Fractionation of Secondary Fiber - A Review

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ABSTRACT

Recovered paper and waste woods constitute a large portion of the municipal solid-waste stream. Recycling efforts of these materials are hampered by the degradation of the papermaking properties of fibers caused by repeated recycling. Fiber fractionation is one method of improving the quality of the raw material by separating the fibers into a higher-grade fraction (typically the long fibers) and a lower-grade fraction (the short fibers and fines). The two fractions can then be used to produce various quality stocks that can be blended to produce desired strength and optical properties.

This paper is a review of the current literature on fiber fractionation. The processing equipment available for fiber fractionation is discussed along with the grades of recovered paper that are considered candidates for fractionation. Because the fiber fractions often have distinctly dissimilar properties, they react differently to the various operations such as cleaning or bleaching. This paper also discusses the characterization of the fractions, modeling of the fractionation, and other recycling operations.

KEYWORDS

Fiber classification, Reclaimed fibers, Review, Waste papers.

INTRODUCTION

Recovered paper and waste wood constitute more than 44% of the municipal solid-waste stream today. This amount of material, heading toward our dwindling landfill capacity, is a large economic and environmental burden that cannot be sustained (1). However, repeated recycling causes the fibers to be less attractive as a papermaking material as the fibers degrade and become less flexible. The result of this loss of flexibility is lower strength and bonding properties, generally resulting in recycled fibers being relegated to lower grades of paper. Additional problems involving the use of recovered paper include reduced drainage, sheet strength problems, and contamination. These problems can be addressed through the use of fractionation (2). Thus, in addition to the technical aspects of recycling paper, the economic and environmental aspects of recycling must be considered.

Fractionation is viewed as one method of improving the quality of the raw material (3). Fiber degradation resulting from recycling can be alleviated by separating the fibers into a high-grade fraction (generally considered the long fibers) and a low-grade fraction (the short fibers and fines). The high-grade fibers can then be used to produce a higher-quality paper, ideally a quality of at least that of the original feedstock. The low-grade fibers can then be used to produce a lower-grade paper or used for other purposes, such as those discussed in a subsequent section. Poor optical properties, contamination, and poor physical properties are the main problems facing recovered paper utilization (4). The basics of fractionation and control of the fractionation process are given in Gehlig (5).

The basic idea of fractionation is to separate the fibers in the raw material based on quality criteria. However, fractionation can have differing objectives (6). Fractionation can be used to produce various quality stocks, which are then used in different products. Another option is to blend the fractions to achieve a certain product specification (7). Fractionation can be used to compensate for the variability that is inherent in the re-

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covered paper supply (8, 9). Fractionation also has the potential to improve the quality of recycled products (10, 11) as well as save energy (12).

TECHNOLOGY OVERVIEW

The equipment used for fractionation depends on the ultimate goal. On a laboratory scale, the Bauer-McNett[a] classifier can be used to separate the pulp into up to five fractions based on the fiber length. This equipment is designed only to fractionate a small amount (10 g) of pulp per operation, but some researchers have fractionated up to 40 g at a time with acceptable results (13, 14, 15, 16). On a commercial scale, much of the normal stock preparation cleaning equipment can also be used for fractionation. By changing the normal operating conditions, pressure screens, centrifugal cleaners, and pulpers can be used. Other options for fractionation include source separation, selective pulping, and screening equipment, such as sidehill screens. An overview of industrial-scale fractionation equipment concluded that screen fractionation and pressurized digestion are the most economically sound when considering the annual return on investment (17).

Pressure Screens

Pressure screens are an integral part of many stock preparation areas, especially in the secondary fiber area. The split of the pressure screen is typically a function of the size and geometry of the particle and the configuration of the screen opening. An overview of pressure screens and a discussion of the major operating variables is given in Levis (18). The use of pressure screens for fractionation is the subject of two British patents (19, 20).

In terms of the fractionation of fibers into long and short components, it was found that the geometry of the basket had an effect on the performance of the screen. Profiling of the flow side prevented the formation of a filter mat and gave less distinct separation but more uniform suspension properties (21). Contour-slotted screens reduced long-fiber fractionation, decreased the reject rate, and reduced sensitivity to consistency and contaminant content (22, 23). It was possible to achieve good separation with slotted screens at either high or low reject rates, where the long-fiber fractions were considered the rejects. However, with holes, good separation could only be achieved at low reject rates (24). The effect of hole size in the pressure screen on fractionation was shown by LeBlanc and Harrison (25) where, as expected, increasing the hole size increased the accepts flow, thus increasing the average length of the long fiber. Equipment operating parameters and suspension characteristics affect the average fiber length and distribution when using a pressure screen for fractionation (26).

When pressure screens are also used for contaminant removal, a competition exists between the fractionation and cleaning functions of the pressure screen. In the case of fractionating contaminated pulp, coarse contaminants, as well as wax and hot melts, tend to be concentrated in the long fraction (27, 28). Profile screens that induce a pulse into the stock flow reduce this tendency.

Pressure screens were found to be the most industrially effective at fiber fractionation (4, 29, 30). A high proportion of long fiber can be achieved with a two-stage screening cascade (31). Various manufacturers market pressure screens designed expressly for fiber fractionation (Table 1).

Centrifugal Cleaners

Centrifugal cleaners can also be used for fractionation of fibers and have been studied in some detail (32, 33). However, in centrifugal cleaners, hydraulic shear, hydraulic drag, density, and centrifugal force play a role in the separation of material. In general, cleaners tend to separate the pulp into flexible and stiff components. The cleaner underflow (rejects) tends to contain the longer-stiffer fibers that have a lower specific surface. The overflow (accepts) contains the well-refined, more flexible fibers as well as the fines (32, 34, 35). Along these lines, a separation into springwood and summerwood fractions was achieved using centrifugal cleaners (36, 37, 38). This allows the stiffer fibers to be separately refined and then returned to the furnish, thus improving properties. Other investigations indicated that cleaners can separate based on specific surface area (39, 40). However, as cleaners also affect contaminants, there is a difference in the impurity content with the wax accumulated in the flexible fraction and aluminum foil concentrated in the less flexible fraction, although this may depend on the specific operating conditions (35). Gonera (26) discusses equipment parameters and suspension characteristics in relation to the average fiber length and distribution when using a hydrocyclone for fractionation.

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[a] *The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Dept. of Agriculture of any product or service.*

Fractionation Pulping

Selective or partial pulping of the secondary fiber supply can lead to fractionation by fiber type or source. This idea is the subject of two British patents (41, 42). Selective pulping achieves separation by pulping to the point where the component of the recovered paper that defiberizes easier is sufficiently disintegrated so as to be removed from the remainder of the furnish through coarse screening. For example, under the proper mechanical, chemical, and time conditions, the medium of old corrugated containers (OCC) is reduced to smaller pieces than the linerboard, thus allowing a separation.

Other Fractionation Equipment

In one experiment, a Hydrasieve sidehill screen with a wire covering was used to fractionate a pulp by fiber length (31). Sheet wire was also proposed as a method of fractionating fiber on a laboratory scale (26). Fractionation using wires can be indicative of the fractionation that occurs in paper machine operations. The spinning disk separator is also shown to fractionate fibers by length (43, 44, 45, 46, 47, 48) or to extract fibers from a newsprint mill tailing stream (49). BEW's Vario-Split washer is an application of washer technology that can be used to achieve fiber fractionation (50).

FRACTIONATION OF SECONDARY FIBERS

The use of fractionation in secondary fibers offers some promising results. The biggest problems with utilization of secondary fiber are a continually changing source, poor quality of furnish compared to virgin fiber, and the resulting lower-quality product (25). Fractionation can be employed to address many of these problems. Theoretically, the long fraction will contain mostly softwood fibers and will enhance the strength properties of the paper, while the short fraction will yield fibers that enhance the smoothness and opacity of the sheet.

Fiber fractionation has the potential to be used for several grades of recovered paper and in several combinations of operations (33, 46, 51, 52, 53). Fractionation can be used to split the pulp into two different pulp streams, with each furnish used for different grades of paper. Alternatively, the two fractions can be reblended in proportions (and perhaps after treatment of one fraction) to produce desired qualities in the pulp. Finally, fractionation can be used to remove an unwanted portion from the fiber stream. The following outlines the use of fractionation for several grades of recovered paper.

Linerboard and Medium

Fractionation of secondary fiber for corrugated containers and paperboard offers some impressive benefits. The fiber supply of waste corrugated boxes is abundant (53). New cleaning and pulping technologies make the production of multilayer paperboard from secondary fiber very inviting (54). Fractionation can be an integral part of the production of both of these products from secondary fiber and can be economically feasible because the value of the components is often greater than the value of the mixture (55). Fractionation can also address some problems that are encountered in the use of increased amounts of OCC, such as decreased drainage and sheet strength (2).

Fractionation in the production of recycled OCC generally produces two furnishes: long-fibered fraction that has improved strength properties and can be used for the linerboard and a short-fibered fraction to be used for medium or other lower-quality products (56, 57, 58, 59).

Alternatively, removal of the short-fiber fraction improved the pulp freeness and strength properties of the remaining furnish (60, 61).

Boxboard and Multilayer Paperboard

Fractionation is used in multilayer paperboard manufacture to create a sheet that can be altered to fit the required properties (54). The short fraction can be used for the filler in the center of the sheet, and the long fraction can be used for the liner stock (62, 63). The desired properties of the final sheet determine the proportion of the split in the fractionation process (64).

Grocery Bag (Kraft Paper)

A pilot-scale study fractionated a high-yield pulp (Kappa number 85-95) into two fractions, the longer of which could be substituted for the typical low-yield kraft pulp commonly used in grocery bags (65). This substitution resulted in no significant loss of strength or product quality. The remaining short-fiber fraction could be used in lower paper grades.

Mixed Office Waste Printing and Writing Papers

Fractionation of secondary fiber is generally aimed at separate treatment of the resulting fractions for some economic benefit (66). One major benefit of fractionation of recovered paper is that the long-fiber fraction can be a low-cost supplement to expensive virgin fiber. Mixed office waste represents a grade for which fractionation has not been fully investigated, although preliminary results are disappointing (67). An investigation into the use of fractionation of mixed office waste was performed on a laboratory scale using a Bauer-McNett classifier (68). Fractionation was successful at separating the office recovered paper into two streams of different fiber length, freeness, and physical properties. More specifically, the long-fiber component resulting from fractionation was significantly upgraded compared to the short-fiber fraction. The addition of virgin kraft fiber to the unrefined long-fiber component showed great promise for the ability to substitute secondary office recovered paper fiber for more expensive virgin fiber.

However, the investigation is not complete. The main problems facing the widespread use of secondary fiber from office recovered paper include an ever-changing fiber supply and little investigation into the use of this fiber source. The following areas need to be examined:

- A fractionation method that economically separates mixed office waste.
- An optimum split between what should be utilized as long-fiber and short-fiber fractions.
- An optimal amount of virgin fiber addition to maintain strength and other valuable paper properties.
- A classification system for the properties of secondary fiber from office recovered paper to quantify the changing raw material.

Nonwood Fiber Sources

Several nonwood sources have also been investigated with regard to fractionation as a method of making these fibers more attractive for papermaking. Unfortunately, economic and technological considerations often limit the usefulness of these materials for papermaking in the United States (69). However, nonwood sources, such as rice, straw, bagasse, and reed, are important fiber sources in countries where increased use of fractionation may replace imported long fibers (70). Fractionation of bagasse for use in newsprint has been used in a commercial trial in which the long fraction was subject to a post-fractionation chemi-mechanical pulping step (71). Compared to wood fibers, refining of the long fraction of bagasse pulp did not improve the quality of the pulp to any significant degree because the long fraction, in general, contained the slenderest of the fibers (72).

POST-FRACTIONATION PROCESSING

The results of fractionation are two (or more) fiber fractions that have markedly different characteristics that react differently to subsequent processing. Because of this difference, significant improvement in properties and possible energy savings can result by processing only that fraction of the fiber that is required to improve the quality of the final product.

Selective Refining

One post-fractionation operation is to separate the fibers into two fractions and then refine only the fraction that requires additional treatment. That is, the coarser, long-fiber fraction can be selectively refined to improve the bonding capabilities of the furnish without adversely affecting the properties of the shorter fraction (13, 63, 64). This may possibly result in energy savings, because refining is one of the most energy-intensive stock preparation operations (27, 66, 73, 74). In some cases, although the energy savings was evident, strength properties did not show a net increase (75). The short fraction, on the other hand, may only need a light refining to optimally develop the properties. Another advantage of treating only the long fiber fraction is that it preserves the optical properties of the shorter fibers as it is not subject to the treatment that may degrade its optical properties (76).

Selective Disperging

Another post-fractionation operation is to selectively disperge only the longer fibers. Similar to refining, disperging is also a highly energy-intensive process. By selectively treating only the long-fiber fraction, significant energy savings can be realized, while improving the optical quality of the resulting sheet. After dispersion, the long-fiber stock can be remixed with the short-fiber stock for the production of boxboard. Alternatively, the long fiber can be used for the topliner sheet, where the improved optical qualities aid in the appearance of the sheet; the untreated short fiber is used as the backliner and filler materials.

Sulfonation

In addition to separately treating the fractions mechanically, it is possible to chemically enhance one fraction or the other. Compared to simple refining, alkaline sulfonation of the long-fiber fraction improves the strength and surface properties through an enhancement of the conformability of the fiber that increases the bonded area (76). The fines fraction is excluded from this treatment; therefore, the process has a negligible effect on the optical properties of the pulp (31).

Bleaching

Fractionation also has implications in the bleaching of recycled paper because the various fractions may respond differently to bleaching chemicals. The ray cells in a kraft pulp are often as much as five times greater in lignin content than are the fibers. Furthermore, the same is true of the outer parts of the fibers that can become detached during beating. Both these components are represented in the fines fraction of the pulp; therefore, the fines can consume a disproportionate amount of bleaching chemicals (77). In mechanical pulps, it has been theorized that the chromophore groups are concentrated in the shorter fraction (78). However, no evidence of a difference in bleaching efficiency was found between an unfractionated mechanical pulp and the short fraction (31). The bleaching of the mixed recovered paper fraction, along with the strength properties, was investigated (79). The short-fiber fraction was less reactive with respect to substitution and addition reactions but was more sensitive to oxidative reactions which are responsible for yellowing (80).

The fines fraction is generally considered to have the most detrimental effect on the brightness of the pulp, which can be attributed to some degree to the ink and dirt that tend to concentrate in the fines fraction. As mentioned, the short fibers also consume bleaching chemicals to a greater degree. Because of these two effects, a proposed approach to recycling has the long-fiber fraction being bleached, while the short-fiber fraction, with its concentration of ink, being flotation deinked (81, 82). This method would reduce the consumption of bleaching chemicals and simultaneously reduce the load on the flotation system.

DISPOSAL OF FINES FRACTION

One key component to the effective use of fiber fractionation in the recovery of secondary fiber is the effective and economic use of the short-fiber fraction. In general, the short fraction is considered to be of lower papermaking value and, thus, only usable in the lowest grades of paper. Further complicating the use of the short fraction is the relatively higher ash content of this fraction. Alternatively, the short-fiber fraction can be incinerated for energy production if it can be dewatered enough to combust effectively. Another option is to use the short fraction as feed supplement for cattle (83, 84).

FRACTIONATION EFFECT ON PAPERMAKING PROPERTIES

The general idea behind fractionation is to produce two furnishes that overall have different (and more desirable) papermaking properties than the original furnish. Only when this can be done economically will fiber fractionation be a viable approach to paper recycling. This section deals with the measurable differences between the two fractions and the effect of the fractions and their combinations with each other and with virgin fiber on paper properties.

Difference Between Fractions

Many authors have investigated the effect of fractionation on the properties of the pulp and the paper. Depending on the fractionation equipment used, either two, three, or more fractions were investigated, with two being the most common, especially when using industrial fractionation equipment and two to five fractions being produced in laboratory-scale equipment. Of course, the multiple fractions from laboratory equipment can be combined to produce fewer fractions, and multiple passes of the industrial equipment can produce more fractions.

Freeness.

The degree of fractionation is often measured by the difference in Canadian Standard Freeness (CSF) between the fractions (24). Because the amount of fines and short fibers in the pulp has a significant effect on CSF (often accounting for up to 60% of the variation in this measurement), this measure can often be seen as the removal of the fines from the long fraction. In the case of well-washed pulps that have most fines and fillers removed in the previous cleaning stages, the difference in freeness between the fractions is typically not as dramatic.

Chemical composition.

It is also noted in the literature that there is a difference in the composition of the fractions. Long fibers tend to be relatively high in pitch, and short fibers tend to be high in ash (85). Fractionation could be used to reduce pitch problems and deposits by removing the problematic elements (86). Also, as mentioned previously, there is a difference in the lignin content of the fractions. This suggests that the fractions should be treated differently, depending on their composition.

Cleanliness.

Much of the equipment used for fractionation is also used for pulp cleaning; therefore, it is often a difference in the cleanliness of the two fractions if the feedstock contains contaminants. In using pressure screens, the long fibers are generally considered "rejects" and hence tend to be enriched in those contaminants usually rejected by pressure screens. On the other hand, the short fibers tend to be enriched with ink and smaller dirt particles. The type of screen basket can have an effect on the cleanliness of the fractionated pulp; slot fractionation produces a short-fiber fraction with excellent cleanliness, and hole fractionation produces a better separation by fiber length. A combination can produce optimum results (87).

Fraction Strength Properties: The Synergistic Effect

The effect of fractionation on the tensile and burst strength of paper has not been conclusively established. For example, the short fraction has higher tensile and burst strength properties than does the long fraction (24). Also, the burst strength was lower in the long fraction (88). However, the much higher freeness of the long fraction is indicative of a much greater strength development potential. Hence, after refining, the long fraction will again have greater strength.

Other researchers have indicated that the long-fiber fraction has much higher strength properties than does the short-fiber fraction (68). In this case, the freeness difference was much less significant. Others have reported that the middle fraction, when three fractions were created from a bamboo pulp, had higher tensile strength than did the long fraction (14). A similar addition of the long fraction decreased these strength properties. This led to the conclusion that there is a synergistic effect between the fractions for the development of strength properties (15, 31, 89). In the case of bamboo pulp no fraction had the strength properties of the whole pulp (14). It is generally considered that an increase in the average fiber length of a pulp produces an increase in the tear strength of the paper. This was confirmed in many cases where the long-fiber fraction had greater tear strength than did the short-fiber fraction (24).

Average fiber length and character of the fines are considered the most important factors in the development of strength (90). The effects of different blends of the fractions of groundwood pulp on freeness, bulk, wet-web strength, burst, and breaking length are discussed. High strength properties are achieved by mixing a high-freeness, long-fibered pulp with a well-refined, short-fiber pulp. The presence of fines was important for sheet development (91).

CHARACTERIZATION AND MODELING

One problem with using secondary fiber, and especially in attempting to model the processes involved, is the characterization of the pulp. Unlike virgin pulp, the composition of the pulp - whether chemical, mechanical, softwood, or hardwood - is unknown except for what can be deduced by testing the pulp or possibly from knowing the source. For this reason, to fully understand the processes involved, it is necessary to characterize the pulp and relate this characterization to ultimate paper properties. A good characterization method is useful to account for the inherent variation in the secondary fiber supply (92).

Several methods of characterization have been proposed. The parameters considered important for the control of pulp quality are Brecht wet strength, fiber classification (with a 28-mesh screen), CSF, and a modified freeness (using only the 28/200 fraction) (93). An early method of pulp characterization of mechanical pulps is Forgac's *L* and *S* factors. The *L* factor, closely related to fiber length, is the weight of fibers retained on a 48-mesh screen. The *S* factor is the CSF of the 48/100 mesh fraction and is related to the specific surface of the pulp. Others have built on these basic variables in developing relationships, sometimes involving a variety of measurements (94).

In addition to the characterization of the pulp and its effect on paper properties, methods of characterizing the process also need to be defined. Fractionation usually produces two fractions: a long-fiber

Table 1. Summary of Pressure-Screen Fractionators Used in Studies.

Manufacturer	Brand Name	Reference
Bird	Centrisorter	65
Black Clawson	Cellu-Sizer	9, 12, 73, 88, 95, 96, 97, 98, 99
Voith	Multifractor	5, 27, 58, 100, 101, 102
Celli	Biturbo 500	88, 97
Escher Wyss	Fiberfractor	8, 60, 64, 87
Escher Wyss	Omnifractor	8, 87, 92
Tampella	TL-50	24

and a short-fiber fraction, with the long-fiber fraction being the one that is retained on the fractionator screen. The relative fiber quantity for a given pulp stream is the quantity of that fiber length relative to the total quantity of fiber. Fractionation efficiency is defined as the ratio of the fiber quantity of a certain length class in the long-fiber component to the fiber quantity of that length in the inlet (87). Hence, it is important, when modeling fractionation systems, not only to measure the bulk split of the flows but also the changes in the distribution of the fiber lengths. Also, fractionation efficiency is best reported as a function of fiber length and not as a single value.

CONCLUSIONS

Fractionation is successful at separating recycled paper into two or more fractions with different fiber properties. An optimal combination of the two fractions can produce a paper that is significantly upgraded with respect to the original furnish. The addition of virgin kraft fiber to the long-fiber component showed promise for the ability to use mixed office waste in high-quality paper (68).

Research in this area should further explore the feasibility of using commercial fractionation methods on low-quality papers such as mixed office waste. Pressure-screen fractionators, centrifugal cleaner fractionators, and selective pulping are among the technologies available. As shown, the split necessary to produce the desired paper qualities is not well-defined. The determination of the optimal split between what is classified as long and short fibers is needed to realize the full benefits of the utilization of secondary fiber.

The realization of the full benefits from secondary fiber fractionation also requires the optimal level of virgin fiber addition. This optimal amount is the minimal amount of virgin fiber required to maintain acceptable paper properties for a specific grade of paper. The paper properties to be considered should include optical and strength. The literature to date has concentrated on the latter.

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