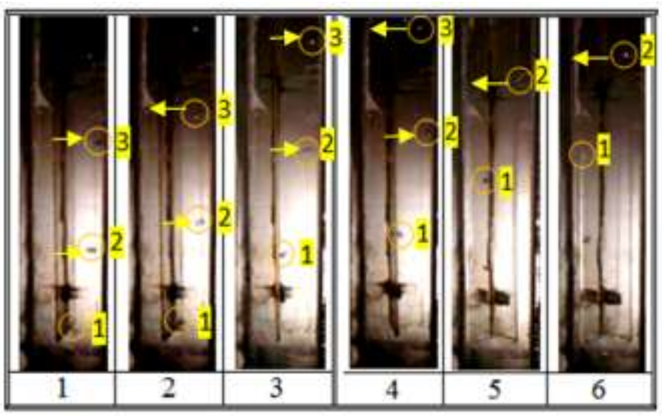

Figure 2: Bubble behavior in the collection zone, $f = 0.7$ Hz

When the oscillation frequency was increased to 1.0 Hz, the fins lightly hit the bubbles (e.g., bubbles No. 2, 3 in Figure 3). The bubbles push toward the column sidewall and collide with it. Therefore, the bubbles are not well distributed across the column cross-sectional area.

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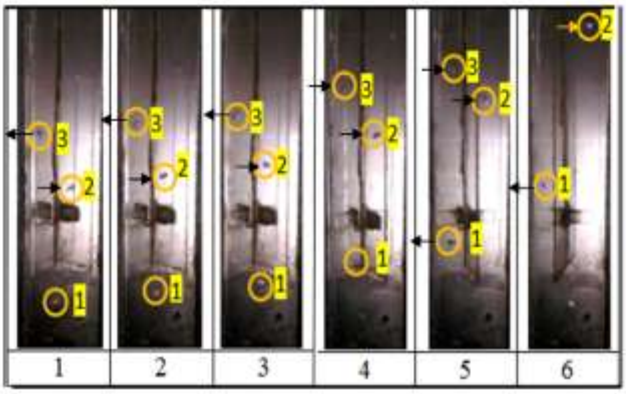

Figure 3: Bubble behavior in the collection zone, $f = 1.0$ Hz

For oscillation frequency of 1.7 Hz, two phenomena were observed. One phenomenon was that the fins strongly hit the bubbles towards the column sidewall. The bubbles strongly collide with the sidewall and bouncy again toward the fins. Therefore, the bubbles move "back and forth" across the column between the fins and the column sidewall similar to the ping pong ball movement as *shown* by *the pictures in Figure* 4. As a result, the bubbles raise velocity decreased. The result is that a much more difficult to distribute the bubbles out over the full cross-sectional area of the column.

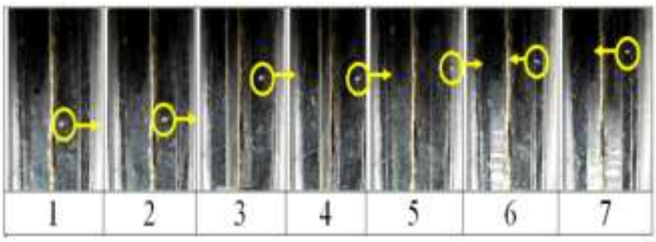

Figure 4: Bubble behavior in the collection zone, $f = 1.7$ Hz

The second phenomenon was that some bubbles at the column center in-between the fins were observed to move downward (sink) as shown in Figure 5. When these bubbles move away from the center of the column, they rise up again. The phenomenon was observed for the small bubble size. As reported by Brennen [9], when acceleration is exerted on a fluid by acceleration of a body moving through the fluid, additional inertial forces act on the body due to the 'added mass' effect. The added mass concept was proposed by Friedrich Bessel in 1828 to describe the motion of a pendulum in a fluid, [10]. Therefore, in the absence of oscillation, the bubbles move upward because the buoyancy force on the bubbles is greater than the gravitational force. When the oscillation is imposed on the flow, the bubble gains an added mass. When the oscillation is fast enough, the added mass will cause the gravitational force to be greater than the buoyancy force. Thus, the bubble sinks.

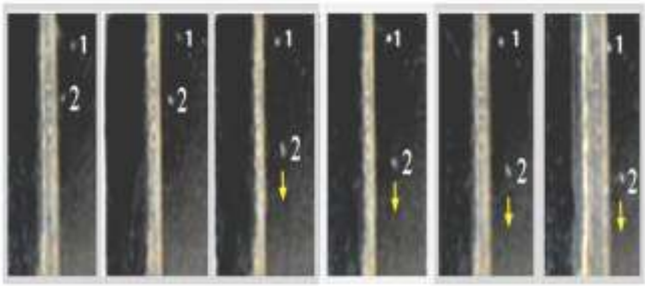

Figure 5: The sinking bubbles phenomenon, $f = 1.7$ Hz

b) Flotation results

To determine the effect of oscillatory rotary motion on the ink recovery, tests were performed at different feed ink concentrations and different oscillation frequency. The average feed flow rate was 222 mL/min. Figure 6 shows the effect of feed ink concentration on ink recovery at different rotational oscillation frequency, *f*. As expected for all tested frequencies, the experimental data show that the ink recovery decreases with the increase in feed ink concentration. As feed ink concentration increases bubble surface available for flotation decreases.

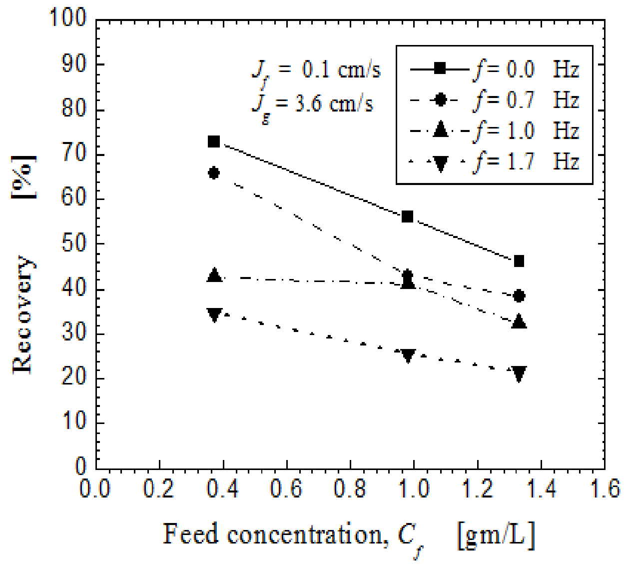

Figure 6: Effect of feed ink concentration on ink recovery

Fig. 7 shows the effect of rotational oscillation frequency f. on ink recovery at different feed ink concentrations. It can be observed that the ink recovery decreases as the rotational oscillation frequency increases.

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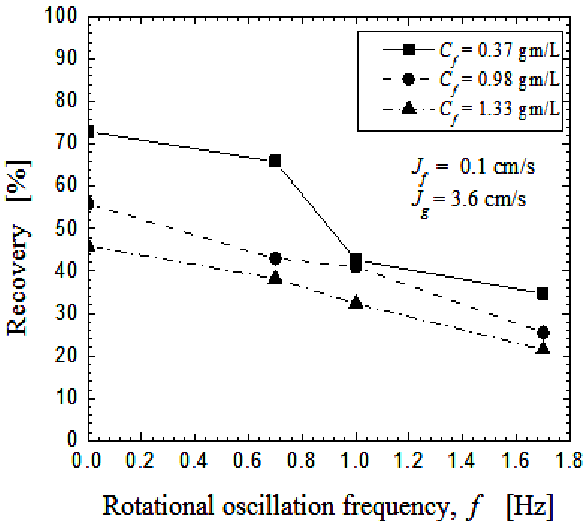

Figure 7: Effect of oscillation frequency on ink recovery

According to the bubble photography results, these findings can be explained as follows: At low frequency ($f = 0.7$ Hz) the bubble collides with column sidewall. Thus, the bubbles may lose some ink particles. Moreover, there is an improper distribution of gas bubbles across the column cross-sectional area. Therefore, the ink recovery decreases. As previously discussed, when the frequency was increased to 1.0 Hz, the fins lightly hit some rising bubbles, and the number of bubbles that collide with the column sidewall increased. This may result in more detaching of ink particles from the bubbles' surfaces and consequently, more decreasing in the recovery. For oscillation frequency of 1.7 Hz, the fins strongly hit the bubbles and the bubbles collide with the column sidewall. This causes much more detaching of ink particles from the bubbles' surfaces. Additionally, the sinking bubbles phenomenon increases the possibility that the ink particles will detach from the bubbles' surfaces. Therefore, further decreasing in ink recovery.

Finally, the present study indicates that the oscillatory rotary motion adversely affects the performance of the flotation column due to the following:

1. The lack of good bubble distribution across the cross-sectional area of the column
2. Hitting the bubbles with the oscillating fins
3. The sinking bubbles phenomenon

IV. CONCLUSION

The effect of oscillatory rotary motion on the ink removal by flotation was studied. *Bubble photography* and flotation experiments were conducted and the *following conclusions* were drawn:

1. A lack of good bubble distribution across the cross-sectional area of the column
2. The sinking bubbles phenomenon was observed at oscillation frequency of 1.7 Hz
3. The oscillatory rotary motion adversely affects the performance of the flotation column where the ink recovery decreases with increasing the rotational oscillation frequency
4. The *photography* results helped in interpreting the flotation results

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