Journal of Agricultural Science; Vol. 5, No. 1; 2013
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Development of an Axial Fractionator for Hemp Shive Cleaning and Industrial Applications of Shives

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Received: September 17, 2012 Accepted: October 9, 2012 Online Published: December 13, 2012

doi:10.5539/jas.v5n1p9 URL: http://dx.doi.org/10.5539/jas.v5n1p9

Abstract

Due to increasing shortage of raw materials, traditionally used for production of wood based panels and other composite materials, there is a growing call for the use of raw materials from agricultural production. Hemp shive, a by-product of hemp straw processing, is in eager demand due to its wood-like material properties. In order to be suitable for industrial use, respective agricultural raw material must be competitive in price, as well as be available in respective quantity and quality. ATB has developed a new processing technology for the cleaning of shive-fibre mixes for better accommodation such requirements. Ultimate goal is the generation of dust and fibre free shives as well as the recovering of high quality short fibres from shive fractionation.

This is facilitated by a new type of axial fractionators, which utilizes a multi-stage paddle screw and a screen drum, corresponding with the screw. This allows classification and cleaning of the shives as well as recovering of the short fibres in only one processing step. Finished products are widely dust and fibre-free, high value shives; and shive-free short fibres. The shives can be used for the production of particle boards without further preparation. The recovered short fibres are mainly suitable for the use as reinforcing fibres in composite materials due to their short fibre length (<50 mm).

In cooperation with a machine engineering company, the design of the developed axial fractionator shall be adapted for industrial application. Owed to its simple and flexible design, common by-products of hemp processing can be processed at reasonable costs into high-quality market-going products.

1. Introduction

For a considerable period of time, growing shortage and a cost increase of raw materials for the wood based panel and composites industry has been evident. The use of wood as a fuel additionally boosts the demand in cellulose raw materials (Pecenka et al., 2010). Wood-like raw materials, e.g. from agricultural production, can be understood as alternative or supplement to the classical range of raw materials. Besides cereal straw, hemp and flax could play an important role as wood substitute in future. Some of the biggest hemp producers are Europe (approx. 8,000 ha/year 2011), Canada (approx. 16,000 ha/year 2011) and China (more than 80,000 ha/year 2008) (Kruse, 2012; Müssig, 2010). Especially in Canada hemp is mainly cultivated for seed production. Therefore, the straw could be used at reduced raw material costs for industrial applications if adequate processing technologies are available. Furthermore, in year 2012 more than 430,000 ha of flax have been cultivated for seed production in Canada alone (Agriculture and Agri-Food Canada, 2012). Because modern processing facilities for bast fibre production are able to process hemp and flax with the same equipment, an interesting additional income for farmers could be generated from flax straw.

A large proportion of the produced natural fibre from hemp and flax is used for the production of insulation material and fibre fleeces. Substitution of synthetic fibres (e.g. glass fibre) in composite materials by natural fibres, yet maintaining similar properties of the composite, is also considered feasible (Graupner & Müssig, 2009). Natural fibres and glass fibres show comparable specific strengths and Young's moduli (Bledzki, Gassan, Fink, & Kleinholz, 1999). The demand for shive, which at 50-60 mass-% make up for the significantly larger proportion compared to the fibre in hemp straw (FNR, 2008), is well nurtured by a stable market of animal bedding materials for pets and horses. Besides that, cleaned, high quality shives for particle boards are increasingly interesting as partial or complete substitution for shavings in the wood based panel industry.

This, however, requires an efficient cleaning technology for hemp shives. The high quality requirements of the wood based panel and composites industry regarding shives and fibres could only be met, if fibre can be effectively recovered from the mix, and shives are cleaned properly from dust.

In recent years, intensive research has been done in the development of efficient technologies for fibre decortication (Munder, Fürll, & Hempel, 2004; Pecenka, Fürll, Gusovius, & Hoffmann, 2009) as well as fibre and shive cleaning (Pecenka, 2008; Fürll, Pecenka, & Bojdzinski, 2008), at the Leibniz Institute for Agricultural Engineering Potsdam-Bornim (ATB). As a result of researching different processes for shive cleaning, a new variant was developed; registered for patent (Fürll, Pecenka, & Bojdzinski, 2010); and successfully tested under lab conditions (Fürll et al., 2008). For further development of this process, a test plant for the processing of up to 1.5 t/h shive-fibre mix was build, which is currently tested under industrial conditions in a fibre decortication plant and further developed to practice application.

2. Industrial Conditions in Fibre Decortication

Figure 1 shows a schematic drawing of the fibre decortication plant developed in cooperation with the ATB and currently used in practice test operation. Normally, in high capacity fibre decortication plants, hammer mills or sifter mills are used for the decortication of straw - the core process of the overall processing (Munder et al., 2004)-(stage 4). Here the actual decortication takes place, i.e. the mechanical separation of shive and fibres. The shive is the milled part of the ligneous core of the hemp straw. In order to process the hemp straw in continuously good quality at high plant flow rates, it must be shortened prior processing using a cutting machine. The hemp straw is then evenly and loosely supplied to the hammer mill via a hopper. Subsequently, the fibres are cleaned, whereby different shive-fibre mixes accumulate as by-products. The shives have to be cleaned from dust, and the fibres contained in the mix must be recovered, if possible.

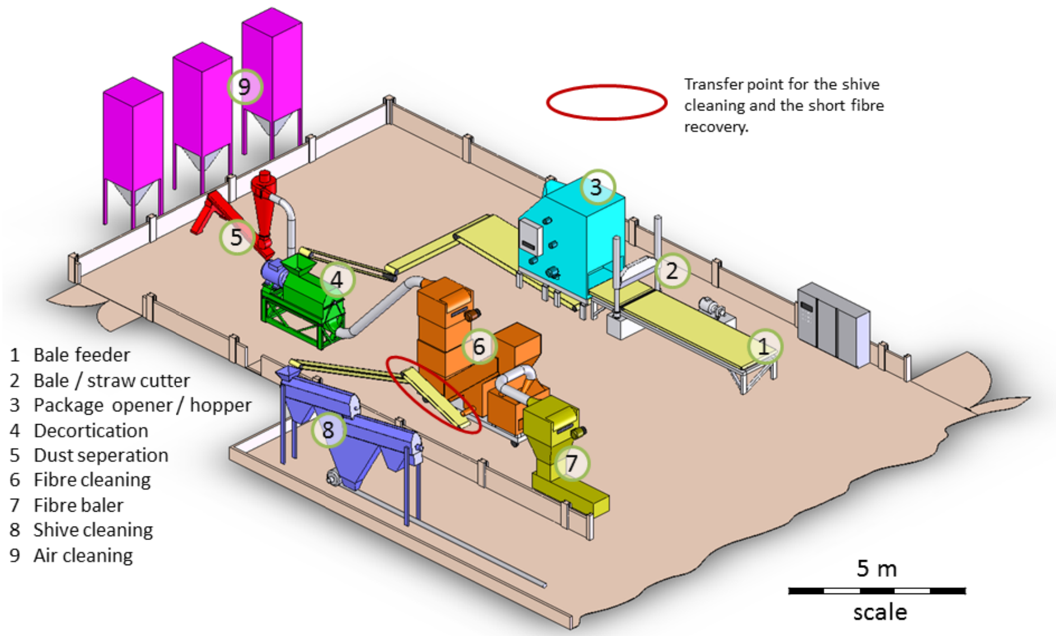

Figure 1. Schematic drawing of an industrial fibre decortication plant

3. Current Situation in Shive Processing

The decortified fibre content in hemp straw -dependent on the type of straw and growing conditions- is at ca. 30 mass-% (Francken-Welz & Léon, 2003; Höppner & Menge-Hartmann, 2000). This, however, means that ca. 70 mass-% of by-products will accumulate on fibre production. A large proportion of these by-products are shives and fibre mixes (Figure 2). For the efficient operation of a fibre decortication plant these accumulating by-products must be processed in ways that can be marketed effectively.

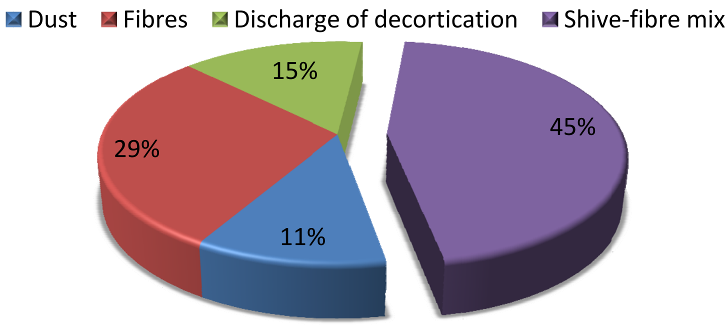

Figure 2. Mass ratio of accumulating by-products in fibre production of hemp straw
(for retted hemp straw at a mass flow of 1.1 t/h)

The goal is to develop a flexible fractionator and cleaning plant for shive-fibre mixes for the processing of a large range of different straw types, based on the principle of an axial fractionator examined at ATB. The latter has to accommodate a mass flow of 2 t/h, matching a plant mass flow of ca. 4 t/h hemp straw. This straw mass flow can cater for efficient fibre production (Pecenka et al., 2009). During this process, the shives shall be cleaned from dust and short fibres with a mass content in shives of less than 6 mass-% shall be recovered. Additionally, ultra short fibres (5-20 mm length) contained in the mix, shall be separated and made available for industrial use as reinforcing fibres, e.g. in injection moulding.

4. Material and Methods

The composition of the shive-fibre mix to be cleaned (Figure 3) depends on the retting degree of the used hemp straw. Different straw types require an adaptation of the operation parameters in a fibre decortication plant, which results in modifications of the composition of the shive-fibre mix. Generally, the mix consists of the main components dust, shives, and short fibres. The main problem for effective cleaning of the mix is that the shives are entangled and partially enclosed in the fibre flakes. This form closure between the fibres prevents an unhindered drop out of the shives. Furthermore, there are shives that have no clean fracture but still have fraying. Thereby it is in this case a form closure with the fibres. It should be mentioned that an inadequate decortication of hemp straw, which is especial noticeable at slightly retted straw, shives are still firmly bound to the fibres by a force closure.

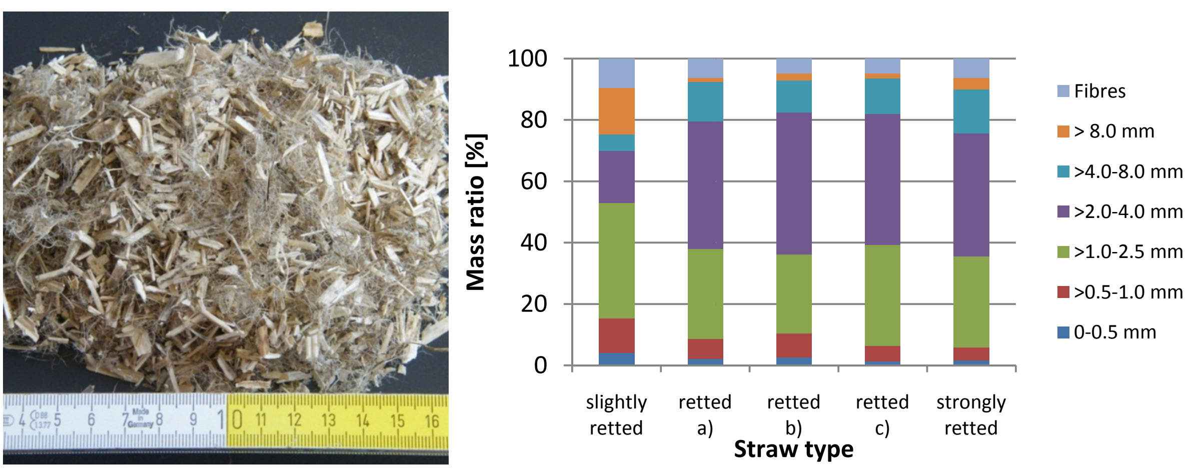

Figure 3. Shive-fibre mix as accumulated by-product of fibre production, and mass ratio of screen fractionation for different straw types

It is thus not possible to separate the mix to a sufficient degree with the usual classing technologies. Since shives and fibres are very light weight and feature similar lifting speeds there is a lack of driving weight force for a separation (elimination/excess of binding forces between shive and fibres). Only active, mechanical intervention, as realized in the axial fractionator (Figure 4), can accommodate a reliable separation of the mix into its main components.

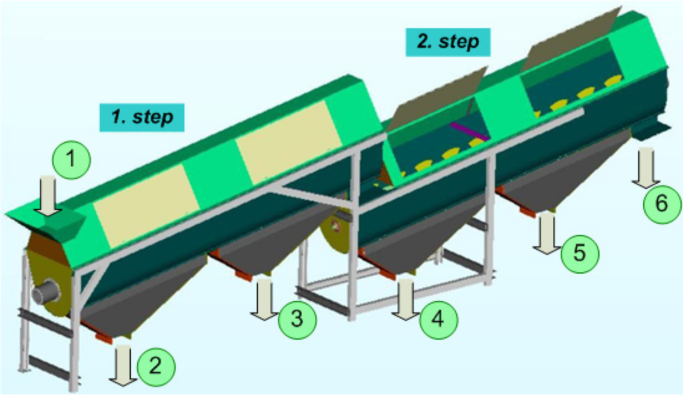

Figure 4. ATB-test plant for cleaning of shive-fibre mixes (axial fractionator)

1) shive-fibre mix; 2) fine shives; 3) rough shives; 4) shives and short fibres; 5) shives and short fibres; 6) cleaned short fibres

The plant consists of two cleaning stages, featuring the paddle screw principle. The movement paths of the particles at the paddle as well as the respective material flows are schematically shown in Figure 5. Three different movement types, facilitating effective separation of the shive-fibre mix, can be realized dependent on parameters like paddle form, paddle pitch, and circumferential speed.

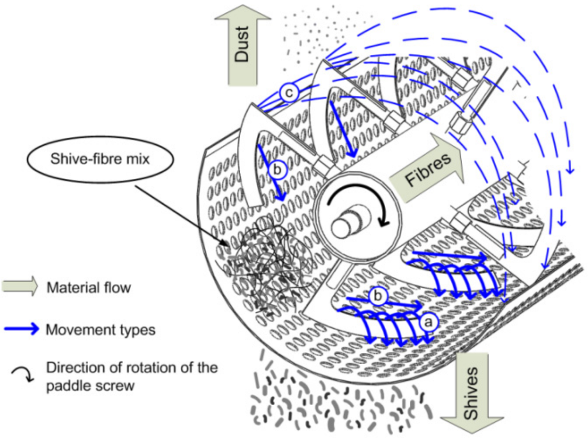

Figure 5. Material flow and straining process of a shive-fibre mix in the axial fractionator

a) flow over the paddle; b) flow along the paddle; c) dropping from paddle.

On the one hand, as in material flow a) the mix flows over the paddle and the newly aligned shives can pass through the cleared screen behind the paddle. On the other hand, as in material flow b) the mix is moved forward over the screen by pitching the paddle axially, thus causing the shives to pass through the screen as well. By dropping the flake from the paddle, as in material flow c) and simultaneously crushing the fibre flake by a successive paddle, the shives are threshed from the flake and can thus pass through the screen.

5. Results

Figure 6 shows selected fractionation examples, generated by cleaning of shive-fibre mixes in an axial fractionator. Figure 7 shows the detailed proportionate content of end products from the shive flow, as collected after the cleaning of the shive-fibre mix in the axial fractionator.

Figure 6. Separated output fractionations from axial fractionator
(left to right: dust/smallest shives; cleaned shives; recovered fibres)

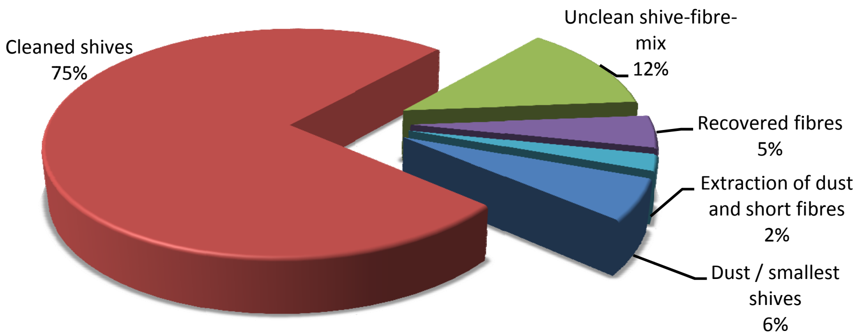

Figure 7. Fractionations after cleaning in axial fractionator (slightly retted hemp straw)

By variation of suitable screen mesh widths the mass distribution and thus the composition of the individual fractionations can be adjusted. The apparently still unclean flake of shive-fibre mix makes up the so-called excess of processing in the axial fractionator. It consists particularly of very large shives, as well as shives still firmly entangled with the fibres. This excess can either be used for targeted marketing, e.g. as loose material insulation, or e.g. redistributed to the decortication plant for further milling and complete decortication.

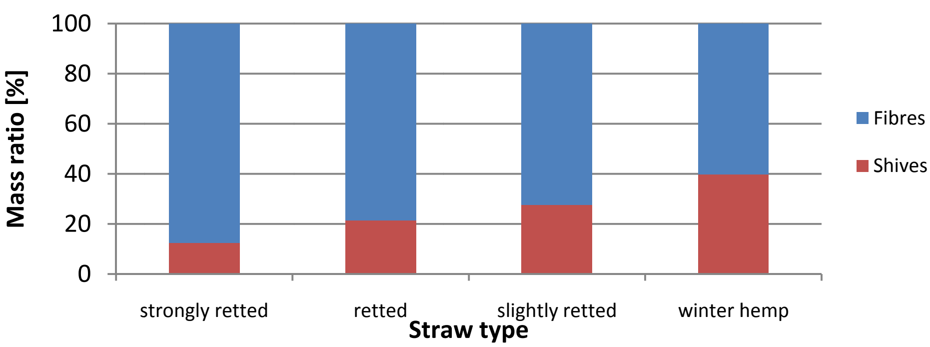

Figure 8. Composition of the recovered fibre by using the axial fractionators

The recovered fibres of 5 mass-% (relative to the shive-fibre mix to be cleaned) are a substantial factor for the efficiency of the plant operation (considered usual fibre prices), since they make up nearly 1/10 of the fibres contained in the hemp plant. Currently an additional cleaning step is required to supply such fibres in market-going quality. The required content of shives in the recovered fibres of 6 mass-% maximum could not yet be achieved with the test plant, due to its insufficient dimensions for industrial application (Figure 8).

Moreover, the currently existing test plant was fitted with a close-meshed screen in the first section of the paddle screw for the separation of dust and sand particles. The utilization of dust separation via gravitation and the respective load reduction in the further cleaning process has also proved to be very effective (Figure 9).

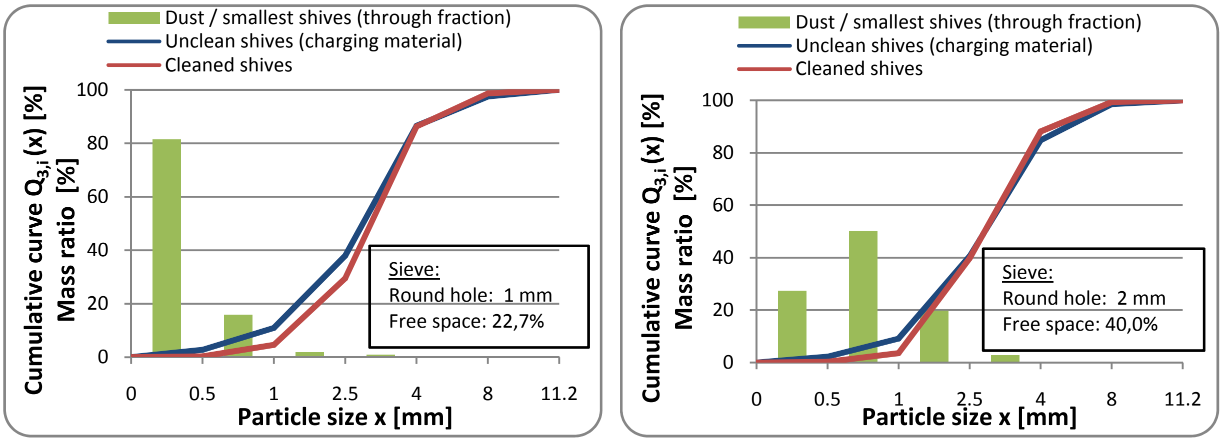

Figure 9. Particle size of cleaned and unclean shives, using different mesh sizes for dust separation in the axial fractionator (shown without fibre)

By variation of the first screen mesh-width, the composition of the separated dust ratio can be controlled and the quality of cleaned shives can be adapted to market requirements. The cleaned shives are the largest proportion of the generated materials and have an insignificant content of dust and short fibre.

The processed shives were recovered to fibre and subsequently pressed to medium density fibre boards (MDF) and particle boards. Figure 10 shows the compared bending strengths of the boards made from different raw materials under addition of 10 mass-% of PF-resin.

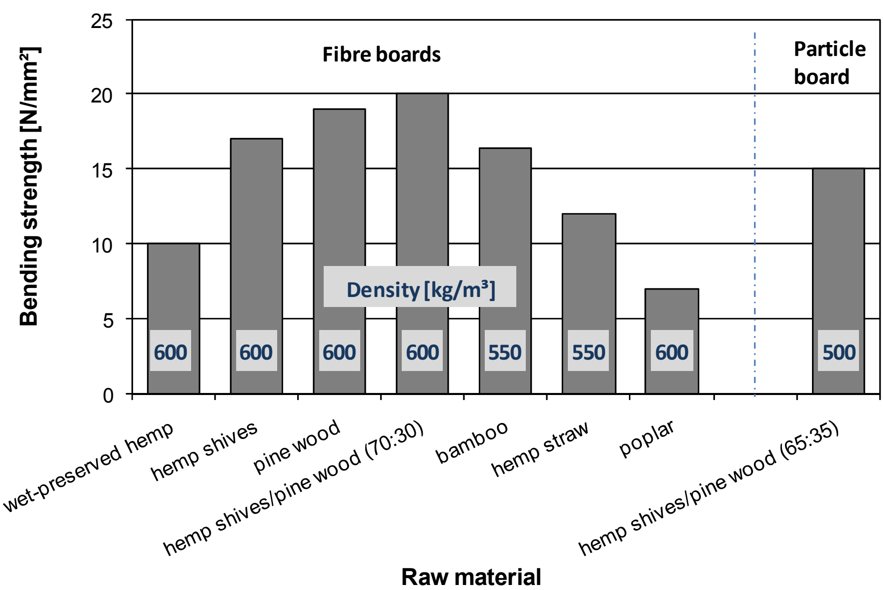

Figure 10. Bending strength of medium density fibre and particle boards from different raw materials

Due to their high purity, the shives (free of dust and short fibres) could be directly processed to particle boards (Figure 11).

Figure 11. Shive particle board with HPL-surface and 2 mm front liner, shavings completely substituted by shives

Potential particle board densities, dependent on the shive properties, are currently examined in detail. This is supplemented by research about the suitability of the separated short fibres and the ultra-short fibres for the use in injection moulding materials. Current findings allow expectations for production potential of composites based on these fibres, featuring similar properties as composites produced from conventional hemp fibres. Using these fibres for injection moulding processes has advantages due to the improved agglomeration properties of the recovered ultra-short fibres and low costs for raw-material or granulates respectively.

6. Conclusions

Farmers need reliable partners in the processing industry for profitable cropping of bast fibre plants for industrial applications. Efficient technologies for fibre processing have been developed in the last decade. Additionally, the implementation of efficient shive cleaning technologies in new processing lines plays an important role for the overall economy of hemp and flax processing.

The research to the axial fractionator has shown that hemp shives can be effectively cleaned with the developed plant concept and consequently be used in wood based panels due to their high quality. The manufacturing cost on the basis of dried chips or shives for producing shive boards are similar to particle boards. The quality hemp shives as a raw material can be offered for a price from 150 to 180 € t^{-1}. The recovering of short fibres and ultra-short fibres in the axial fractionator can result in an increased fibre generation for the overall process by up to 10 mass-% (relative to the fibre content) and thus improve the efficiency of plant operation. Due to the shorter fibre length of the recovered fibre compared to the conventional technical hemp fibre, they are well suitable for the use in injection moulding materials. Currently, detailed research is carried out for this application with respect to processing and product properties compared to conventional reinforcing fibres.

According to experience with the test plant, operated under practice conditions, a reviewed plant concept for industrial application of a shive cleaning plant has been developed with a machine engineering company. Advantages of the new axial fractionator will be a simpler design of the screen path, higher mass flow (2 t/h shive-fibre mix) and relatively higher quality of recovered fibres (rest shive content <6 mass-%).

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