

# *Fractional pulping of packaging board in high consistency drum pulping*

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**ABSTRACT:** A wide variety of packaging materials with different wetting rates and wet strength properties are used in old corrugated container (OCC) processing. The disintegration rates of the different grades also vary and enable the use of the fractional pulping concept where easily disintegrated material is removed at the early stages. In the present study, fractional drum pulping was studied by pulping (Pilot drum pulping) and fractionating (Tampella oscillating screen) a mixture of strong-grade kraftliner and weak-grade fluting at high consistency to determine if energy consumption could be reduced. The results showed that a 25% energy saving could be realized through fractional pulping and an even higher potential might be possible if pulping conditions are optimized. Average fiber length, fines content, and ash content in the separated fractions were analyzed. The separated short fiber fractions and long fiber fractions could be individually processed, thus decreasing the volumes in the unit processes on the OCC line.

**Application:** Mills can increase capacity and improve energy savings in OCC recycling processes.

Packaging board is one of the most recycled raw materials in the world. The recycling rate of packaging board is 74% on average in Europe but can be as high as 80% in some countries, such as Belgium [1,2]. The recycling process for packaging board is the simplest method in the field of fiber recycling. The different types of packaging grades vary due to their various uses, and strength properties of packaging materials vary greatly. Corrugated board is a multilayered product, and each layer has its own purpose. Depending on its intended use, corrugated board can be produced partially from recycled packaging material instead of virgin materials.

The first unit process in old corrugated container (OCC) recycling is pulping, where recovered board bales are disintegrated into a pumpable suspension and coarse contaminants are removed. Two processes are used to pulp packaging board. One is continuous low consistency vat pulping (LC, consistency <6%) using a rotor that produces high shear forces, which disintegrate board into a fiber suspension [3,4]. In continuous LC pulpers, the disintegrated material is continuously removed during pulping. The other pulping option is a rotating drum, where the board is disintegrated at high consistency (HC, consistency <19%) by impact due to the repeated lifting and falling of the material [5]. After the pulping process, contaminants are separated from the pulp suspension in different unit operations and the pulp suspension can be divided into a short fiber fraction and a long fiber fraction.

A drum pulper typically consists of two sections. The first section of the drum is used to disintegrate the packaging board, and the second section is used as a screen to separate

the disintegrated pulp suspension from coarse contaminants and flakes. Consistency in the disintegration section is 14%–20%, and is lowered to 3%–5% in the separation section to achieve efficient screening.

The target of pulping is to achieve high material efficiency by avoiding fiber losses due to the rejection of nondisintegrated fiber material (i.e., flakes). The disintegration forces in the pulper must overcome the wet strength of the material during pulping. Because of the wide variety of packaging materials used, weaker wet strength materials disintegrate faster than stronger materials during pulping. This leads to a situation where the pulper lifts and uses energy in material that has already been disintegrated. Thus, it could be beneficial to remove disintegrated material from the pulper at the early stage of pulping so that unnecessary material movement is avoided [6]. This approach has been studied in LC pulping where two batch pulpers are used in series with a screening stage between the pulpers [7,8]. First, 2 min of pulping was carried out for the whole OCC batch. Then, the disintegrated pulp was screened out and the pulping of the undisintegrated material was continued in another pulper unit. Even though the results were promising, fractional pulping has not yet become a commercially common concept. The fractional pulping concept in HC pulping has been studied from the perspective of the deinking process [9], but the fractional pulping of OCC at HC has not yet been studied.

The present work is a study of the fractionation of packaging material pulp in an HC pulper. The aim was to study how effectively disintegrated materials can be separated in a drum pulper. Pulp properties (ash content, fiber length, and fines content) were studied after fractionation at different pulping

| Material                   | Grammage, g/m <sup>2</sup> | Ash Content 525°C, % | Tensile Index, kNm/kg | Wet Tensile Index, kNm/kg | Average Fiber Length, mm |
|----------------------------|----------------------------|----------------------|-----------------------|---------------------------|--------------------------|
| Kraftliner (virgin fibers) | 120                        | 2.8                  | 131.7                 | 13.0 (9.8% wet/dry)       | 1.2                      |
| Fluting (secondary fibers) | 90                         | 11.8                 | 80.1                  | 2.1 (2.7% wet/dry)        | 0.8                      |

## I. Properties of kraftliner and fluting materials.

times to evaluate how easily disintegrating fluting could be separated from kraftliner, which has a higher wet strength, and how this affects the total energy demand of pulping with a chosen fractionation point.

## MATERIALS AND METHODS

The materials used in this study were virgin-pulp containing linerboard and recycled pulp containing fluting; both materials were obtained from a Nordic board factory. **Table I** summarizes the specifications for the materials used. Ash content was analyzed with a PrepASH129 (Precisa Gravimetrics; Dietikon, Switzerland) according to TAPPI T 211 om-02 “Ash in wood, pulp, paper, and paperboard: combustion at 525°C.” The tensile strengths of the materials were tested with an Instron 5544 (Instron; Norwood, MA, USA) equipped with a 100 N load cell using the TAPPI T 456 om-03 “Tensile breaking strength of water-saturated paper and paperboard.”

The material was cut into 200 mm x 400 mm specimens. The specimens were stored at 50% relative humidity and 24°C temperature. Materials were mixed with each other before being loaded into the drum pulper. **Figure 1** is an image of the pilot scale drum pulper used in this study. The diameter of the drum is 1.5 m, the width is 0.26 m, and the lifters are 0.1 m. The circumferential velocity of the drum during pulping was adjusted to 1.3 m/s. The drum pulper was rotated by two 2.2 kW motors.

In this study, two pulping trial series were conducted. In both trials, the consistency was adjusted to 15%. The temperature at the beginning of pulping was adjusted to 24°C. In industrial processes, a temperature of 50°C is typically used. A lower temperature was chosen for this study to eliminate the effect of temperature changes during pulping and fractionation with used setup. A Tampella oscillating screen (Ø 4 mm) was used to fractionate pulp gently without excess disintegration of flakes. **Figure 2** is a schematic of the experimental setup.

In the first trial (reference), the pulping batch size was 100 kg consisting of 75 kg kraftliner and 75 kg fluting (50:50). Pulping kinetics were performed and after 5, 10, 15, and 20 min, the pulper was stopped and 300 g of pulp were sampled for laboratory analysis. Samples were fractionated with a Tampella vibration screen with a hole diameter of 4 mm (**Fig. 3**). The sample size in the screen fractionation was 200 g (of dry matter content). The consistency was adjusted to 0.5% before each fractionation. Both reject and accept sam-

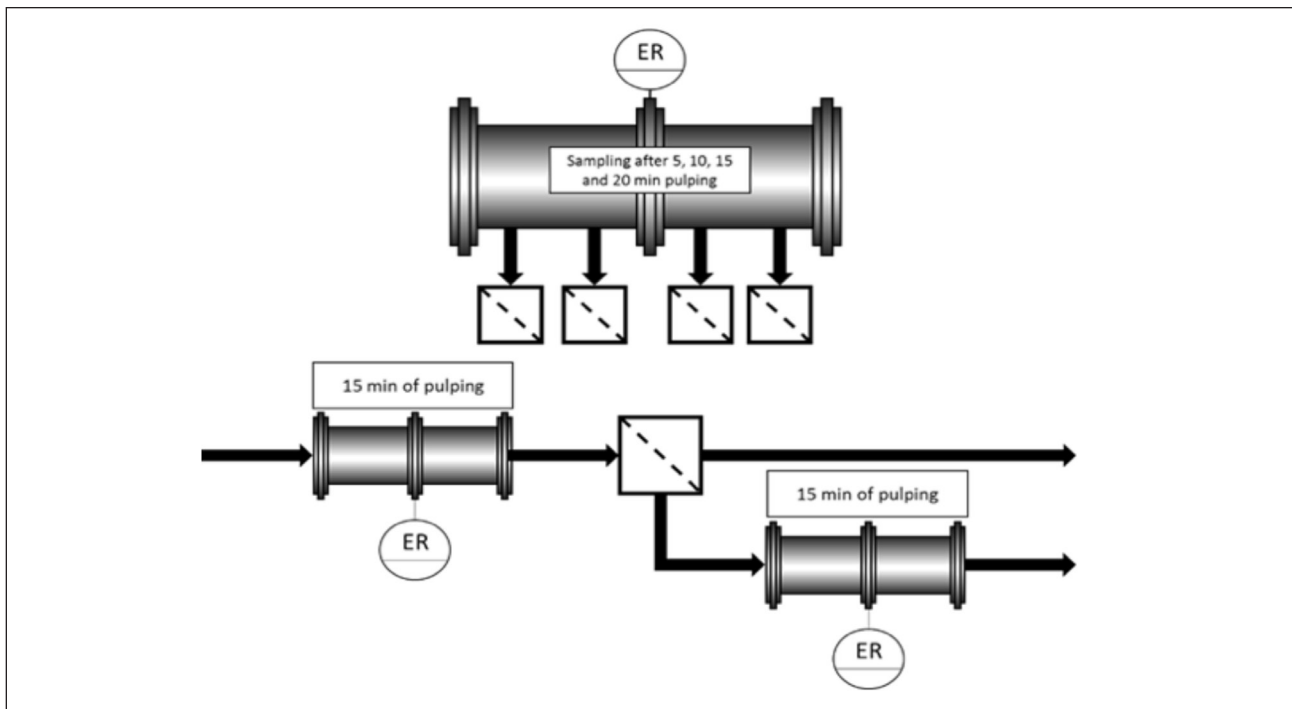


1. Drum pulper with 1.5 diameter, 8 lifters, and 10 cm lifter size.

ples were collected for further analysis.

Various characteristics from the fractions (fine content, average fiber length, and ash content) were analyzed. Fines content was measured using Somerville equipment (Techlab Systems; Itasca, IL, USA) with 200 mesh wire; 80 L of water was used to wash the fines. Average fiber length (length weighted) was analyzed with a Fracon (Metso; Helsinki, Finland) tube flow fractionation device equipped with a charge-coupled device camera that allowed the analysis of fiber length through an image analysis procedure [10]. Ash content in the reject and accept samples was analyzed with a PrepASH (Precisa PrepASH129) by incinerating samples at 525°C.

A second series of trials was performed to compare the disintegration of the board mixture and the energy consumption in fractional pulping to conventional drum pulping (first trial acted as reference). In this trial, the whole batch was diluted and fractionated after 15 min of pulping in screening consistency of 0.5%. A batch size of 166 kg was used with the same consistency and mixture as in the reference pulping process. The reason for the larger batch size was an attempt to obtain the same batch size after fractionation as in the reference sample. After fractionation, the consistency of the reject material was measured from the reject and adjusted back to 15% and pulping was allowed to continue for another 15



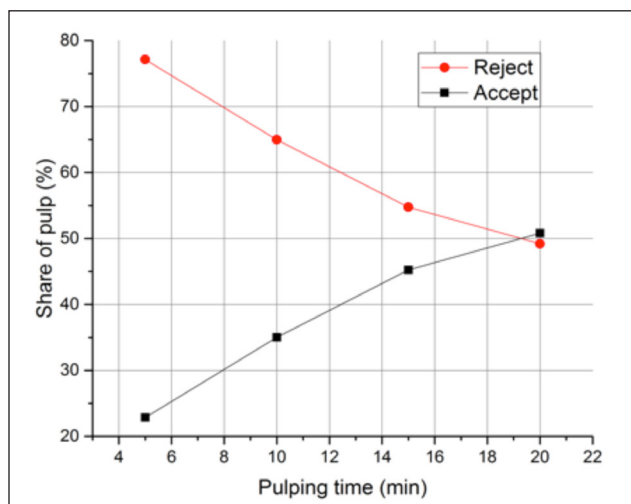
**2. Schematic of experimental setup used in fractional drum pulping study. Top: first trial pulping (reference), bottom: second pulping (fractional pulping where whole batch was fractionated). Consistency in each pulping was adjusted to 15% with starting mixture of 50:50 kraftliner and fluting.**

min. During fractionation, 46.5% of pulp went to accept. Somerville flake content was used to evaluate the efficiency of the pulping process along with energy consumption data. The analysis was conducted according to TAPPI T 275 sp-02 “Screening of pulp (Somerville-type equipment).” For screen-

ing, a 40-g sample of dry matter content was taken, and the flake content was calculated as the mass of the retained pulp on the screen compared with the mass of the feed sample.

## RESULTS

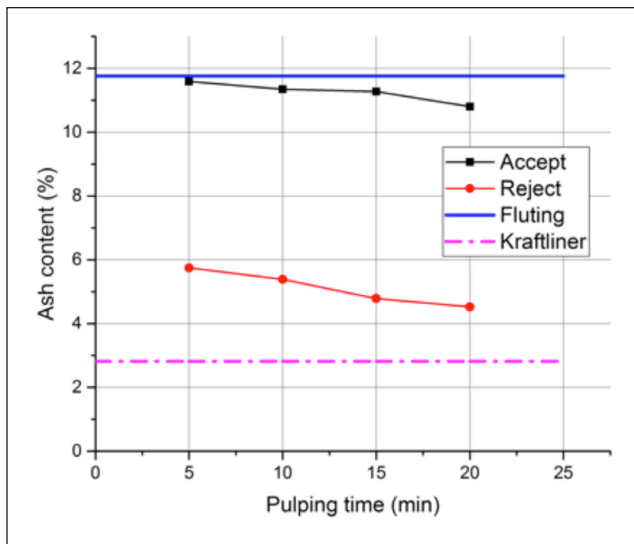
For the reference pulping, the mass reject rate experimentally calculated at various sampling times by vibration screen is shown in **Fig. 4**. As the pulping progressed, the share of the accepted material increased due to the defibering actions of the pulper.



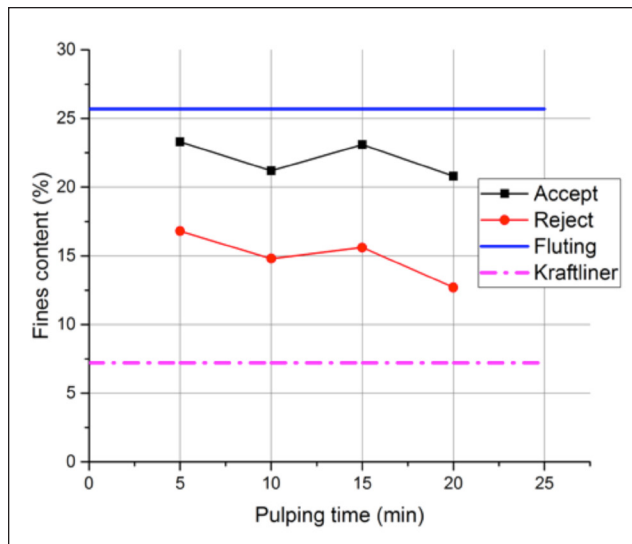
**4. Shares of accept and reject in fractionation as a function of pulping time.**



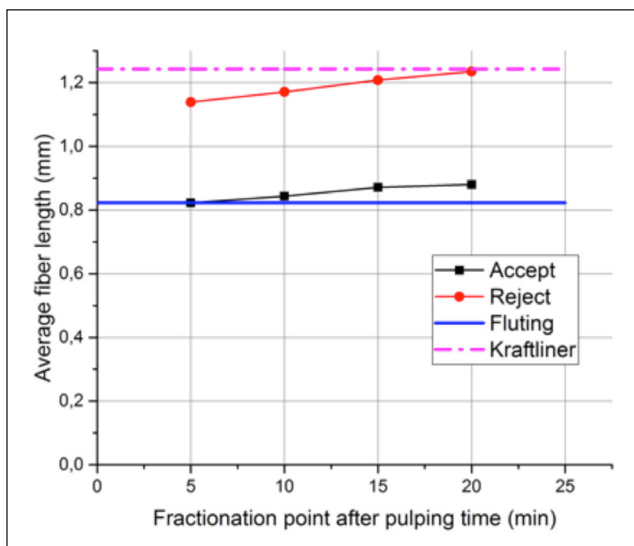
**3. Tampella oscillating screen (Ø 4 mm). The feed sample was divided into reject (flakes) and accept (disintegrated pulp) samples. For all fractionations, feed consistency was adjusted to 0.5%.**



**5. Ash content of fractionation accept and reject as a function of pulping time.**



**7. Fines content of accept and reject as a function of pulping time.**



**6. Length-weighted fiber length of fractionation accept and reject as a function of pulping time.**

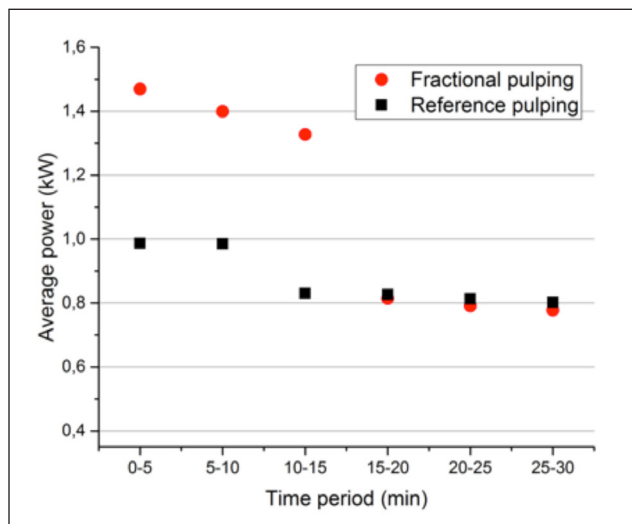
The average fiber length, fines, and ash contents were analyzed from each fractionation sample. The results from this analysis are illustrated in **Figs. 5, 6, and 7**, respectively.

As expected, a greater number of longer fibers were found in the fractionation reject than in the fractionation accept. Average fiber length increased in the fractionation accept and fractionation reject as the pulping proceeded. The length difference remained virtually unchanged. After 5 min of pulping, the fractionation accept had the same average fiber length as fluting, indicating that fluting disintegration mainly occurs in the early stage of pulping. After 20 min of pulping, fiber length in the fractionation reject reached the same level as that in the kraftliner, indicating that all fluting basically disintegrated in this phase.

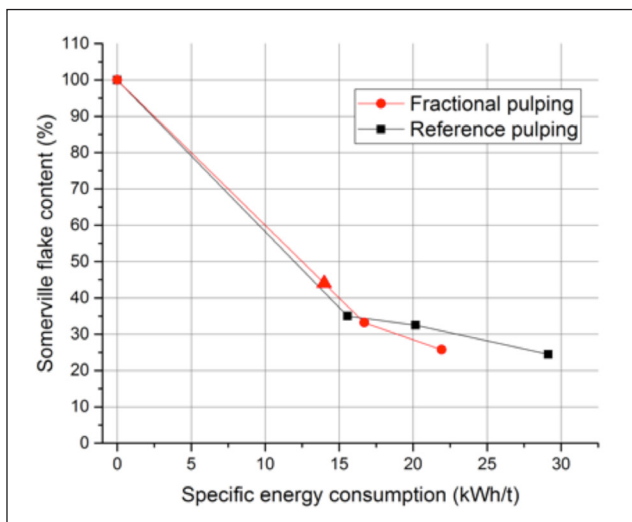
Fines and ash contents were higher in the accept than in the reject. Decreasing trends in their contents were seen both in the fractionation accept and reject. Unlike fiber length, the ash and fines contents of the reject did not reach the contents of the kraftliner, indicating lower separation in fractionation.

In the second series of trials, we studied how fractionation affects pulping efficiency. The average power consumption for the fractional pulping and the reference pulping is shown in **Fig. 8**. Initially, the pulping power consumption was at a higher level because of the greater batch size (i.e., the degree of filling in the pulping). Later, the fractionation power consumption remained at the same level because the degree of filling remained the same.

Pulping efficiency (i.e., the degree of disintegration level



**8. Average power consumption between periods. Fractionation point occurred 15 min after pulping. Starting batch sizes in the fractional and reference pulping were 166 kg and 100 kg, respectively.**



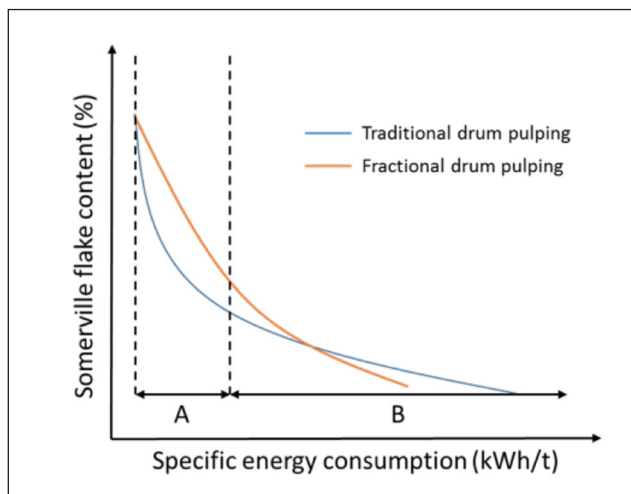
**9. Somerville flake content after 15, 20, and 30 min of reference and fractional pulping.** Triangle symbol indicates the fractionation point. Fractional pulping total Somerville flake content is calculated from final pulp Somerville flake content recombined with the screening accepts according to the mass split; 47% of the dry mass was removed from the pulper in the fractionation.

measured by the Somerville flake content as a function of specific energy consumption) is presented in **Fig. 9**. With fractional pulping, specific energy consumption was about 25% lower at the 25% flake content level than in the reference pulping. Initially, the reference pulping seemed to have more efficient disintegration; the lower filler degree probably offered more favorable wetting and disintegration conditions. Fractional pulping, however, gave better disintegration efficiency at the later stages of pulping than did the reference pulping.

## DISCUSSION

In OCC processes, a wide variety of different packaging materials all have different properties, such as wet tensile strength. Disintegration of different materials is known to occur with different kinetics depending on the materials' wet strength properties [3]. The idea of fractional pulping is to easily remove disintegrating material (i.e., material having a low wet strength) from the pulper at the early stage of pulping to decrease the pulper's load and thus increase pulping efficiency. Fractionation is done to separate long and short fibers into different layers of product or different products or to remove ash and fines from the stock [11].

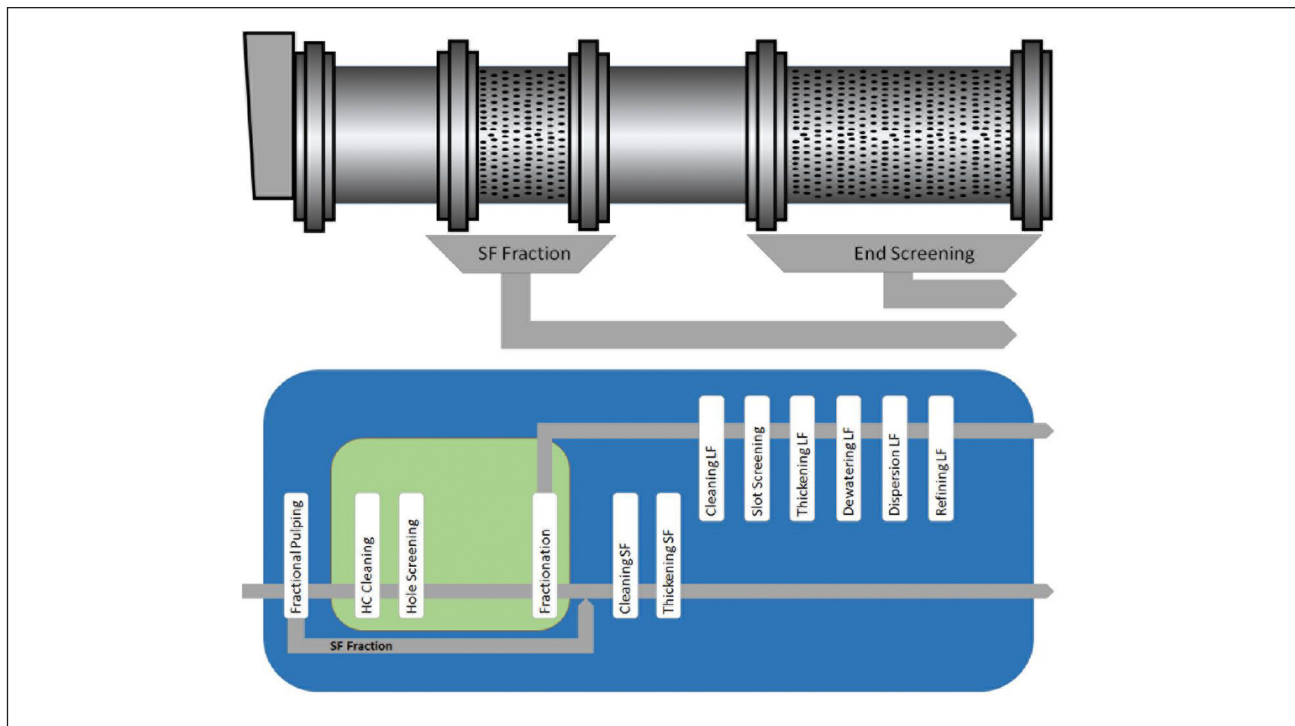
In our previous study [12], the amount of mass was found to have a positive effect on the disintegration of stronger materials. Fractional pulping would have decreased disintegration kinetics after fractionation if operated at the traditional fill level. In addition, the material after fractionation can be considered to have good quality properties (Figs. 4, 5, and 6) of the product produced from it. On the basis of these determinations, it could be beneficial to have an optimal fill level after fractionation to maximize energy efficiency at the end



**10. Illustration of disintegration efficiency in drum pulping.** Phase A is disintegration at the beginning of pulping and phase B is pulping after fractionation in the case of fractional pulping.

of pulping. Therefore, the starting fill level should be higher than usually used in traditional drum pulpers. With an increased fill level, fractional pulping would have decreased disintegration kinetics and efficiency (**Fig. 10**, phase A) and increased total energy consumption at the beginning stages of pulping. However, the specific energy demand would be lower after the decreased load in fractionation (**Fig. 10**, phase B). Energy savings with the setup used in the present study was approximately 20%, not taking into account the energy consumption for separation. The fractional pulping here was probably not optimal; however, a considerable energy saving was still achieved.

In addition to the energy savings in fractional pulping, two fractions having different fiber and papermaking potentials are obtained. The analysis indicates good results in the selective separation of different types of materials because of the different wet strength properties and wetting kinetics of the raw materials. It has been shown in different studies that previous recycling cycles increase the fibers' internal and external fibrillation, which increases tensile strength; however, simultaneously, fiber shortening and cutting also occur, which increases the fines content in recycled pulp and decreases the strength properties of the resulting product [13,14]. Recycling increases the nonpaper component content in recycled fiber products, which also has a negative effect on strength properties [15]. Because of this, fluting disintegrates rapidly in the early stages of pulping. In the present study, the rapid disintegration of fluting could be seen in the fiber length; the fractionation accept after 5 min of pulping had practically the same fiber length as the fluting. As pulping proceeded, the kraftliner began to disintegrate, causing the fractionation accept fiber length and the fractionation reject fiber length to increase because the amount of fluting decreased. Similar, but inverse, trends were also seen for ash and fines contents.



**11. Possible concept advantages of fractional pulping. The green area represents opportunities for possible energy savings in cleaning processes. LF = long fiber fraction and SF = short fiber fraction. SF fraction might need additional cleaning processes.**

In this study, the dropping height of the pilot drum was relatively low compared with industrial drum pulpers, which resulted in low disintegration kinetics of stronger material as well as high residual flake content after 20 min of pulping. In our previous study [12], the dropping height was found to be important in the disintegration of stronger raw materials.

Fractional pulping might provide an opportunity for the design of OCC processes with smaller units and decreased energy consumption or increased capacity of the process line. Easily disintegrated grades usually are also short-fibered grades and the short fiber fraction could bypass coarse cleaning and screening as well as pressure screen fractionation.

This concept, presented in **Fig. 11**, could lead to energy savings in cleaning, coarse screening, and pressure screen fractionation because of lower volumes being processed. Energy savings depend on the fractionation split as well as the selectivity of fractional pulping. On the other hand, there is also an option to increase the capacity of the pulping process.

**Table II** summarizes the rough estimation of energy saving potential in the fractional pulping concept on the basis of the raw material and fractionation selectivity in this study. Results from various shares of the short fiber fraction together with the pulp properties for the short fiber and long fiber fractions are presented. Energy savings potential can be cal-

| Share of Short Fiber Accept in Pulping | 0  | 25%  | 40%  | 50%  |
|----------------------------------------|----|------|------|------|
| Coarse screening, kW·h/t               | 12 | 9.0  | 7.2  | 6.0  |
| Fractionation, kW·h/t                  | 5  | 3.8  | 3.0  | 2.5  |
| Total energy consumption, kW·h/t       | 17 | 12.8 | 10.2 | 8.5  |
| Energy saving potential, kW·h/t        | 0  | 4.3  | 6.8  | 8.5  |
| Ash content in reject, %               | -  | 5.7  | 5.0  | 4.5  |
| Ash content in accept, %               | -  | 11.5 | 11.3 | 10.9 |
| Average fiber length in accept, mm     | -  | 0.82 | 0.85 | 0.87 |
| Average fiber length in reject, mm     | -  | 1.14 | 1.18 | 1.23 |

## II. Estimated energy savings from cleaning processes and qualities of fractions.

culated from the total energy consumption with the share of short fiber accept in pulping. For example, with 60% short fiber accept, the energy savings would be 10.2 kW·h/t.

It is difficult to estimate the optimal fractionation point in the pulper. Variables such as ash contents, average fiber length, and fines content change depending on the fractionation point, which affects the quality aspects of the fractions. On the other hand, energy consumption aspects change depending on the fractionation point. This raises the question of determining the significance of the quality aspects and efficient pulping (minimum fiber loss) versus energy consumption savings. According to previous studies and patents, both fractions might need separate cleaning devices [8,16].

## CONCLUSIONS

Fractional pulping is a method that can be used to potentially decrease energy consumption in OCC pulping. Pulp can be fractionated according to the disintegration rates of different grades; that is, between weaker, shorter-fiber products (e.g., fluting) and stronger, longer-fiber products (e.g., kraft-liner). Fractional pulping could make it possible to reduce the size of unit processes in OCC lines or increase pulping capacities. **TJ**

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## ABOUT THE AUTHORS

We chose this topic because pulping is one of the most energy consuming unit operations in the OCC recycling process. Only a few publications exist about OCC pulping, especially drum pulping. In packaging material recycling, there is huge material diversity, all of which have different strength properties. Previous fractional pulping studies show there is potential in this kind of system.

Even though the experiment setup looks simple, the workload during the pulping and fractionation stage, including the preparation, was huge. We were surprised about the analysis results regarding differences in fiber length and ash content.

Our hope is that these results can give some basic knowledge about drum pulping and some new ideas for new, next-generation drum pulpers that work more efficiently. Surely, there is potential.



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