DECORTICATION OF HEMP (CANNABIS SATIVA) FIBERS USING DROP WEIGHT impacting: FIBER YIELD AND PROPERTIES

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CSBE100768 – Presented at Section III: Equipment Engineering for Plant Production Conference

ABSTRACT Hemp (Cannabis Sativ L.) is an important lignocellulosic raw material for the manufacturing of cost-effective environmentally friendly composite materials. However, traditional decortication processes using hammer mill, cutterhead or crushing rollers often generate low fiber purity, do not allow for an entire separation of fiber from cores. These machines also have high energy requirements. In this study, a decortication processing of hemp was conducted to mainly improve the fiber yield. A lab-scale drop weight impact test was used to separate hemp fibers from cores. The hemp stalks were from the hemp variety of USO 31 produced in Manitoba, Canada. There were two groups of hemp stalks: unretted and retted. Before decortication, the hemp stalks were cut into a length of 40 mm. The hemp stalks were decorticated using a hammer and a mold under without sieving and with sieving conditions at different impact energy levels: 254, 508, 763, 1017, 1271, and 1525 J. Fiber yield and effectiveness of impact tests were determined following decortication. Results showed that impact energy level and sieving conditions affected fiber yield and separation effectiveness. Higher impact energy and more sieving allowed for a greater separation of fiber and resulted in greater fiber yields. The obtained fiber yield and fiber detaching index were 22% and 90%, respectively at an energy level of 1525 J with sieving condition. Low impact energy and sieving resulted in a poor separation of fiber.

Keywords: Hemp, decortication, drop weight impact force, compaction tools, energy requirements, fiber yield, fiber properties.
INTRODUCTION

Natural fibers are considered to be a renewable and environmentally friendly material for industrial applications due to their outstanding advantages. Among the traditional natural fibers, hemp fiber possesses a wide range of unique properties and is comparable to glass fibers in high volume applications, in terms of tensile and modulus strength, and durability (Brazis et al., 2000; Williams and Wool, 2000). The process of extracting hemp fibers from the core of the stalk is called decortication. There are a number of different decortication machines, such as hammer mills, cutterheads, and crushing rollers.

Hammer mills use mainly impact forces to separate fiber from core (Fürll and Hempel, 2000). Cutterheads involve cutting and impact forces to separate fiber from the core (Gratton and Chen, 2004). Both hammer mills and cutterheads are energy intensive machines, and their energy requirements are affected by many factors, such as screen size of the hammer mill, moisture content, bulk and particle density of hemp material and feed rate (Yu et al., 2006; Lopo, 2002; Shi et al., 2003). Crushing rollers utilize fluted, pinned, and flat rollers to crush and separate hemp feedstock. The major separation force is compressive force. Hammer mills and cutterheads have greater processing capacity (mass per unit time) when compared to crushing rollers, which could imply that impact forces are more effective to separate fiber from the core.

The major drawback of the aforementioned decorticating machineries is that the rotating parts of the machines are in contact with the hemp material, resulting in fiber wrapping around the rotating parts (Hobson et al., 2001). This requires periodically clean ups. In some cases, damages may occur to the bearings of the machines, causing fires and even destroying the machine.

In recent years, many researchers have paid great attention to designing and developing new decorticating processes using machines in which fibers do not contact any rotating parts while being processed. A ball milling was lately used for hemp decortication by Baker et al. (2009). The working principle of the ball mill is the combine use of impact and shear forces to separate fiber. According to Baker et al. (2009), ball mills are more suitable for retted hemp than for unretted hemp. Using drop weight to generate impact force and using it for fiber separation would be an alternative decortication method. The drop weight method may also impact the fiber quality, such as fiber fineness.

In summary, some research has been performed on the decortication of hemp using hammer mills, roll crushers, cutterheads, and ball mills. However, no research has been done on the decortication of hemp by the drop weight method. The purpose of this study was to investigate the performance of the drop weight method for hemp fiber decortication. The specific objectives were to study fiber yields and machine effectiveness in the decortication of unretted and retted hemp under different energy levels input by drop weight. Sieving conditions during the decortication were also studied.

MATERIALS AND METHODS
Description of feedstock

Two types, unretted and retted, hemp feedstock materials from the hemp variety USO 31 were used for the impact experiment. They were grown in Dauphin, Manitoba, Canada. The unretted materials were baled and directly collected from the field in July 2009. For retted materials, the hemp stalks were kept in the field for about six weeks prior to being baled. Before impact test, samples were cut into 40 mm and stored for air drying.

Equipment

A simple manual soil compaction tester (ELE International, USA) was adopted to perform hemp decorticication tests using the drop weight impact method. The tester included a compaction hammer guide sleeve and a compaction mold as shown in Fig. 1(a). The specifications of the hammer were: diameter 50.8 mm, weight 4.5 kg, and drop height 457 mm. There was a guide sleeve on the top end of the hammer to release air pressure during compaction. The mold dimensions were: 152.4 mm (inner diameter) × 116.4 mm (height). The cross-sectional area of the mold was exactly nine times that of the hammer. To impact all material in the mold as uniformly as possible, dropping the hammer nine times into the mold at the positions shown in Fig. 1(b) would be the optimal choice, although it still had missing and overlapping parts.

Figure 1. Impact test machine: (a) compaction tools; and (b) surface area.
Experimental design

A randomized complete block design (2×6) was used for the drop weight tests. The block was feedstock type (unretted and retted hemp) and treatments were the six energy levels of drop weight, described below. Treatments were completely randomised within each block. Each treatment was replicated four times, and the total number of tests performed was 48 (2 feedstock types × 6 energy levels × 4 replications).

The energy released from the drop weight impact test was calculated using the following equation (Ku et al., 2005):

\[ E = mgh - l \]  

where

- \( E \) = impact energy (J)
- \( m \) = mass of hammer (kg)
- \( g \) = gravitational acceleration (m/s²)
- \( h \) = drop height (m) and
- \( l \) = losses incurred by friction and other sources (J). The loss is negligible in the test.

Prior to selection of energy levels, a number of preliminary tests with varying hammer drops were completed to choose the appropriate number of drops that would result in effective decortication. If grouping the nine drops shown in Fig. 1(b) as 1 blow, and considering the mold as a clock, for the first blow, the hammer was dropped at 0:00, 1:30, 3:00, 4:30, 6:00, 7:30, 9:30, 10:30, and 12:00; for the second blow, the hammer was dropped in between these times, i.e. starting from 0:45 and with an interval of 90 min. These two patterns were repeated for the following blows (i.e. the first one for odd-numbered blow numbers and the second one for even-numbered blow numbers). This was to ensure the feedstock in the mold would receive the most uniform impact.

Based on the trial results, the numbers of blows selected were 1, 2, 3, 4, 5, and 6 blows. According to equation (1), the corresponded impact energy levels were 254, 508, 763, 1017, 1271, and 1525 J. The more blows, the more energy was input into the feedstock, and therefore, more effective decortications would be expected.

As every drop weight would result in some chaff (defined as particles smaller than 20 mm in this study) being generated in the mold. The undesired chaff would absorb part of the input energy from the next drop. If the chaff was removed between drops, the longer particles would receive more energy, which would improve the effectiveness of decortications. Thus, the aforementioned experiment was performed in two scenarios: with-sieving and without-sieving. For the with-sieving scenarios, the feedstock was sieved between blows to remove the chaff.

Experimental procedure

Marks were made along the circumference of the mold wall to identify the nine angular positions and the centre of the mold. For each test run, a 40 g feedstock sample was used. The sample mass was measured using a precision scale (Mars electronic scale, Model MS200, NorthYork, Canada). The sample was placed into the mold (Fig. 2a). The
hammer was dropped from the fixed dropping height (Fig. 2b), starting at the 0:00 o’clock mark and finishing at the 12:00 o’clock mark, counted as one blow. For the without-sieving scenario, blows were continuously made. For the with-sieving scenario, blow and sieving were made alternately. Sieving was done using a stainless steel sieve shaker (Retsch AS200, Hann, Germany). The screen opening size of the shaker used was 20 mm. Particles smaller than 20 mm were removed as chaff. Particles greater than 20 mm were divided into three fractions: fiber ($\geq$20 mm), fiber attached with core, and core. Each fraction was weighed and recorded. The same procedure was repeated for the next test.

Figure 2. Decortication of hemp stalk using drop weight impact force: (a) feedstock put on compaction mold, and (b) striking of feedstock with hammer.

**Measurement**

*Fiber mass fraction after impact*

To examine how much of the feedstock remained as fiber, $w_1$, fiber with core, $w_2$, core, $w_3$, and how much was rejected as chaff $w_4$, the mass of each fraction from each impact test was weighed using a precision balance. The fiber mass fraction was determined using the following equation:

$$\mu = \frac{w_1}{W} \times 100$$

(2)
where

\( \mu = \text{fiber yield} \)

\( w_f = \text{weight of fibers (g)} \)

\( W = \text{weight of feedstock (g)}. \) The parameter \( W \) was constant, which was equal to 40.0 g

*Fiber detaching index*

To assess the effectiveness of the decortication process by impact test, the reduction in the amount of fiber bound to core was determined. This parameter shows how much fiber was detached from the core for a given dropping impact energy in blows. The fiber detaching index was defined as follows:

\[
\lambda = \frac{W - w_2}{W} \times 100
\]

where

\( \lambda = \text{fiber detaching index} \)

\( w_2 = \text{weight of fibers attach with cores (g)} \)

*Data analysis*

Analysis of variance (ANOVA) (Steel and Torrie, 1980) was performed on the measured data at different energy levels and number of sieving to examine the main effects the experimental factors and their interactions using a Statistical Analysis Software V9.1 (SAS/STAT). No interactions of the experimental factors were detected. Thus the main effects are presented. Means of treatments were compared using Duncan’s multiple range tests. All analyses were made at a significance level of \( P < 0.10. \) Regression equations were obtained from all data to observe trends.

**RESULTS AND DISCUSSION**

**Fiber yield**

The fiber yield \((>=20\text{mm})\), \( \mu \) obtained after drop weight impact decortication varied with impact energy levels and sieving conditions (Fig. 3a,b). Under without sieving condition, the value of \( \mu \) at an impact energy level of 254 J was 3.7% and 14.0% for unretted and retted fiber, respectively. The differences in \( \mu \) at different impact energy levels were statistically significant for both retted and unretted fiber. For unretted fiber, the value of \( \mu \) was 12.1%, 12.8%, 14.5%, 15.7%, and 13.0% in different energy levels 508 J, 763 J, 1017 J, 1270 J and 1525 J, respectively and the corresponding value of \( \mu \) was 13.2%, 14.3% 18.2%, 20.9% and 21.9% for retted fiber (Fig. 3a). The results indicate that fiber yields were higher for retted fiber at different energy levels than those of unretted fiber. The fiber yield increased linearly for retted fiber with a coefficient of determination \((R^2)\) of 0.88, whereas the trends followed non-linear log functions \((R^2 = 0.78)\) for unretted fiber. The followings are the regression functions:
For retted fiber,

$$\mu = 0.0074e + 10.501$$  \hspace{1cm} (4a)

For unretted hemp,

$$\mu = 5.6505\ln(e) - 25.521$$  \hspace{1cm} (4b)

where

$e = \text{impact energy level (J)}$

Fiber yield was significantly improved with input impact energy after sieving samples between each energy level (Fig. 3b). The differences in $\mu$ at different sieving were statistically significant for both retted and unretted fiber. The value obtained of $\mu$ was 10.2%, 12.8% 13.2%, 16.4%, 16.2% and 13.2% for unretted hemp, and 16.8%, 14.5%, 12.5%, 17.5%, 22.0%, and 21.2% for retted hemp, respectively at energy levels of 508 J, 763 J, 1017 J, 1270 J and 1525 J.

![Figure 3. Fiber yield of hemp decorticated using drop weight impact force at different impact energy levels: (a) without sieving; (b) with sieving. Means followed by the same lowercase or uppercase letters are not significantly different.](image)

The feedstocks were reshuffled at every stage of sieving and then, striked at the desired impact energy level which caused ease to individualize and separate fibers from hemp stem. Overall higher yields were obtained for retted fiber under sieving condition. The curve trend of retted fiber followed linear functions ($R^2 = 0.83$) and non-linear power functions ($R^2 = 0.74$) for unretted fiber, respectively. The regression functions were as follows:

For retted fiber,

$$\mu = 0.0074e + 10.315$$  \hspace{1cm} (4c)

For unretted fiber,
\[ \mu = 2.995e^{0.2281} \] (4d)

Munder et al., (2003) reported that the practical fiber yield mainly depends on the grown variety of hemp and the mean fiber (>20mm length) yield ranged between 23% and 27%. The results obtained indicate that hemp decortication using drop weight impact force is most significant for getting higher yield, especially for retted fiber.

**Fiber detaching Index**

The fiber yield after decortication is one desired parameter to quantify the quality of the resultant product. Whereas, the fiber detaching index, \( \lambda \) is another important parameter reflecting the effectiveness of the decortication process. The differences in \( \lambda \) at different impact energy levels under both without sieving and with sieving conditions were statistically significant for both unretted and retted fiber. Under without sieving condition, the value of \( \lambda \) increased to the energy level 1017 J and then almost saturated at about 74.7% (for retted fiber), and that was gradually increased with increasing energy level to 1525 J for unretted fiber (Fig. 4a). In regard to different impact energy levels 254 J, 508 J, 763 J, 1017 J, 1270 J and 1525 J, the values of \( \lambda \) were 38.0%, 52.6%, 58.6%, 62.3%, 65.2% and 68.8% for unretted fiber and 50.9%, 65.6%, 70.7%, 74.7%, 72.7% and 73.1% for retted fiber, respectively. The curve trends were non-linear power function with \( R^2 = 0.86 \) and 0.97 for retted and unretted fiber, respectively. The regression equations were as follows:

For retted fiber,

\[ \lambda = 17.596e^{0.2024} \] (5a)

For unretted hemp,

\[ \lambda = 6.7688e^{0.3199} \] (5b)

Sieving between each energy level plays an important role in machine effectiveness. Under with sieving condition, the corresponded value of \( \lambda \) was 47.7%, 51.7%, 62.3%, 75.0%, 86.0% and 87.9% for unretted hemp and 54.7%, 80.3%, 84.3%, 90.9%, 87.4% and 89.9% for retted hemp, respectively (Fig. 4b). For retted fiber, the value of \( \lambda \) increased following a non-linear log function with \( R^2 \) of 0.85, whereas it followed a linear function (\( R^2=0.97 \)) for unretted fiber. The regression equations were as follows:

For retted hemp,

\[ \lambda = 18.891\ln(e) - 44.096 \] (5c)

For unretted hemp,

\[ \lambda = 0.0356e + 36.735 \] (5d)
Figure 4. Fiber detaching index of hemp decorticated using drop weight impact force at different impact energy level: (a) without sieving; (b) with sieving. Means followed by the same lowercase or uppercase letters are not significantly different.

CONCLUSIONS

After decortication with drop weight impact, the fiber yield obtained varied from 3.7% to 22.0% depending on impact energy levels and sieving conditions. In general, fiber yield increased with increasing impact energy levels. The fiber yield was higher for retted hemp in comparison to that of unretted hemp. Under without sieving condition, the fiber yield values were 3.7%, 12.1%, 12.8%, 14.5%, 15.7%, and 13.0% for unretted fiber and 14.0%, 13.2%, 14.3% 18.2%, 20.9% and 21.9% for retted fiber for the impact energy levels of 254 J, 508 J, 763 J, 1017 J, 1270 J, and 1525 J respectively. Under sieving at each impact energy level, the corresponded fiber yield were increased to 10.2%, 12.8% 13.2%, 16.4%, 16.2% and 13.2% for unretted hemp, and 16.8%, 14.5%, 12.5%, 17.5%, 22.0%, and 21.2% for retted hemp. Low impact energy and sieving resulted in a poor separation of fiber. By increasing the combination of energy levels and sieving the value of the fiber detaching index was increased. Under with sieving condition, the corresponded values of the fiber detaching index were 47.7%, 51.7%, 62.3%, 75.0%, 86.0% and 87.9% for unretted hemp and 54.7%, 80.3%, 84.3%, 90.9%, 87.4% and 89.9% for retted hemp. It is possible to conclude that the optimum fiber yield obtained can be obtained using drop weight impact machine. However, the major limitation of this study was the manual operation of the impact machine. Further research is required to confirm the above conclusions that are based on only two replications of the test. Further test will be carried out to draw final conclusions.

Acknowledgements

The study was funded by Natural Sciences and Engineering Research Council of Canada (NSERC). The authors wish to acknowledge Keith Watson, Manitoba Agriculture, Food & Rural Initiatives for providing hemp stalks. Thanks are also given to Composites Innovation Centre, Emerson Hemp Distribution Company, and Parkland Industrial Hemp Growers Co-op Ltd for their support to the project.
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