First Industrial Flotation Column in a Paperboard Recycling Plant

1 Yuxia Ben, 1 Gilles Dorris, 1 Natalie Pagé, 1 Sylvain Gendron, 1 Norayr Gurnagul, 2 Christian Desrosiers, and 2 Patrick Maltais

1Pulp and Paper Research Institute of Canada, Pointe-Claire, Québec, Canada
2Kruger Inc., Place Turcot Paperboard Mill, Montreal, Québec, Canada

ABSTRACT

We describe the steps that have led to the construction of a small industrial flotation column in an Old Corrugated Container (OCC) recycling plant. First, flotation tests were carried out at Paprican using samples from the mill. Following this evaluation phase, a laboratory column was installed at the mill, where OCC fresh pulp and process rejects were processed in the column. Flotation removed macrostickies, wax, fillers, and organic extractives, while fibre loss was minimal. The laboratory column was then used to develop control algorithms aimed at reducing variations in froth heights and air content in the column. After this successful testing phase, the mill installed a 0.6 m by 6.0 m column. Flotation efficiencies in the larger column approached those obtained with the laboratory column. At this stage of development, the mill column is used as an R&D unit to establish its long-term performance and to determine the impact of recovered materials to the main OCC pulp line. Flotation trials to date have shown no negative impact of recovered fibres on mill operation. The R&D column will be in full-time operation this year for the recovery of 2.5–3.5 tpd of fibre from reject streams.

INTRODUCTION

In the first report of a series on column flotation application in paper recycling, the basic principles of the technology were presented [1]. Reject streams from newsprint, fine paper, and board recycled mills were treated using a laboratory flotation column. The technology showed good potential for recovering valuable fibrous materials from certain streams, such as the solid rejects of dissolved air flotation (DAF), used for water clarification. Moreover, column flotation was also evaluated for its ability to clean recycled pulps for newsprint, fine paper, and board production, respectively. In all pulp streams, column flotation was very effective in removing ink and hydrophobic contaminants, while froth washing resulted in material losses in the 1% to 3% range.

These encouraging results prompted one of the participating project partners (Kruger Inc., Place Turcot mill) and Paprican to further pursue the evaluation of this technology. This recycling plant produces paperboards from recovered OCC and waste papers. The diversity of raw materials leads to large fluctuations in the type and amount of hydrophobic contaminants in the pulp stocks. Of the non-fibrous elements in recovered papers, stickies and wax have the most detrimental effects on paperboard quality and machine runnability. To remove these contaminants, OCC is processed in a conventional stock preparation process consisting of low-consistency pulping, HD cleaning, coarse screening, fine screening, cleaning, washing, thickening, and water clarification by dissolved air flotation using a Krofta unit. Figure 1 presents a simplified process layout of the OCC recycling plant. Though these unit operations remove a significant part of the contaminants in the stocks, more stringent quality requirements in new board products combined with more contaminated recovered papers dictate that new and/or improved separation steps be included in pulp processing for paperboard production. Currently, flotation in conventional cells is not being used in North American board mills but there is a definitive trend to include it in the separation steps [1–5]. Some key limitations to the installation of conventional flotation cells in the OCC recycling process are high flotation losses [3] and large floor space requirement. These restrictions are largely overcome by the use of flotation columns, which differ from conventional cells by their greater height-to-diameter ratios, lack of mechanical agitation, and the presence of a downward water stream to wash a tall froth.

In the first phase of this project, flotation tests were carried out at Paprican using samples shipped from the mill in totes of 1 m³ capacity [1]. Following these preliminary tests, a laboratory column was installed at the mill site. The fresh OCC pulp and process rejects were pumped directly into the column. In this report, we present representative results obtained from these samples. We also describe how the laboratory column was used to develop control algorithms aimed at reducing variations in froth heights and air content (also called gas holdup) in
the column. Finally, we provide some details on the construction of a 0.6 m by 6.0 m column erected at the mill site, using scale-up parameters determined by Paprican. The same streams, previously tested in the laboratory column, were floated this time in the larger column and the results compared with those obtained with the laboratory column.

![Diagram of OCC recycling process at Kruger Inc. Place Turcot mill.](image)

**Figure 1.** Simplified process layout of OCC recycling process at Kruger Inc. Place Turcot mill.

## EXPERIMENTAL

*Laboratory and Mill Flotation Columns*

To evaluate column flotation, Paprican’s laboratory flotation column (10.2 cm in diameter and 4.65 m in height) was installed at the Kruger Inc., Place Turcot mill. The flotation column, which was previously described [1], is presented in Figure 2a.

Following the initial testing, the plans and Pump and Instrumentation diagrams were prepared for the construction of a small industrial unit of 0.6 m in diameter and 6.0 m in height. The mill installation is shown in Figure 2b.

To carry out the tests in the laboratory column, pulp or reject samples were piped directly into a feed reservoir. For the tests with the mill column, pulps and rejects were pumped directly into the column. Choice of operating conditions, such as air velocity, residence time, and washing water flow rate, varied from sample to sample but in general, these conditions were based on the extensive work of Finch, Gomez *et al.*, carried-out on ONP/OMG pulps [6–11]. Samples of feed, accepts, and rejects were taken for analysis, after at least three retention times in the column.
Macrostickies and Wax Content

Macrostickies and wax in OCC pulp were quantified using an in-house procedure, based on the BetzDearborn Stickie printing method [12]. From each sample, five handsheets of 1 g were prepared right after sampling and dried in an oven at 100°C. Each handsheet was pressed at 230°C and 13.8 MPa (2000 lb/in²) between two filter papers for 2 min. After pressing, the filter in contact with the top (felt side) of the handsheet was dyed in black using a flexographic ink. The un-dyed macrostickies and waxes transferred to the filter paper were counted by image analysis using the reverse imaging mode.

Extractives Content

Chloroform extractions were carried out on flotation feed, accept, and reject using a Soxtec system (HT 1043 Extraction Unit) on filter pads prepared with a fixation aid [13-14]. The chloroform extracts contained a complex mixture of wax, wood resin and stickies components.

Flotation Losses

Flotation losses were calculated based on the mass balance of ash contents in the flotation feed, accept, and reject. Organic and inorganic contents in each stream were determined by thermogravimetry [15].

Fibre Length Distribution

Fibre length distribution of the samples before and after column flotation was determined with a Bauer McNett classifier according to TAPPI Method T233 cm-82.

Board Strength Properties

The effect of flotation on board strength properties was determined on the OCC pulp and on Krofta rejects. Handsheets of high basis weight (127 g/m²) were prepared before and after flotation for physical testing. Strength properties were determined using Standard PAPTAC Methods.
RESULTS AND DISCUSSION

Laboratory Flotation Column

OCC Recycled Pulp

Figure 3 shows that, over a period of one month, macrostickies and wax in the OCC pulp varied significantly with time. Previous work had indicated that the contaminants in this type of pulp were naturally hydrophobic and that the pulp contained natural frothing materials [1]. Thus, column flotation tests at the mill were carried out without any additional flotation collector. At pulp consistency of 0.7–0.9%, air content of 18–20%, froth level of 50 cm and retention time of 3 to 4 minutes, removal of macrostickies and of wax in the OCC pulp was very good (Figure 3). Moreover, after flotation treatment, the concentration of hydrophobic contaminants in pulps was quite constant despite the highly variable concentrations of contaminants in the feed pulps.

Table I summarizes column performance in removal of macrostickies and wax, filler, and extractives; and in flotation losses. Overall, the flotation efficiency of macrostickies and wax was consistently in the 70–85% range, even without any chemicals added. Flotation also removed 15% of inorganic fillers and 30–35% of extractives. Counter-current washing of the froth helped to keep the total material loss below 2%.

Table I

<table>
<thead>
<tr>
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<th>Column performance on contaminant removals and on flotation loss.</th>
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<tbody>
<tr>
<td>Macrostickies and wax removal, %</td>
<td>70-85</td>
</tr>
<tr>
<td>Filler removal, %</td>
<td>15</td>
</tr>
<tr>
<td>Chloroform extractives removal, %</td>
<td>30-35</td>
</tr>
<tr>
<td>Flotation loss, %</td>
<td>&lt; 2</td>
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</tbody>
</table>

Figure 3. Macrostickies and wax in OCC pulp before and after column flotation; Y-axis is a relative scale. Value of one was arbitrarily assigned to the feed sample of November 3, 2006.
The Bauer McNett classification of the OCC pulp before and after column flotation indicated that fibre length distribution remained unchanged, which was consistent with the low flotation losses. These results, obtained at mill sites with fresh samples, confirmed previous data obtained for similar samples in Paprican testing [1]. Clearly, flotation is an effective technology for decontamination of OCC pulps.

Process Rejects

As shown in Figure 1, the process rejects to be treated by column flotation come from two sources: solids discharged from the Krofta and heavy rejects from Cleanpac cleaners. In Cleanpac cleaners, and heavy and light contaminants are removed simultaneously by different outlets. The feed of Cleanpac cleaners was a blend of secondary cleaner rejects and tertiary screen rejects. The feed for the column was based on the analyses of the flow, consistency, and composition of each reject stream making up the total rejects. Figure 4 illustrates the widely variable range of size and amount of macrostickies and wax in Krofta rejects, secondary cleaner rejects and tertiary screen rejects, respectively. The amount and size of macrostickies and wax in Krofta rejects were much lower than those in the two other reject streams. Hence, the Krofta rejects was the most promising stream for treatment by column flotation and its segregation was desirable. However, we were not able to isolate Krofta rejects from other reject streams. Thus, column flotation tests were performed with a blend of Krofta and Cleanpac heavy rejects.

Column flotation at six-minute retention time removed 70–80% of macrostickies and wax from the process rejects. However, because of high concentration and very large-size contaminants in the rejects, the amount of contaminants in the flotation accepts was still high. Figure 5 shows macrostickies and wax (white spots) in handsheets prepared from flotation feed, accepts, and rejects. Clearly, column flotation significantly reduced macrostickies and wax contaminants in accepts and concentrated hydrophobic contaminants in the flotation froth. The photos also illustrate that the particle size of macrostickies in flotation accepts was larger than that in the flotation feed, which indicates that larger particles of macrostickies and wax were less floatable than smaller ones.

![Figure 4](image1.png)  
**Figure 4.** Macrostickies and wax in Krofta rejects, secondary cleaner rejects, and tertiary screen rejects.

![Figure 5](image2.png)  
**Figure 5.** Illustrations of the fate of macrostickies and wax during column flotation of process rejects.
Impact of Column Flotation on Board Strength Properties

At the Kruger mill in Place Turcot, macrostickies and wax particles are removed mainly by screening and centrifugal cleaning. Because of frequent changes of papermaking stocks, the performance of screens and cleaners was highly variable. It was felt that a flotation step of pulp stocks could enhance contaminant removal and improve board strength properties. Hence, we evaluated the physical properties of OCC pulp before and after column flotation tests. Table II summarizes the changes in Canadian Standard Freeness (CSF) and strength properties induced by flotation. For average of the three tests, column flotation enhanced the freeness and strength properties of the pulps. The increase in strength properties may be attributed to a combination of ash and lipophilic material removal and enhanced refining potential of the pulps after flotation.

<table>
<thead>
<tr>
<th>Pulp</th>
<th>CSF</th>
<th>Burst</th>
<th>Tensile</th>
<th>Ring Crush</th>
<th>Scott Bond</th>
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<tbody>
<tr>
<td>OCC-1</td>
<td>+9</td>
<td>-0.5</td>
<td>-5</td>
<td>-9</td>
<td>-15</td>
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<td>OCC-2</td>
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<td>OCC-3</td>
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</tr>
<tr>
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</tr>
</tbody>
</table>

Control of Flotation Column

To obtain full advantage of column flotation, it is important to control and optimize the process variables which have a strong influence on contaminants removal. To ensure a stable operation and consistent flotation efficiency despite frequent changes in feed flow and composition, the laboratory flotation column was used to develop a supervisory control system that oversees air content (also called gas holdup) and froth level of the column.

Figure 6 illustrates the salient points of the supervisory control strategy for the laboratory flotation column. The air content and the froth level are inferred from two pressure measurements. To adjust the air content and froth level, the control system manipulates the accept flow and the air flow. The feed flow is not manipulated by the supervisory control but may vary independently according to production requirements. It is thus treated by the flotation control system as a measured disturbance.

The structure of the supervisory control system is presented in Figure 7. The operator provides setpoints for the froth level and air content. The supervisory controller is a Model Predictive Controller (MPC) which computes setpoints for air and accepts flows that are then supplied to low-level PID (proportional-integral-differential) controllers.
There are three steps involved in implementing the MPC controller: 1) inject test signals in the form of ‘bump’ changes in the manipulated variables and record the variations of the measured variables; 2) from the data acquired in the first step, estimate the dynamic models connecting the manipulated variables (air flow, accepts flow) to the measured variables (the pressures); 3) Supply the estimated models to the MPC controller and run it. If the control performance is not satisfactory, this may be due to modelling uncertainty stemming from inadequate estimation data (e.g. bumps were not big enough or long enough or process was disturbed by unmeasured disturbances). In that case, one may repeat the model estimation procedure (usually one or two iterations are sufficient).
Figure 8 shows the performance of the MPC controller for the laboratory flotation column running at Kruger Inc., Place Turcot. During this run, the feed flow was modified at certain indicated instants. These caused froth level variations that were quickly corrected.

![Figure 8. Variation of froth level and air content caused by column feed changes. MPC controller on laboratory process.](image)

**Mill Flotation Column**

**Scale-Up, Construction, and Control**

Following successful laboratory-scale tests, a 0.6 m by 6.0 m column was constructed in the mill. However, the efficiency of flotation tends to decrease with increasing column size [16] and this must be taken account in the column design. As columns get wider, internal circulation increases, wall support for froth layer decreases, and solids in froth have greater tendency to drop back in suspension because of longer lateral distances to reach the column lip. Great care is therefore required in the scale-up of flotation columns. Considerable efforts made during the last 20 years in modelling flotation columns have led to more reliable column sizing. A good overview of scale-up procedures for column flotation has been presented by Finch, Dobby and Xu [17–18]. Currently, the best criterion of a column scale-up is the superficial bubble surface rate, which is the surface area of air bubbles generated per unit time per unit cross-sectional area of the column. This variable controls the collection rate constant and will eventually dictate column geometry, feed and washer rates, froth height, and the degree of aeration required to obtain the desirable flotation efficiency. In this work, we used the axial dispersion model and the bubble surface area flux theory [19] to scale-up the flotation column for the mill.

Based on our trial results obtained at the mill site, it was established that the 0.6 m by 6.0 m flotation column could recover 2.5–3.5 t/d of valuable materials from reject streams. Thus, based on flotation kinetics obtained using the laboratory column and the tonnage to be processed, a flotation column with proper geometry was designed to meet the mill’s needs. The column itself was made from a standard 60 cm diameter 304 SS pipe of schedule 10. The construction involved modifications to the pipe, installation of the plumbing, column accessories, and electrical wiring in the DCS. The accessories (pumps, valves, flow meters, and sensors) needed for column operations were assembled by the mill.

After the large column installation, automatic control of column operations developed using the laboratory column was applied to this production column. Though the MPC controller was very effective for the laboratory flotation column, it could not be implemented in the plant distributed control system (DCS). We resorted to using built-in DCS, functions such as the Smith predictor, to replicate the functions of the MPC controller. Figure 9 shows...
an example of supervisory control performance that was eventually applied to the mill column. The Smith predictor obviously mimicked well the MP controller. It should be noted that the OCC pulp was used for tuning the control loops because it was the most uniform stream-treated in the column. However, parameters determined for the OCC pulp did not have to be changed when other streams were feeding the column.

Performance for Contaminant Removal

To verify that the column was properly sized, the same streams tested in the laboratory column were floated in the larger column. Figure 10 shows the results of 17 flotation tests carried out with OCC pulp, of 17 tests with Krofta rejects and 14 tests with a blend of Krofta rejects and Cleanpac heavy rejects. To achieve the best results on stickies and wax removal, flotation parameters, such as retention time, air velocity, washing water flowrate, air content in the column, and froth level, were optimized. For all these trials, macrostickies and wax removal was between 60% and 90% for both OCC pulps and Krofta rejects, and 50% and 85% for the blend of Krofta rejects and Cleanpac heavy rejects. The average value of flotation efficiency was around 70%. The variation on flotation efficiency was mainly due to the changes of operation parameters and of incoming furnish properties. The material loss during column flotation was 2–4% for OCC pulp, and 5–10% for reject streams due to removal of P200 fraction (fillers and fines). Thus, the performance of the mill column approached that of our laboratory column.

Of the streams tested, most attention was paid to the Krofta rejects because the return of recovered Krofta solids in the process would have the best payback for the mill. After characterization of flotation accepts, we found that flotation accepts of the Krofta rejects were suitable for re-use in the process. This finding was verified by operating the column five times for a period of 10–14 consecutive hours. After introducing the recovered Krofta rejects in the OCC pulp line, no negative impact on paperboard machine operation was observed.

As shown in the previous section, flotation in the laboratory column improved strength properties of the various pulp samples. These observations were also verified in the large column. As shown in Table III, strength properties of the recovered Krofta rejects significantly increased after column flotation treatment.
Status of the Mill Flotation Column

At this point of the development, the mill column is still used as a R&D unit to establish the long-term performance of the column and to better determine the impact of returning treated rejects in the main OCC pulp line. The column will be in full time operation this year for the recovery of 2.5–3.5 tpd of fibres from Krofta rejects.

CONCLUSIONS

In the first phase of the work, flotation tests were carried out with our laboratory flotation column installed in an OCC recycling plant. OCC pulp and reject streams were then tested for their responsiveness to flotation. Overall, flotation was very effective for removal of macrostickies, wax, fillers, and organic extractives while fibre loss by entrainment in the froth was low. Elimination of hydrophobic contaminants and inorganic fillers also enhanced pulp strength properties. The laboratory column was then used to develop control algorithms aimed at reducing variations in froth heights and air content in the column. After this successful testing phase, a 0.6 m by 6.0 m column was built in the mill. The same pulp and reject streams, tested in the laboratory column, were floated this time in the larger column. Flotation efficiencies in the bigger column reached those obtained with the laboratory column. The recovered materials from Krofta rejects were judged to be suitable pulp for returning into the process. The mill operated the column five times for a period of 10–14 consecutive hours. After re-introducing the recovered Krofta rejects in the OCC pulp line, no negative impact on paperboard machine operation was observed. At this point of the development, the mill column is still used as an R&D unit to establish the long-term performance of the column and to better determine the impact of recovered materials to the main OCC pulp line. The R&D column will be operating full-time this year to recover 2-5-3.5 tpd of fibres from Krofta rejects.
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REFERENCES


