New Technology to Separate Fiber and Shive from Seed Flax Straw

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Abstract. Seed flax stalk is usually considered a waste product but it can be separated into marketable fiber and shive. The fiber can be used for applications such as composites and paper. Separation of traditional long line fiber from fiber flax stalks is a rigorous and expensive process that requires the stalk to be biologically degraded (retted) before processing. This process is not economically feasible for seed flax stalks. This study evaluated the potential of several machines traditionally used to remove foreign matter from cotton in terms of their capability to remove flax fiber from chopped seed flax straw. The successful mechanical principles of several machines were then incorporated into a single machine and used to separate the fiber and shive from the straw. The new machine consists of components of a modified gin cleaner typically used for cleaning seed cotton and components of a machine typically used for cleaning lint. The initial version of the machine did not yield the desired 80% fiber purity, so more saw cylinders were added. The most effective version produced 13.8% yield out of a possible 20% fiber with a purity of 81.4%. The yield can be improved with additional modifications to the machine.

Keywords. Flax, linen, shive, bast fibers, gin machinery, cotton.
Introduction

Flax (Linum usitatissimum) fibers for cloth originated about 10,000 years ago. Ancient Egyptians placed scenes of flax cultivation on the walls of tombs, and bodies were mummified in flax shrouds (Oelke et al. 1987). Flax is a naturally renewable resource and requires low levels of agricultural inputs such as fertilizers and pesticides. Two general types of flax are grown – fiber flax and seed flax. Fiber is extracted from fiber flax stalks and divided into two classes - long line fiber and short staple fiber (tow). Long line fibers are used in manufacturing items such as linen apparel and are produced from varieties specifically selected for fiber production. The short, damaged fiber called tow is sometimes referred to as “cottonized” flax and is used in lower quality fabrics. Tow is also blended with other products such as cotton to make fabric. The flax stalk consists of fiber bundles located between the epidermis or bark surface and an inner wood core (shive). The fiber bundles in flax stalks are usually separated into individual fibers before use.

Different varieties of flax are grown for seed and fiber. Flax is an annual herbaceous plant that grows to a height of 40 to 91 cm (16 to 36 in.). The life cycle of the flax plant is 90 to 125 days. The plant has a main stalk and branches. The seeds are harvested for their oil content, and the stalks remain in the field to degrade biologically or to burn in a manner similar to that for wheat, oats, rice and soybeans. Flax straw requires a much longer time to degrade than many other agricultural wastes (Anthony 2002). Fiber from the seed flax straw, which is usually shorter in length than long line fiber, has potential for non-textile uses such as composites for automotive interior components to replace manmade materials. However, this fiber is very difficult to separate from the stalk, which is composed of fiber and shive. The shive also has many potential uses, such as particle board. According to Foulk, et al. (2000), the greatest potential for flax in the U.S. is for short staple fiber rather than long line fiber. As a result, recent research has focused on producing uniform, short staple fiber from fiber flax and seed flax straw.

Long line fiber is separated with a complex and extensive arrangement of specialized machinery that has a relatively low processing rate (1,818 kg (4,000 pounds) per hour). Separation of fiber from flax straw is done in a process generally referred to as decortication. The short staple fibers removed during long line fiber production are called tow and used for lower-value products. The separation process is greatly enhanced by a process called retting. In this technique, the stalk of the flax is harvested and degraded either naturally with dew or rain, or with some type of controlled process involving excess moisture. Retting initiates separation of the fiber from the stalk and decreases the difficulty of subsequent separation efforts.

In natural retting, fungi and bacteria partially decompose the plant stalks. Naturally retted flax fibers usually range in color from black to gray depending upon fungi and bacteria and extent of colonization as opposed to its natural golden color. These organisms produce enzymes capable of degrading the stalk and also influencing the quality of the fiber. Selective biodegradation of the pectinaceous and matrix substances with enzymes facilitates removal of fibers from the woody portion of a flax plant (Van Sumere, 1992). Other types of retting such as chemical retting (Van Sumere, 1992), enzyme retting (Akin. et al., 1997) and steam explosion techniques (Kessler and Kohler, 1996) may also be used to help separate the fibers from the stalk. Structural differences exist between unretted, dew-retted, weather-retted, enzyme-retted, and chemically-retted flax stalks. The stalk of recently harvested, non-retted flax straw is tightly bound together whereas the fiber and shive are loosely bound in retted flax straw. These differences in fiber-shive bonding dramatically impede efficient separation.
The U.S. imports nearly all of its flax for domestic textile use. Federal, state and private research is currently underway to develop technologies to support flax production in the U.S. Researchers at Athens, GA, are evaluating technologies to chemically or biologically ret fiber flax to enhance separation of the fiber from the shive (Akin, et al., 1997). Researchers at Stoneville, MS, are developing mechanical methods to separate fiber from straw. Researchers at Clemson, SC, are evaluating textile and other uses of the fiber (Foulk, et al., 2000). Flax is grown in a wide range of field conditions, primarily in cool and moist climates. Since flax is a cool weather crop, in subtropical climates it may be grown in the winter and double-cropped with crops such as peanuts, soybeans, corn or cotton in the spring and summer. The most recent interest into growing fiber flax has been in the southeastern region of the United States. Flax has actually been grown as a winter crop for paper production along the southeastern coastline of South Carolina since the 1960's.

Separation of the waste straw from seed flax production is not possible without major renovations to the extensive arrangement of specialized machinery used for the high-value long line fiber. With all the long line fiber separation equipment overseas, the mechanical separation of the fiber using traditional as well as modified cotton ginning machinery was considered. Since the fiber was to be used as short staple fiber, a purity of 80% was selected as the target level. Typical cotton gin machinery for cleaning seed cotton such as cylinder cleaners, stick machines, impact cleaners, and Trashmaster cleaners as well as a fiber cleaner known as the saw-type lint cleaner was considered as alternative cleaning machines.

Machinery used to separate foreign matter from cotton was considered as likely for use with flax straw because of its aggressive mechanical characteristics. Cylinder cleaners remove finely divided particles and prepare the seed cotton for the drying and extraction processes. Cylinder cleaners consist of a series of spiked cylinders that rotate about 500 r/min and agitate and convey the seed cotton across cleaning surfaces containing small openings or slots. The cleaning surfaces may be either concave screen or grid rod sections, or serrated disks, such as those found in the impact cleaner. Foreign matter that is dislodged from the seed cotton by the action of the cylinders falls through the openings. Another type of cylinder cleaner, the Trashmaster also has a retrieval section to prevent fiber from being wasted. Once the seed flax stalks are chopped into lengths less than 5.1 cm (2 in.) and the fiber-shive bond broken, the cylinder-type cleaners have the necessary mechanical features to separate flax fiber and shive.

Stick machines utilize the sling-off action to extract burs and sticks from seed cotton by centrifugal force. Seed cotton is fed onto the primary sling-off saw cylinder and wiped onto the saw teeth by one or more stationary brushes. Foreign matter and some seed cotton are slung off the saw cylinders by centrifugal force 25-50 times the force of gravity. Grid rods are strategically located about the periphery of the saw cylinder to help control the loss of seed cotton and to aid in the extraction process. However, some loss of seed cotton is inevitable to obtain satisfactory cleaning. Additional saw cylinders are used to reclaim the seed cotton extracted with the burs and sticks. Reclaimer saw cylinders resemble the primary saw but usually operate at slower speeds and are equipped with more grid rods. The stick machine also has the potential to separate seed flax fiber from shive.

Lint cleaners remove leaf particles, motes, grass, and bark that remain intermingled with cotton fiber after seed cotton cleaning, extracting, and ginning. The controlled-batt saw cleaner is the most common lint cleaner in the ginning industry. Lint is formed into a batt on a condenser screen drum. The batt is then fed through one or more sets of compression rollers, passed between a very closely fitted feed roller and feed plate or bar, and fed onto a saw cylinder that
rotates about 1,000 r/min. Each set of compression rollers rotates slightly faster than the preceding set and causes some thinning of the batt. The feed roller and plate grip the batt so that a combing action takes place as the saw teeth seizes the fibers; the feed plate clears the saw by about 0.16 cm (0.06 in.). The teeth of the saw cylinder convey the fibers to the discharge point. While the fibers are on the saw cylinder, which may be 30.5 to 61.0 cm (12-24 in.) in diameter, they are cleaned by a combination of centrifugal force, scrubbing action between saw cylinder and grid bars, and gravity assisted by an air current. The saw cylinder is covered with toothed wire wound in a spiral from one end to the other. Usually there are eight spiral wraps of wire per 2.54 cm (1 in.) of saw cylinder length. There is normally 5-6 teeth/linear 2.54 cm (1 in.) of wire, creating a cylinder population of about 45-teeth/6.45 cm² (1 in.²). The number of grid bars (cleaning points) in a lint cleaner may vary from four to nine depending on the model used. The nose of the grid bar is set 0.16 cm (0.06 in.) from the saw providing means for aggressive separation of materials. The aggressive action of the lint cleaner has the necessary mechanical action to do the final cleaning of the flax fiber after much of the shive is removed.

Anthony (2002) reported on three studies to determine the cleaning effectiveness of gin machinery in separating flax fiber from chopped seed flax straw. His initial work included processing small quantities of flax raw material that contained about 25% fiber by weight which had been chopped to about 5.1 cm (2 in.) lengths through different gin machines. Two stages of standard cylinder cleaners divided the chopped seed flax straw into 38% fiber with considerable shive contamination and 52% shive with considerable fiber contamination (by weight); about 10% of the material was lost in the process. When the fiber portion of the material was also processed through a saw-type lint cleaner equipped with only two grid bars, 37% fiber with some shive and 63% shive with some fiber were produced based on manual separation of fiber and shive by technicians and weighing. The shive or waste ejected by the lint cleaner contained considerable fiber; thus, that material was then processed through a second lint cleaner, and 11% fiber and 89% shive were obtained. Further processing of the rejected shive through the lint cleaner again produced 14% fiber and about 86% shive. Thus, the process which included two cylinder cleaners and a lint cleaner recovered about 14% of the material as fiber. When the waste material from the lint cleaner was reprocessed twice and added to the fiber component, then 18% fiber was obtained or 72% of the total available fiber. This rigorous recycling suggested that the fiber was extremely difficult to remove from the chopped straw.

In his three studies, retrieval of pure fiber (corrected for shive content) ranged from a low of 7.1% to a high of 12.8%. These differences were a function of the amount and type of cleaning equipment used as well as the degree of retting of the raw product. Manual separation of samples of the raw material indicated substantial differences in the degree of retting. When the raw material is properly retted, separation equipment can be greatly simplified. When the raw material is not retted, it is very difficult to separate the fiber from the shive. Based on the large amount of waste removed by the lint cleaner when the pre-cleaning treatments were not used, pre-cleaning treatments must be used to improve the quantity of fiber retrieved. Lint cleaners are also required to achieve purities above 80%. The large amount of fiber in the lint cleaner waste indicates that the waste should be cleaned again with a saw-type lint cleaner in order to retrieve the good fiber.

Anthony (2002) processed 25,000 kg (55,000 lbs) of chopped seed flax straw and produced fiber contents ranging from 9.6 to 15.8%. Three cylinder cleaners followed by one saw-type lint cleaner produced 13.7% fiber at 86.1% purity after recycling the lint cleaner waste twice. Anthony found that cotton cleaning equipment appeared feasible for separating fiber from seed flax stalks, especially if the stalks are retted properly. However, the extensive amount of
machinery required to retrieve an acceptable quantity of fiber greatly hinders its potential for adoption. As a result, research efforts were devoted to developing a simplified machine or process.

**Purpose**
The purpose of this research was to develop a machine to efficiently separate fiber with 80% purity from seed flax straw.

**Methodology**

**Study 1**
Seed flax straw (Figure 1) was obtained from Saskatchewan, Canada, chopped with a Roto-Grind (GranuTech-Saturn, Dallas, TX) into 5.1 cm (2 in.) lengths (Figure 2), and processed through several standard and modified gin cleaning machines and sequences to determine the most effective principles used by the machines. These machines were as follows:

1) cylinder cleaner equipped with standard 0.95 cm (0.38 in.) round grid rods spaced 1.91 mm (0.75 in.) apart on centers + stick machine + Trashmaster + impact cleaner;
2) saw-type lint cleaner;
3) cylinder cleaner equipped with 0.88 cm (0.38 in.), square grid rods spaced 0.64 cm (0.25 in.) apart;
4) cylinder cleaner equipped with standard 0.95 cm (0.38 in.) round grid rods spaced 1.91 cm (0.75 in.) apart on centers + cylinder cleaner equipped with 0.95 cm (0.38 in.), square grid rods with the pointed surface turned upward and spaced 0.64 cm (0.25 in.) apart;
5) Trashmaster;
6) Stick machine;
7) cylinder cleaner equipped with standard 0.95 cm (0.38 in.) round grid rods spaced 1.91 cm (0.75 in.) apart on centers + cylinder cleaner equipped with 0.95 cm (0.38 in.), square grid rods spaced 0.64 cm (0.25 in.) apart;
8) Impact cleaner;
9) cylinder cleaner equipped with 0.95 cm (0.38 in.), square grid rods spaced 0.64 cm (0.25 in.) apart;
10) Cylinder cleaner (equipped with standard 0.95 cm (0.38 in.) round grid rods spaced 1.91 cm (0.75 in.) apart on centers.

About 25 kg (55 lbs) of chopped flax was metered into the machines via a standard gin feed control and samples were taken before and after processing to determine the purity of the materials. Materials were weighed before and after processing. Three replications were used.

The material removed by the machine treatments as fiber was recycled four additional times and the materials weighed. The purity (percent fiber) of the fiber sample was determined after
the first pass and then after five passes, but before the lint cleaners. After lint cleaning, the purity was determined again. Fiber purity was determined by manually separating the fiber and shive from 3g samples of the materials, and weighing them.

**Study 2**

An experimental machine (Figure 3) that consisted of a standard cylinder cleaner modified to operate at 1100 r/min and to use 0.95 cm (0.38 in.) square grid rods spaced 0.64 cm (0.25 in.) apart combined with a standard fine-toothed saw cylinder from a gin lint cleaner was developed as reported by Anthony (2003). This machine combined the better cleaning principles that were reported in earlier studies. Variations of the machine as described by Anthony (2003) were also evaluated. These variations included 1) addition of a secondary cylinder (Figure 4) to prevent the flax fiber from being ejected with the shive waste, and 2) addition of an additional primary cleaning cylinder after the secondary retention saw (Figures 5 and 6). The evaluation also included the use of a standard cylinder to remove some of the shive before it entered the experimental machines, as well as an additional lint cleaner after the experimental machine. Specifically, the following machinery treatments were used:

1. Drier + experimental cylinder cleaner;
2. Drier + experimental cylinder cleaner + one lint cleaner with two grid bars;
3. Drier + experimental cylinder cleaner + one lint cleaner with five grid bars;
4. Experimental cylinder cleaner/lint cleaner saw + one lint cleaner;
5. Experimental cylinder cleaner/lint cleaner/reclaimer saw + one lint cleaner;
6. Cylinder cleaner + experimental cylinder cleaner/one lint cleaner/reclaimer saw;
7. Experimental cylinder cleaner/one lint cleaner/reclaimer saw/lint cleaner saw.

The purity of the machine output was determined as in Study 1, and the same raw material was used for both studies. Five replications were used of about 22.7 kg (50 lbs) each.

**Results**

**Study 1**

The chopped flax straw was processed through the machine sequence and the material removed as fiber was processed again four times in order to extract as much fiber as possible with one machine sequence. For example, one pass through the machine sequence for the traditional gin machinery of cylinder cleaner (round grid bars), Trashmaster, and stick machine as well as the cylinder cleaner with square grid bars yielded fiber quantities ranging from 34 to 55% but purities of only 34 to 48% indicating that a single pass was insufficient. The quantities and purities after one and three passes are given in Table 1. Fiber yield ranged from 20 to 31% but purities were only 44 to 62% indicating that the mechanical actions by the precleaning machines were unable to achieve the proper purity regardless of the number of passes. However, addition of the saw-type lint cleaner to the pre-cleaned fiber did produce the required cleanliness of 80% although the yields were only 10 to 14%. Almost all the material easily removed as shive was removed on the first pass through the first machine of the sequence. The quantity of material removed as shive decreased dramatically after the first machine.
49 to 64% of the total material was taken out as shive although it contains a small amount of fiber. This material can be used to make building products.

After processing the fiber through a saw-type lint cleaner with only two grid bars, the amount of fiber retrieved ranged from 12.3% for the standard cylinder cleaner followed by a cylinder cleaner equipped with square grid bars to 14.7% for the cylinder cleaner equipped with standard 0.95 cm (0.38 in.) round grid rods spaced 1.91 cm (0.75 in.) apart on centers + stick machine + Trashmaster + impact cleaner treatment. The purity of these two treatments was 73.8 and 84.6%, respectively. Unfortunately, five passes through the four-machine treatment is too extensive to be feasible. A cylinder cleaner equipped with round grid bars followed by one equipped with and then a saw-type lint cleaner with two grid bars produced 12.9% at 83.6% purity which appeared to be a possible solution. When processed through the lint cleaner equipped with five grid bars, the purity increased but the amount of fiber recovered was reduced. Nearly all treatments achieved the target 80% purity, so the amount of fiber recovered becomes the critical factor. Based on physical scrutiny of the fiber samples as well as the data in this study, the cylinder cleaner equipped with square grid bars spaced 0.64 cm (0.25 in.) apart was chosen as the basis for the experimental machine. Since the lint cleaner treatments were required to achieve the required purity, the new machine must also include a saw-cylinder.

When representative samples of the raw, chopped straw were manually separated into fiber and shive, the fiber percentage ranged from 13.2 to 23% and averaged 20%. Observation of the waste removed by each of the cleaning machines indicated that the first stage of pre-cleaning removed almost all the shive for the standard cylinder cleaner; however, as the number of cleaners increased, the amount of the potential fiber wasted also increased. For the lint cleaner treatment, a large amount of fiber was wasted. In fact, sufficient fiber was wasted to indicate that the material rejected as shive should be passed through an additional stage of lint cleaning to retrieve the fiber from the waste.

**Study 2**

The three versions of the experimental cleaner were evaluated over a period of several months as the changes were made to the basic machine. The cylinder cleaner portion of the experimental cleaner remained unchanged as the lint cleaner portion was changed. The various versions of the lint cleaner section of the experimental cleaner were constructed as modules and bolted to the cylinder cleaner section.

For the first version of the machine, 19.9, 45.8, and 34.3% of the chopped flax was removed as fiber, shive and waste (line 1 in Table 2). The fiber purity was 53.6%, suggesting the need for additional cleaning. Further studies that also included a saw-type lint cleaner with either two or five active grid bars increased fiber purity to 80.4 or 82.5%, respectively, but decreased the fiber yield to 14.2 and 12.8%. Similar studies without the drier for moisture removal decreased purity and increased turnout slightly. The additional cleaning from the standard saw-type lint cleaner achieved the target 80% purity but yield was sacrificed.

An additional saw cylinder was added (Figure 4) that prevented some of the fiber from being discharged with the waste and the yield was increased to 17.6% and the purity was 68.5%. Further cleaning with a saw-type lint cleaner increased the purity to 82.1% but fiber turnout was reduced to 12.6%.
Since the shive appeared to be overloading the cylinder cleaner section of the experimental machine, a standard cylinder cleaner was used to clean the chopped flax before it entered the experimental machine. Most of the shive was removed by the pre-cleaner and only 12.6% was removed by the cylinder cleaner section of the experimental machine. The material removed as shive by the first cylinder cleaner represented 54.6% of the total material and consisted of 95% shive and 5% fiber by weight. The material removed as shive by the cylinder cleaner section of the experimental machine represented 12.6% of the total material and consisted of 84% shive and 16% fiber by weight. This finding suggested that more than 6 stages of cleaning in the cylinder were needed but less than the 12 that were used. Fiber purity was improved to 73.3% with addition of the cylinder cleaner but was still short of the 80% objective.

Based on these findings, an additional saw-type cleaning cylinder was added to the machine as shown in Figure 5. The material removed as shive by the cylinder cleaner section of the machine is shown in Figure 7. The material removed as fiber by the saw-cylinder section of the machine is shown at Figure 8. Fiber purity increased to 81.4% but yield decreased to 13.8% (line 7, Table 2).

These data suggest that the 80% purity can be met with the experimental machine if it contains two or more lint-cleaner-type cylinders that are used for cleaning. Yield can be increased if a reclaiming cylinder is used to prevent excessive fiber loss. Moving the reclaiming cylinder from the position shown in Figure 5 to the location shown in Figure 9 will likely increase fiber turnout substantially and exceed the 80% fiber purity objective. The version shown in Figure 9 will be constructed, tested and reported later.

**Summary and Conclusions**

The purpose of this research was to develop a machine to efficiently separate fiber with 80% purity from seed flax straw. This study evaluated the potential of several machines traditionally used to remove foreign matter from cotton in terms of their capability to remove flax fiber from chopped seed flax straw. One pass through the machine treatments produced purities ranging from 34 to 48% and fiber yields of 34 to 55%. After three passes, purities were 44 to 62% and fiber yields were 20 to 31%. Addition of a saw-type lint cleaner to the cleaning sequence produced fiber purities of over 80% but the yields were only 10 to 14%.

The successful mechanical principles of several machines were then incorporated into a single machine and used to separate the fiber and shive from the straw. The new machine consists of components of a modified gin cleaner typically used for cleaning seed cotton and components of a machine typically used for cleaning lint. In order to achieve a purity above 80%, a second saw cylinder was incorporated into the experimental machine. The fiber yield of 13.8% requires improvement because about 20% is possible based on the raw material used. Modifications to the machine to improve fiber yield were suggested and results will be reported later. In addition, fiber quality assessment and economic analyses are needed.
References


Table 1. Summary data, in percent, for comparison of the effectiveness of gin cleaning machines in separating fiber from chopped seed flax straw[^a].

<table>
<thead>
<tr>
<th>Pre-cleaners</th>
<th>Precleaning</th>
<th>Lint cleaner grid bars</th>
<th></th>
<th></th>
<th>Two</th>
<th></th>
<th>Five[^b]</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Fiber yield</td>
<td>Purity</td>
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<td></td>
<td></td>
<td></td>
<td>One pass</td>
<td>Three passes</td>
<td>Two</td>
<td>Five[^b]</td>
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<td>None</td>
<td>NU</td>
<td>NU</td>
<td>NU</td>
<td>NU</td>
<td>12.9</td>
<td>72.4</td>
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<td>Cylinder cleaner 1 (CC1[^c])</td>
<td>43.6</td>
<td>38.0</td>
<td>27.9</td>
<td>52.6</td>
<td>14.7</td>
<td>71.2</td>
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<td>54.7</td>
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<td>13.5</td>
<td>78.4</td>
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<td>Trashmaster ™[^c]</td>
<td>33.6</td>
<td>33.6</td>
<td>22.0</td>
<td>56.2</td>
<td>13.0</td>
<td>76.2</td>
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<td>Impact cleaner (IC)</td>
<td>38.6</td>
<td>NA</td>
<td>23.4</td>
<td>61.8</td>
<td>13.8</td>
<td>82.6</td>
<td>13.0</td>
</tr>
<tr>
<td>CC1 + SM + TM + IC</td>
<td>NA</td>
<td>NA</td>
<td>24.2</td>
<td>62.0</td>
<td>12.3</td>
<td>82.4</td>
<td>12.3</td>
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<tr>
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<td>42.5</td>
<td>NA</td>
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<td>46.6</td>
<td>10.9</td>
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<td>57.8</td>
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<td>83.4</td>
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[^a]: The raw material had 20% fiber before processing based on manual separation.
[^b]: Continental Eagle Model Sixteen D, saw-type lint cleaner.
[^c]: Cylinder cleaner equipped with 0.95 cm (0.38 in.) diameter, round grid rods spaced 0.95 cm (0.38 in.) apart.
[^d]: Cylinder cleaner equipped with 0.95 cm (0.38 in.) square grid bars spaced 0.64 cm (0.25 in.) apart with a sharp corner perpendicular to the cylinder.
[^e]: Cleaner in footnote [c] followed by cleaner in footnote [d].
[^f]: Cylinder cleaner equipped with 0.95 cm (0.38 in.) square grid bars turned flat perpendicular to cylinder and spaced 0.64 cm (0.25 in.) apart.
[^g]: Cleaner in footnote [d] followed by cleaner in footnote [e].

NA= not available.
NU= not used.
<table>
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<tr>
<th>Treatment</th>
<th>Shive from additional cylinder cleaner, %</th>
<th>Shive from cylinder cleaner section of experimental cleaner, %</th>
<th>Fiber from experimental cleaner</th>
<th>Waste from lint cleaner section of the experimental cleaner, %</th>
<th>Fiber from lint cleaner&lt;sup&gt;[f]&lt;/sup&gt;</th>
<th>Material removed as fiber, %</th>
<th>Fiber purity, %</th>
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<td>NU</td>
<td>45.8</td>
<td>19.9</td>
<td>53.6</td>
<td>34.0</td>
<td>NU</td>
<td>NU</td>
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<td>NU</td>
<td>42.5</td>
<td>18.5</td>
<td>61.1</td>
<td>39.0</td>
<td>14.2</td>
<td>80.4</td>
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<td>3--Drier + CCLC&lt;sup&gt;[a]&lt;/sup&gt; + LC&lt;sup&gt;[c]&lt;/sup&gt; w/5GB</td>
<td>NU</td>
<td>43.1</td>
<td>16.1</td>
<td>62.8</td>
<td>41.1</td>
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<tr>
<td>4--CC&lt;sup&gt;[b]&lt;/sup&gt; + LC&lt;sup&gt;[g]&lt;/sup&gt;</td>
<td>NU</td>
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<td>16.3</td>
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<td>NU</td>
<td>67.0&lt;sup&gt;[g]&lt;/sup&gt;</td>
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<td>6--CC&lt;sup&gt;[b]&lt;/sup&gt; + CCLCRLC&lt;sup&gt;[e]&lt;/sup&gt;</td>
<td>NU</td>
<td>54.6&lt;sup&gt;[l]&lt;/sup&gt;</td>
<td>12.6&lt;sup&gt;[l]&lt;/sup&gt;</td>
<td>18.9</td>
<td>73.3</td>
<td>13.9</td>
<td>NU</td>
</tr>
<tr>
<td>7--CCLCRLCRLC&lt;sup&gt;[e]&lt;/sup&gt;</td>
<td>NU</td>
<td>53.8</td>
<td>13.8</td>
<td>81.4</td>
<td>32.4</td>
<td>NU</td>
<td>NU</td>
</tr>
</tbody>
</table>

<sup>[a]</sup> CCLC=combined cylinder cleaner and lint cleaner.

<sup>[b]</sup> CC=cylinder cleaner.

<sup>[c]</sup> LC=lint cleaner.

<sup>[d]</sup> CCLCRLC=combined cylinder cleaner and lint cleaner plus a retaining lint cleaner saw.

<sup>[e]</sup> CCLCRLCRLC=combined cylinder cleaner and lint cleaner plus a retaining lint cleaner saw plus a second cleaning saw.

<sup>[f]</sup> Fiber from the experimental machine was input material.

<sup>[g]</sup> contains about 12% fiber.

<sup>[h]</sup> contains about 11% fiber.

<sup>[i]</sup> contains about 5% fiber.

<sup>[j]</sup> contains about 16% fiber.

NU=not used.
Figure 1. Seed flax straw from material baled in Saskatchewan, Canada.
Figure 2. Seed flax straw chopped into about 5.1 cm (2 in.) lengths.
Figure 3. Experimental flax machine containing six spiked cylinders that scrub the chopped flax against square, 0.95 cm (0.38 in.) grid bars spaced 0.64 cm (0.25 in.) apart in addition to a cleaning saw and doffing brush.
Figure 4. Experimental flax machine containing six spiked cylinders that scrub the chopped flax against square, 0.95 cm (0.38 in.) grid bars spaced 0.64 cm (0.25 in.) apart in addition to a cleaning saw, reclaiming saw and doffing brush.
Figure 5. Experimental flax machine containing six spiked cylinders that scrub the chopped flax against square, 0.95 cm (0.38 in.) grid bars spaced 0.64 cm (0.25 in.) apart in addition to a cleaning saw, reclaiming saw, a second cleaning saw, and two doffing brushes.
Figure 6. Side view of 45.7 cm (18-in.) wide experimental flax machine containing six spiked cylinders that scrub the chopped flax against square, 0.95 cm (0.38 in.) grid bars spaced 0.64 cm (0.25 in.) apart in addition to a cleaning saw, reclaiming saw, a second cleaning saw, and two doffing brushes.
Figure 7. Material removed as shive by the cylinder cleaner section of the experimental machine. It also contains some fiber.
Figure 8. Fiber containing some shive after processing through the experimental machine.
Figure 9. Experimental flax machine containing six spiked cylinders that scrub the chopped flax against square, 0.95 cm (0.38 in.) grid bars spaced 0.64 cm (0.25 in.) apart in addition to a cleaning saw, a second cleaning saw, a reclaiming saw that services both cleaning saws, and two doffing brushes.