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Production of high quality hemp shives with a new cleaning system

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Abstract. A shortage as well as a rise in costs for raw materials as used for production of derived timber products and fibre composites can be observed for quite some time. Especially the use of wood as energy source has led to an increased demand for cellulose raw materials. Non wood resources e.g. from agricultural production are coming into consideration as alternatives or as replenishment to conventional raw material stock. Therefore, there is an increasing demand for high-grade hemp and flax fibres as a raw material e.g. for production of natural fibre reinforced composites. Within this context also the non-fibrous fraction of fibre plants – shives or hurds – are suitable for different applications in composite or fibre board industry. At present, approx. 50% of the income of a hemp fibre processor is generated by marketing quality shives. There is still a substantial need for efficient shive processing and cleaning technologies. Cleaned high quality hemp shives can be used not only for animal bedding, but also for particle board or composite production. Hence, ATB has developed a simple but efficient technology for cleaning of shive-fibre mixtures. It allows classification and cleaning of shives as well as recovering of short fibres in only one processing step. On basis of these results, the developed fractionating system has been patented and scaled up to an industrial system in cooperation with a machine supplier for hemp processing equipment. The machine has been successfully tested with different machine settings as well as different varieties of input material.

Key words: hemp, fibres, shives, shive-fibre mixture, cleaning machine.

INTRODUCTION

The share of decorticated fibre constitutes in hemp straw - dependent on the type of straw and growing conditions - averages at 30 mass-% (Höppner & Menge-Hartmann, 2000; Francken-Welz & Léon, 2003). Consequently, approx. 70 mass-% of by-products will accumulate during fibre production. Unclean shive-fibre mixtures with different compositions at different output stations in the decortication process are the biggest proportion of these by-products. These mixtures represent 50-60 mass-% of the total input material hemp straw (FNR, 2008).

Some of the biggest hemp producers are in Europe (approx. 8,000 ha year^{-1} 2011), Canada (approx. 16,000 ha year^{-1} 2011) and China (more than 80,000 ha year^{-1} 2008) (Müssig, 2010; Kruse, 2012). Especially in Canada hemp is mainly cultivated for seed production. Therefore, the straw is available at reduced raw material prices for industrial applications if adequate processing technologies are available too. For efficient operation of a fibre decortication plant these accumulating by-products must be processed in ways that it can be marketed profitable like fibres.

The natural fibres from hemp can be used for production of insulation materials 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).

The shives have a stable market for application as 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. The high quality requirements of the wood based panel and composites industry regarding shives and fibres could only be met, if fibres can be effectively recovered from the material mixtures, and shives are cleaned properly from dust. Only two systems are currently available for cleaning of shives in fibre processing plants. These are either large screen drums or mixing shafts with fixed bars that turn the material undefined with high speed and transported it over a screen surface. These machines are primary developed for operation in a long fibre processing lines. Using these cleaning systems for processing of shive-fibre mixtures is connected to substantial modification of the machine design or high investment costs. However, a satisfactory cleaning result can often not be achieved.

In recent years, intensive research has been done in development of efficient technologies for fibre and shive cleaning (Fürll et al., 2008; Pecenka, 2008) at the Leibniz Institute for Agricultural Engineering Potsdam-Bornim (ATB). As a result of researching different processes for shive cleaning, a new variant has been developed, registered for patent (Fürll et al., 2010), and successfully tested under lab conditions (Fürll et al., 2008).

The biggest problems opposing a reliable separation of shive-fibre mixtures into its main components were shive locking in fibre flakes, partly entanglement, as well solid connections with fibres. Opening of fibre fluffs can only be achieved by an active mechanical intervention. This could be realized by using a paddle screw. Combining a paddle screw with a mesh strainer constitutes an effective separation system for cleaning of shive-fibre mixtures. In Fig. 1 the movement paths of the particles at the paddle as well as the respective material flows are schematically shown. The shive-fibre mixture is reliable separated into its main components by three different movement types. Thus, shives can pass the mesh strainer and fibres are moved over the screen in axial direction. Dust and ultra-short fibres are caught from the exhaust air on the top of the machine, transverse to the axial direction of the mass flow as well.

Based on this new technology a test plant for processing of shive-fibre mixtures was build and tested under practice conditions in an industrially operating fibre decortication plant.

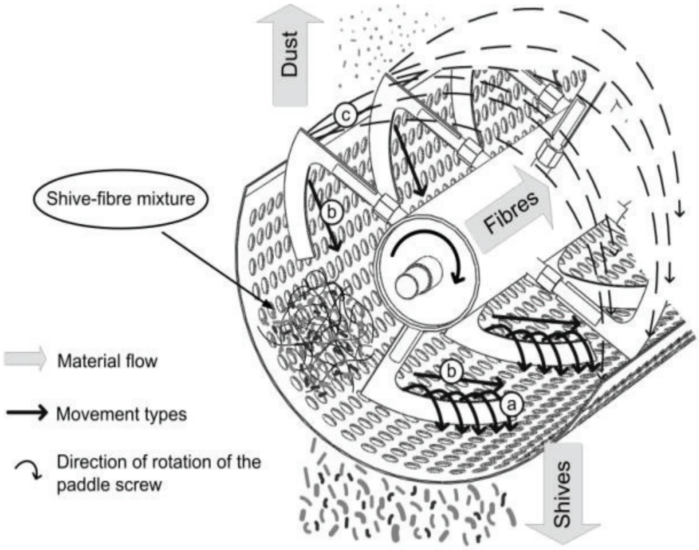

Figure 1. Material flow and straining process of a shive-fibre mixture in the cleaning system: a) flow over the paddle; b) flow along the paddle; c) dropping from paddle.

MATERIALS AND METHODS

Different types of hemp straw (from slightly retted to strongly retted) were used for the screening experiments. Fig. 2 shows the typical shive-fibre mixture and the mass ratio of different particle fractions after screening. Generally, the mixture consists of dust, shives and fibres. The shive-fibre mixtures were produced in a fibre decortication plant, which is working with a hammer mill. Usually, in high capacity fibre decortication plants, hammer mills or sifter mills are used for the decortication of straw - the core process of the whole processing line (Munder et al., 2004).

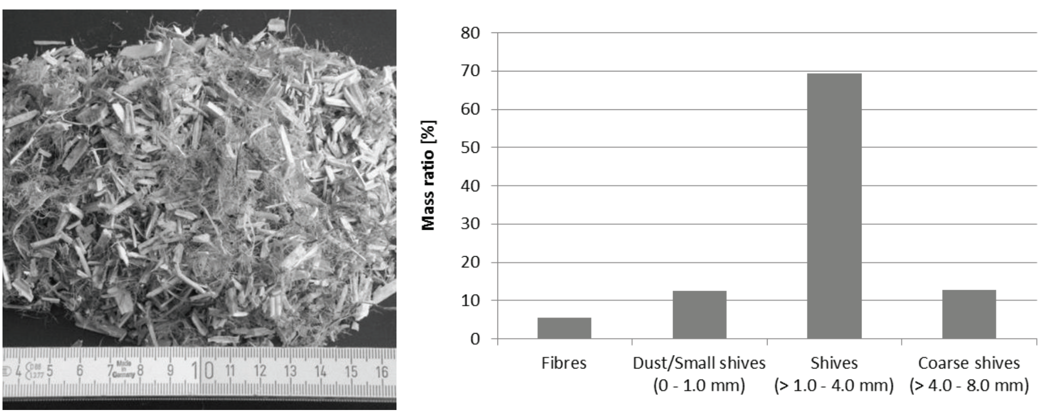

Figure 2. Shive-fibre mixture produced in a decortication plant by using a hammer mill.

The test plant and the experimental setup are shown in Fig. 3. The diameter of the used paddle screw is 1 m. The installed mesh types and the different screen lengths are shown in Table 1. The perforation of the sieves used was adjusted according to current market demands of purified shives. Depending on the particular end use there are the size range of shives or the remaining amount of dust and fibers in the purified shives of essential importance (OENORM S 1030:2008-01-01). The drive shaft of the paddle screw is separated into two parts. With this design parameter it is possible to use two different speeds (n_1, n_2) of the drive shaft at the same time. In the first part of the machine the loose shives are screened along sieve 1 & 2 at a slow shaft speed n_1. At a higher speed n_2 in the second part of the machine (sieve 3) the form-locking of the fibre flocks can be broken and the remained shives can be separated as well. At the end of the screen, clean and almost shive free short fibres can be recovered.

Under the strainer plate 21 boxes are installed to collect the material, which pass through the sieve. The first 20 boxes have a width of 0.3 m. That means, the whole strainer plate is 6 m. The last box is for collecting of recovered fibres. With this experimental setup it is possible to measure the mass ratio, which is passing through the sieve along the strainer plate.

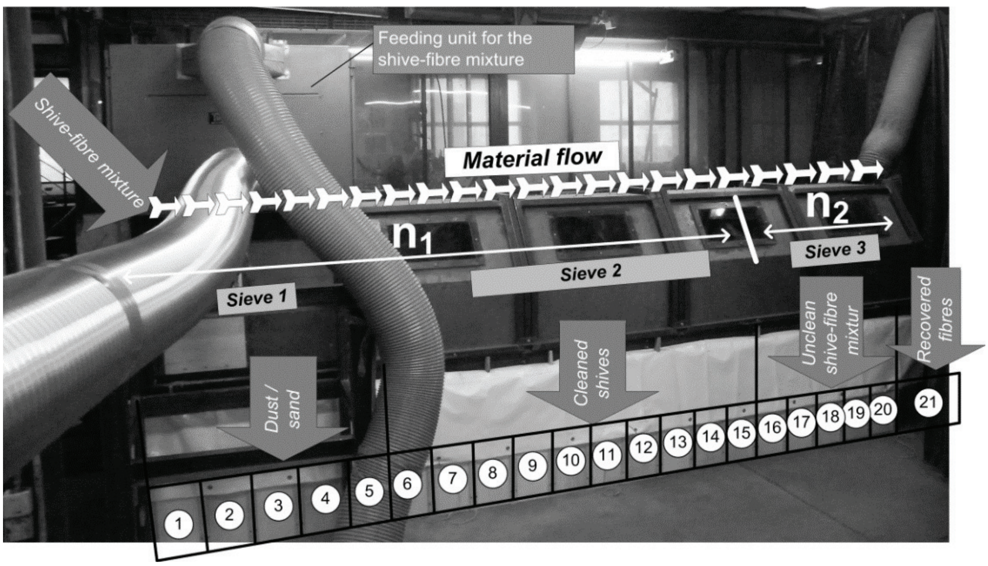

Figure 3. Experimental setup for cleaning of shive-fibre mixtures with a paddle screw over a sieve.

Table 1. Types of sieves used in the cleaning system (RMIG GmbH, 2010/2011)

Description	ISO 7806:1983-12	Perforation	Mesh aperture (mm)	Free space (mm)	Length (m)
Sieve 1	Rv 1.1–2	Round holes	1.10	27.44	1.50
Sieve 2	Qg 10–12	Square holes	10.00	69.44	3.00
Sieve 3	Qg 20–25	Square holes	20.00	64.00	1.50

Fig. 4 shows the installed paddle auger and the used mesh types after a test run. The paddles are fixed with clamps at the drive shaft. The paddles are connected to the clamps with a screw thread. There is the possibility to fixe two paddles on each clamp. With this variability is it possible to define different paddle arrangements as well as different gradients of the paddle screw. Several different arrangements have been realised for the investigation of the screening behaviour of shive-fibre mixtures with this novel cleaning machine. Machine settings and operation parameters have been determined on the basis of a theoretical analysis and a model of the cleaning process has been developed as shown in the next chapter.

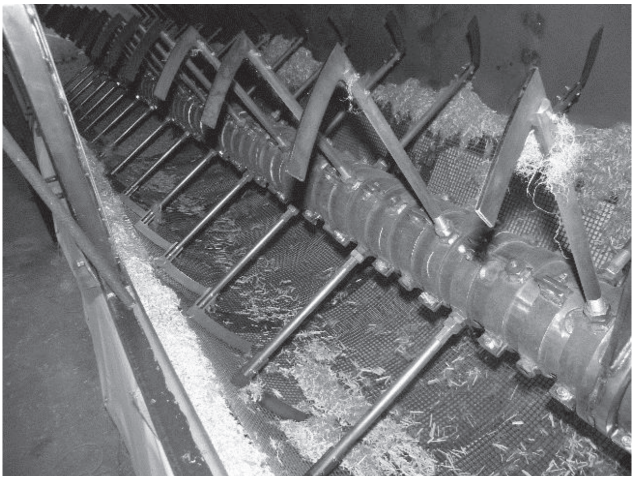

Figure 4. View inside of the cleaning system with the installed paddle arrangement.

Theory and modelling

Three different kinds of paddle arrangements have been investigated in practice experiments. The following variables can be used to describe exactly the differences in the paddle screw arrangements:

G – pitch;
a – intervention-wide of a paddle;
δ – angle distance between two successive paddles;
α – gradient of the paddle;
u – complete paddle screw rotation;
s – distance in the axial direction;
φ – transit angle of the paddle screw.

First basic setup (S1) that has been investigated is the so called 'trailing configuration' (Fig. 5) with an angle δ of 90°. The material needs one complete rotation of the paddle screw to be transported over the distance of one G with this setting.

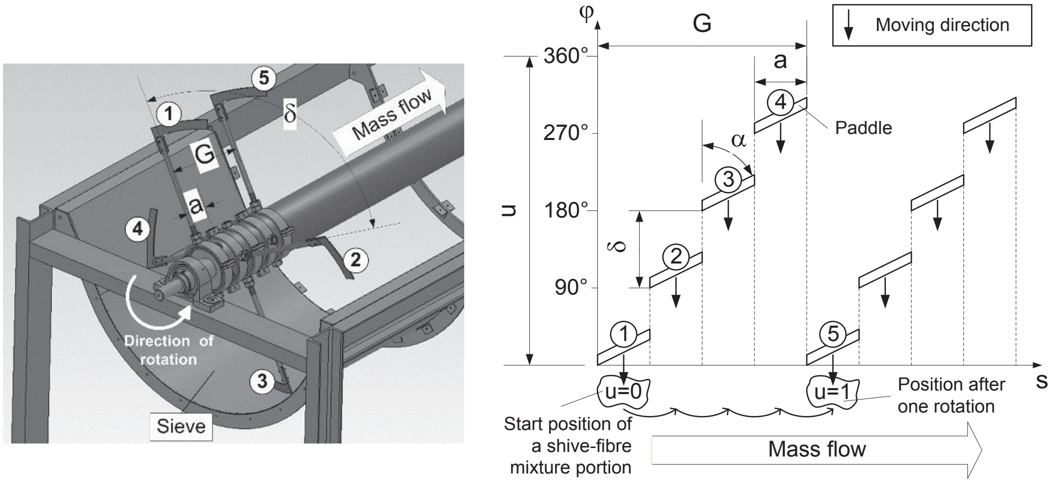

Figure 5. Installed paddles in the trailing configuration (left) and schematic drawing of material transport (right).

Second setup (S2) is the 'in-front configuration' with an angle δ of 270° (Fig. 6). There is also a distance of 90° between two paddles, but in backwards direction. In comparison to the trailing configuration, the material needs to be transported over the distance of one G three rotations of the paddle screw.

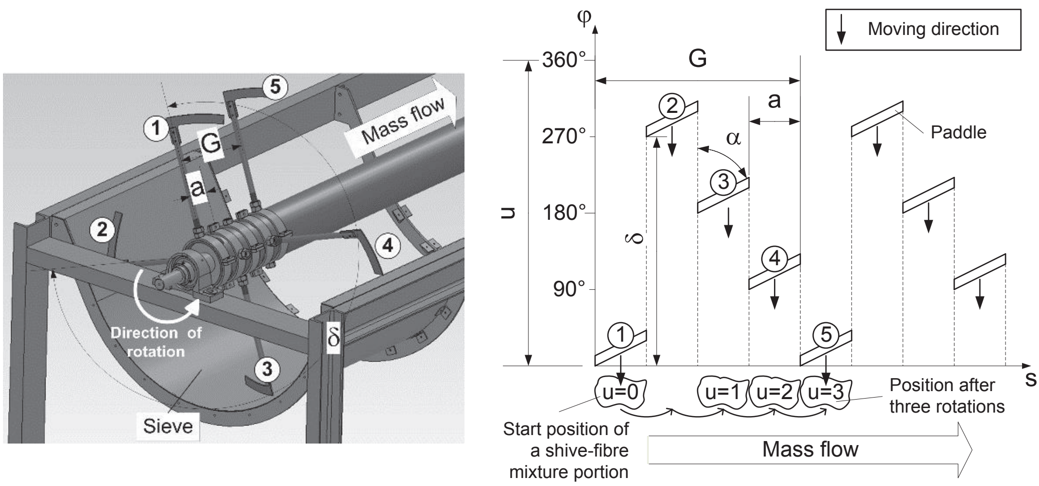

Figure 6. Installed paddles in the in-front configuration (left) and schematic drawing of material transport (right).

The third solution is a paddle screw with double-paddle numbers (setup S3, Fig. 7). This paddle arrangement is working like the trailing configuration, but with the doubled mass flow. That means, without changing the speed of the paddle screw more material can be transported in axial direction.

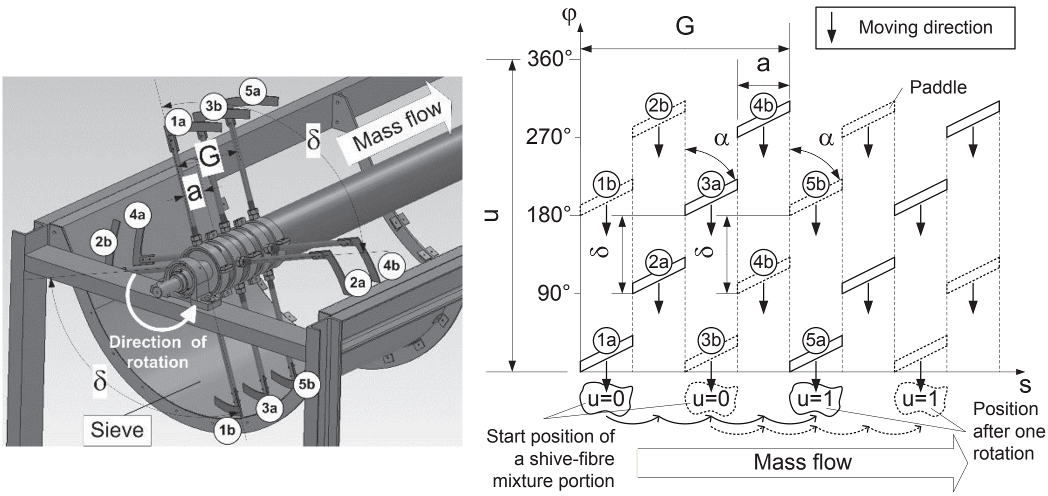

Figure 7. Installed paddles in the double-paddle numbers configuration (left) and schematic drawing of material transport (right).

The relation between material transport in axial direction and the parameters of the paddle screw in dependence to the numbers of rotations is shown in equation 1.

$$s_a = u \cdot \frac{G}{i} \cdot \frac{360°}{\delta} \tag{1}$$

where: s_a – covered distance in axial direction; u – number of complete paddle screw rotations; G – pitch of the paddle screw; i – numbers of paddles for one pitch; δ – angle distance between two successive paddles.

The relation between the velocity of material transport in axial direction in dependence to the drive shaft speed can be described by equation 2.

$$v_a = n \cdot \frac{G}{i} \cdot \frac{360°}{\delta} \tag{2}$$

where: v_a – velocity of material flow in axial direction; n – rotation speed of the paddle screw.

RESULTS AND DISCUSSION

At first, the influence of the three different paddle screw setups on the separation of shive from fibres along the screen length should be investigated. Therefore, the input mass flow should be kept constant by the feeding system. This was not always possible and the realised mass flows varied between 2.42 t h^{-1} and 3.16 t h^{-1}. Despite of these technical feeding problems typical differences in the screening efficiency could be clearly shown (Fig. 8). Setup S2 (In-front configuration) showed the best separation of shives along the shive screening section (screen 2). The disadvantage of this setting was that fibres haven't been transported over the screen at the required rotation speed of the paddle screw. Only at very high rotations speeds a reliable transport of fibres could be realised. Hence, the required gentle transport of shive-fibre mixtures through the cleaning machine is not possible at this paddle setup. Therefore, further investigations focused on the setups S1 and S3 only.

Despite a higher mass flow, the setup with the double number of paddles (S3) showed in comparison to the trailing configuration (S1) a better screening effect. The reason for this is seen in the higher number of paddles pushing the material over the screen.

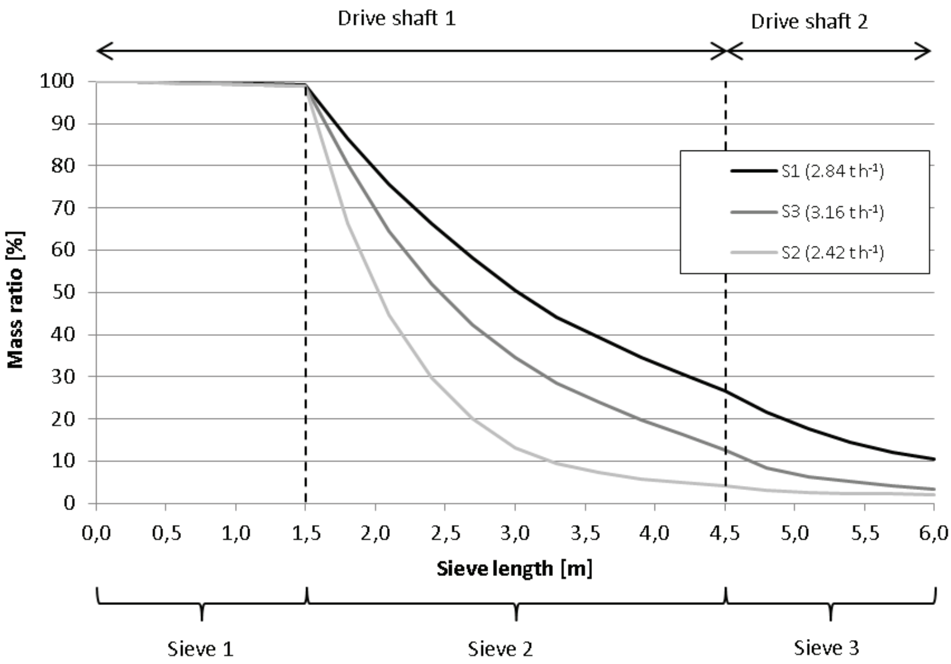

Figure 8. Sieving curve along the strainer plate with a rotation speed of 60 min^{-1} for drive shaft 1 and three different paddle arangements.

In a next step, the dependence between paddle setup and input mass flow has been investigated. The rotation speed of the paddle screw has been kept constant for this purpose. At the same time, the mass flow has been increase at the feeder. An increase of the mass flow leaded to an impairment of the screening efficiency along shive sieve 2 for both paddle setups (S1 and S3). Furthermore, in all test the setup S3 showed the same screening quality as setup S1 but at doubled mass flow. Herby, the model assumptions regarding influence of the paddle setup on the mass flow could be confirmed.

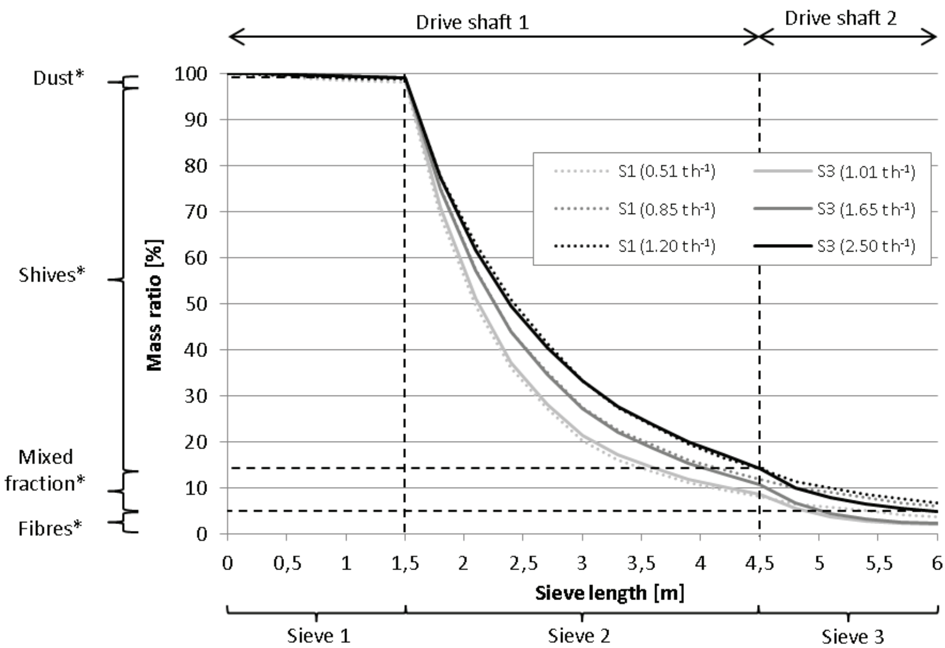

Figure 9. Sieving curve along the strainer plate depending of two paddle arangements and different mass flows.
*Mass ratios of the end products after the cleaning with the double-paddle numbers configuration and a mass flow of 2.50 t h^{-1}.

The influence of different rotation speeds of paddle screw 1 on the mass ratios of fractions of the three end products shives, a mixed fraction with fibres and dust is shown in Fig. 10. With an increase of the rotations speed the ratio of separated dust and clean shives declines. As a result, the ratio of the unclean mixed fraction and of recovered fibres increases. Due to the fact, that the cleaning effect of the paddle screw 2 working in the section of sieve 3 is not considered in this presentation, both fractions can be summarized. The important supplementary cleaning effect of paddle screw two on the end products cannot be shown in Fig. 10.

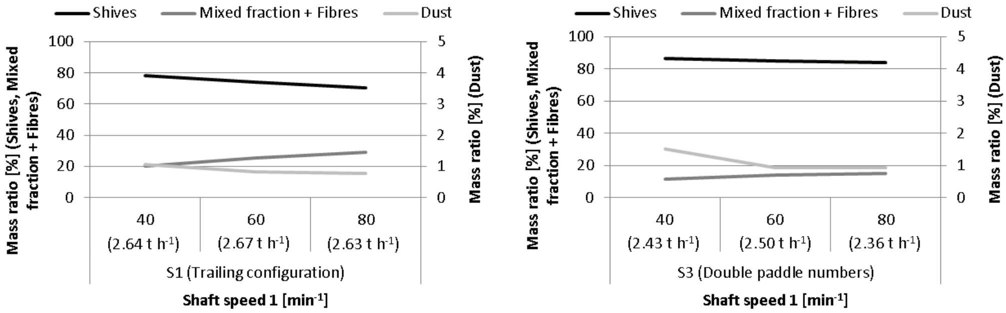

Figure 10. Mass ratios of end products depending of the rotation speed of shaft 1.

Finally, mass ratios of end products after processing in the novel cleaning machine have been determined using different types of hemp straw to provide basic information about the performance of the new cleaning concept. Representative results of all tests are compiled in Table 2.

Table 2. Cleaning results of a shive-fibre mixture after prior straw processed in a hammer mill and followed by a step cleaner

End products	Mass ratio (%)
Dust	1.0–5.0
Shives	80.0–90.0*
Mixed fraction	5.0–10.0
Fibres	3.0–5.0
Dust suction	0.1–0.2

*almost free of dust and less than 0.7 mass-% short fibres in the cleaned shives.

CONCLUSIONS AND OUTLOOK

The experiments with the novel cleaning technology have shown that the developed machine concept has the potential to clean shive-fibre mixtures in a single machine. On the basis of this concept a machine design has been developed fitting to modern powerful fibre processing lines using hammer mills for decortication of hemp straw (Fig. 11). For the industrial machine solution three hoppers and a suction pipe have been installed under the sieve for collecting the main outputs: dust, shives, mixed fraction and fibres. Furthermore, a suction pipe for the discharge of dust polluted air has been installed above sieve 2. It has been shown, that with this machine mass flows up to 2.5 t h^{-1} can be reliable processed to clean, dust free shives as well as quality fibres can be recovered at the same process step. This mass flow corresponds to a throughput of 4 t h^{-1} of hemp straw for the whole processing plant if a ratio of 60 mass-% of shive-fibre mixtures is assumed for the decorticated straw.

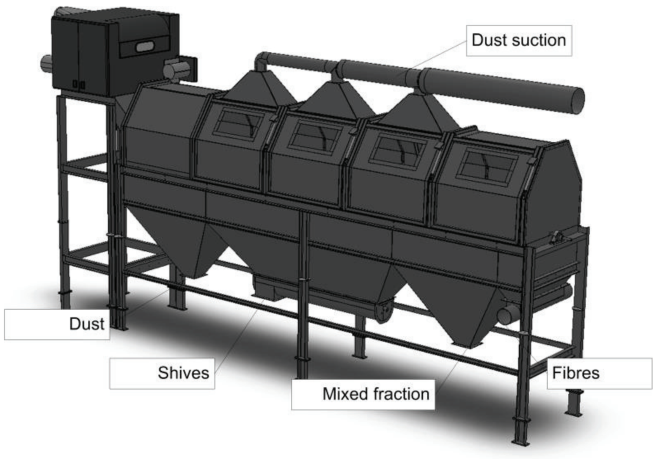

Figure 11. Machine concept for cleaning of shive-fibre mixtures in axial flow.

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