mistra future fashion

automated feeding equipment for textile waste: experiences from the FITS-project

by
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A Mistra Future Fashion Report

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1. background

1.1. towards a circular textile value chain

Production, distribution and consumption of textiles is characterized by a linear value chain with high environmental and societal impacts (Ellen MacArthur Foundation, 2017). A low level of utilization of textiles and ineffective handling of used textiles and textile wastes accentuates the depletion of natural resources in the textile value chain.

Currently less than 1 percent of clothing[1] is recycled into new textiles with same or similar quality applications, so called closed-loop recycling (Ellen MacArthur Foundation, 2017). Less than 5 percent of textiles put on the Swedish market is recycled taking both open-loop and closed-loop recycling into account (calculations based on Fossilfritt Sverige, 2017; and Statistiska centralbyrån, 2019).

The overall collection rate of used textiles is increasing while the share of reusable items in the collected textiles is decreasing (Ljungkvist, Watson, & Elander, 2018). The mandatory obligation for EU Member States to introduce separate collection of used textile by 2025 in EU:s Circular Economy Package (Official Journal of the European Union, 2018) is expected to strengthen both these trends.

Textile collection rates in Western-European countries typically vary between 30-50 percent, even if collection rates in individual Member States can be both higher (Germany) and lower (e.g. Italy and Sweden) (Elander, 2018). Annually 2.7 million ton used textiles are collected separately in Europe, corresponding to an average collection rate of about 30 percent (Elander, 2018). With an assumed European collection rate for used textiles corresponding to 50 percent, the amount of separately collected textiles for recycling (excluding use as industrial wipers) could about triple from today's 0.5 million tons to 1.6 million tons (Elander, 2018).

Several textile and fashion companies (brands) have introduced targets for increased use of recycled content in the production of new textile products, e.g. Global Fashion Agenda's 2020 Commitment (Global Fashion Agenda, 2017), H&M's goal to only use sustainably sourced (including recycled) materials by 2030 (H&M Group, 2019), IKEA's goal to transform into a circular business by 2030 (IKEA, 2019) and Adidas' goal to phase out virgin polyester by 2024 (Adidas, 2019).

The Strategic Reserve Fund in Mistra Future Fashion is to be used in a strategic way to allow for and support new research ideas, prioritizing ideas of applied character such as e.g. pilot studies. Support from the Strategic Reserve Fund enabled utilization of a unique window of opportunity to complement existing research regarding automated sorting of textiles by realization of the project Feeding Into Textile Sorting for recycling (FITS).

[1] Clothing corresponds to more than 60 percent of the total textiles put on the market (Ellen MacArthur Foundation, 2017).

1.2. the role of automated sorting of textiles for recycling

Textile producers' goals for increased use of recycled textile fibers go hand in hand with the development of new (chemical) recycling processes for textiles. The shift from virgin resources to recycled resources for production of new textiles requires that producers get access to large volumes of recycled textile fibers with high and constant quality. Chemical recycling processes enable higher quality recycled textile fibers but generally need higher quality input material than mechanical recycling processes to be able to run efficiently (Ellen MacArthur Foundation, 2017; and Östlund, et al., 2015). Automated sorting of textiles according to fiber type can efficiently provide high-quality feedstocks to textile recyclers and is therefore considered a prerequisite for enabling increased textile recycling and a more circular textile value chain (e.g. Ljungkvist, Watson, & Elander, 2018; Ellen MacArthur Foundation, 2017; Watson, Elander, Gylling, Andersson, & Heikkilä, 2017; and Östlund, et al., 2015).

Generally, post-consumer textile wastes comprise a larger variety of different fiber types and fiber type combinations than pre-consumer textile wastes (industrial textile wastes). The need for automated sorting of textiles for recycling is therefore even higher for post-consumer textiles than for pre-consumer textiles.

Three European research projects have developed pilot facilities for developing and testing different recognition and sorting equipment based on near-infrared spectroscopy (NIR) and (to some extent) visual spectroscopy (VIS) for sorting of textile waste according to fiber type and color: SIPTex Swedish Innovation Platform for Textile sorting (Vinnova, 2019a), FIBERSORT (Circle Economy, 2019) and Resyntex (Resyntex, 2019).

1.3. the role of automated feeding in automated sorting processes

In the NIR-sorting process textiles are fed as items/garments onto a conveyor belt passing under the detection equipment. The textiles are illuminated with near-infrared light. Different textile fibers absorb different wavelengths of the light, reflecting the rest. Sensors detect the reflecting light. Different fiber types generate different spectra. By comparing the spectra with reference materials in a database, fiber types of individual textiles on the conveyor belt can be identified. If an individual textile/garment is identified as the desired fiber type, compressed air separates it from remaining textiles by blowing it into a separate container.

Only the upper surface of the items/garments on the conveyor belt (i.e. the surface facing the source of the near-infrared light) is illuminated during the NIR-sorting process. In case one item/garment is covered by another item/garment, as in the case of heaps or piles of items/garments on the conveyor belt, only the upper item/garment will be detected. The other, not illuminated, item/garment will be sorted in the same way as the illuminated item/garment lying on top of it. Overlying items/garments on the conveyor belt leading to the NIR-unit are therefore a potential source of decreased accuracy in the sorted recycling products and must be avoided.

Simultaneously, as many items/garments as possible must be illuminated and identified per unit of time for the NIR-sorting process to operate efficiently for large volumes of textile waste. This translates into high speeds of the conveyor belt leading to the NIR-unit with as short distances between individual garments as possible.

Efficient, automated feeding of textile waste to the NIR-unit is key for managing large textile waste flows and scaling up automatic textile sorting.

1.4. integrating automated feeding of textiles in SIPTex pilot plant

Within the SIPTex project, funded by Vinnova as part of its Challenge-driven innovation initiative, the SIPTex pilot plant was planned, built and operated for 12 months. The objective of the pilot plant was to test and optimize NIR-based recognition and sorting technology for automated textile sorting. Automated feeing of textile waste was originally planned to be developed and tested in a subsequent project stage.

However, during the planning of the SIPTex pilot plant following Vinnova's approval both SIPTex partners and external stakeholders highlighted the benefits and potential opportunities of testing automated feeding of textile waste in parallel to the rest of the recognition and sorting equipment in the SIPTex pilot plant. The recognition and sorting steps in the NIR-sorting process are fast. Both quantity of sorted textile waste per unit of time and quality in sorted recycling-products is depending on how well textiles feed into these steps. Furthermore, automatic feeding is crucial for scaling up automated textile sorting for large throughputs of textile waste and, as a result, for the business case of automated textile sorting.

1.5. goal and objectives of FITS

FITS' project goal was to contribute to the business case of scalable solutions for automated sorting of textile waste for (fiber-to-fiber) recycling. The project had three objectives to reach this goal:

1. Develop and test automated feeding of loose and baled textiles into automated sorting for recycling onto conveyor belt
2. Adapt and optimize the feeding of textile waste to automated NIR-sorting
3. Demonstrate scalable feeding solutions required for efficient, industrial scale textile sorting for recycling

The ambition of FITS was to integrate research carried out in Mistra Future Fashion and SIPTex to create synergies that strengthen and add value to both initiatives.

2. set-up

The FITS-equipment was rented for the full duration of the operational tests in the SIPTex pilot plant (January – December 2017) and installed as an integrated part of the SIPTex pilot plant, see figure 1. Annex 1 provides additional impressions from the installation.

figure 1 The FITS equipment (not faded in the picture) was fully integrated in the SIPTex pilot plant.

2.1. technical equipment

The FITS-equipment was given the popular name Feeding Bunker throughout the project. The set-up of the Feeding Bunker was similar to automated feeding units for other waste materials but adjusted to fit the specific characteristics and properties of textile waste. table 1 gives an overview of technical data of the Feeding Bunker.

table 1 Technical data for the Feeding Bunker.

Aspect	Specification
Width (inner width/drum width)	1.8 m
Length moving floor	6.0 m
Total machine length	8.3 m
Inner wall height	1.7 m
Fill level	Up to 1.2 m
Effective fill volume	10 m^3
Position of moving floor	horizontal
Stoke length (moving floor)	0-0.15 m (adjustable)
Conveying speed (moving floor)	0-0.2 m/s (adjustable)
Weight	10.5 ton
Power requirement	11.5 kW

The Feeding Bunker consisted of a moving floor conveyor, a dosing unit in form of a rotary drum feeder and supporting structures, see Figure 2.

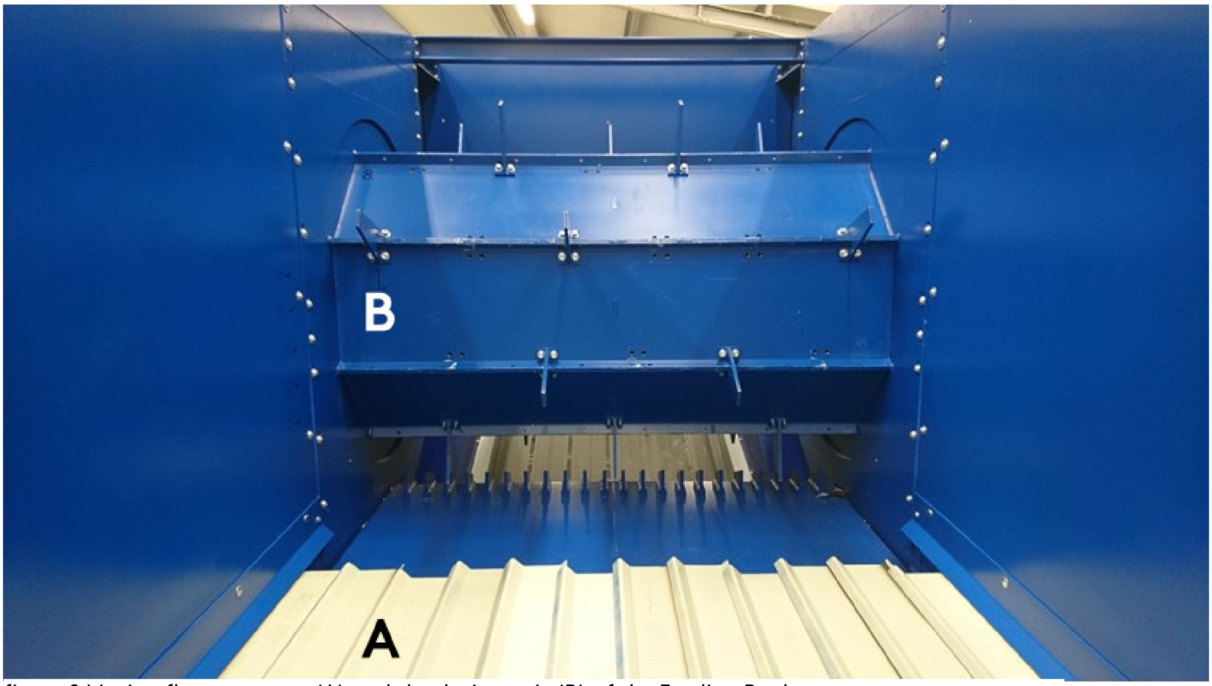

figure 2 Moving floor conveyor (A) and the dosing unit (B) of the Feeding Bunker.

The FITS-equipment was delivered by BRT HARTNER, a German company specializing in developing and producing components and technical equipment for recycling and waste sorting operations (Eggersmann Gruppe, 2019). BRT HARTNER is part of the German Eggersmann Gruppe.

2.2. integration in the SIPTex pilot plant

In an industrial installation, the Feeding Bunker would be continuously loaded via a conveyor belt or non-continuously via forklifts or front loaders. Furthermore, the inbound material would be loaded only once into the Feeding Bunker regardless of the subsequent number or NIR-units in the sorting facility.

The SIPTex pilot plant was not an industrial installation. Inbound material was loaded into 660 liter waste bins on wheels that, in turn, were loaded onto the moving floor of the Feeding Bunker (rear end) using a waste bin turner, see figure 3. In the front end of the Feeding Bunker the feeding drum dropped garments onto the first of three conveyor belts leading to the NIR-unit, see figure 4.

An industrial NIR-sorting facility would generally have several NIR-units in series to sort out different recycling products in an efficient way. The SIPTex pilot plant comprised only one NIR-unit. To simulate multiple NIR-units the inbound material was looped, i.e. after sorting in the NIR-unit it was manually rolled from the NIR-unit back to the Feeding Bunker using the 660 liter waste bins on wheels.

figure 3 Loading of the Feeding Bunker using a waste bin turner.

figure 4 The Feeding Bunker was mounted to the subsequent SIPTex equipment. The feeding drum dropped garments and other textiles onto the first of three conveyor belts leading to the NIR-unit.

3. inbound material

The inbound material to the Feeding Bunker consisted both of textile waste that had been packed and transported in plastic sacks (loose material) and textile waste that had been baled (baled material). However, in the absence of forklifts or front loaders the baled material had to be put in the waste bins before loading of the Feeding Bunker which pre-loosened the textile waste to some extent. The Feeding Bunker could therefore not be tested for completely baled material entering the moving floor conveyor.

In the SIPTex pilot plant feeding and NIR-sorting were tested for both mixed textile waste and pre-sorted textile waste. Mixed textile waste is used to describe the mix of all textile waste that remains after (manually) sorting out reusable garments from separately collected post-consumer textiles, often called "originals". Pre-sorted textile waste is used to describe textile waste that manually is sorted into coarse recycling fractions after the reusable textiles have been separated from the "originals". These coarse recycling fractions are not based on fiber composition, but rather on type of garment (e.g. knitwear) or potential use in mechanical recycling (e.g. white industrial wipers). table 2 gives an overview of the different types of inbound textile wastes that were used in the SIPTex pilot plant.

table 2 Overview of different inbound textile wastes to the SIPTex pilot plant. All inbound textile wastes origin from post-consumer textiles ("originals"). Prior to delivery to the SIPTex pilot plant reusable garments were separated into other material streams.

Name	Pre-sorted	Mixed	Description
Mixed textile waste		x	Mix of non-reusable textiles that arise as sorting rest from basic manual sorting of "originals"
Broken jeans	x		Denim and dark trousers
Woolen clothing	x		A mix of non-reusable textiles that are likely to have some woolen content. However, the mix also includes non-woolen garments.
Knitwear	x		Predominantly knitted pullovers, cardigans, sweaters etc.
Wipers white	x		White (or light) textiles/garments with assumed good absorbing quality and with surfaces typically lager than 0.3 meters times 0.3 meters
Wipers colored	x		Mixed colors (non-white) textiles/garments with assumed good absorbing quality and with surfaces typically lager than 0.3 meters times 0.3 meters

Before loading the Feeding Bunker all packaging material (wires, foils, strings, cords etc.) was removed so that only textile waste entered the feeding process.

4. adjustable parameters in the Feeding Bunker

Different parameters in the Feeding Bunker were adjustable to allow for optimization of the feeding of different textile wastes. The settings were made by adapting the parameters on the control panel, see figure 5.

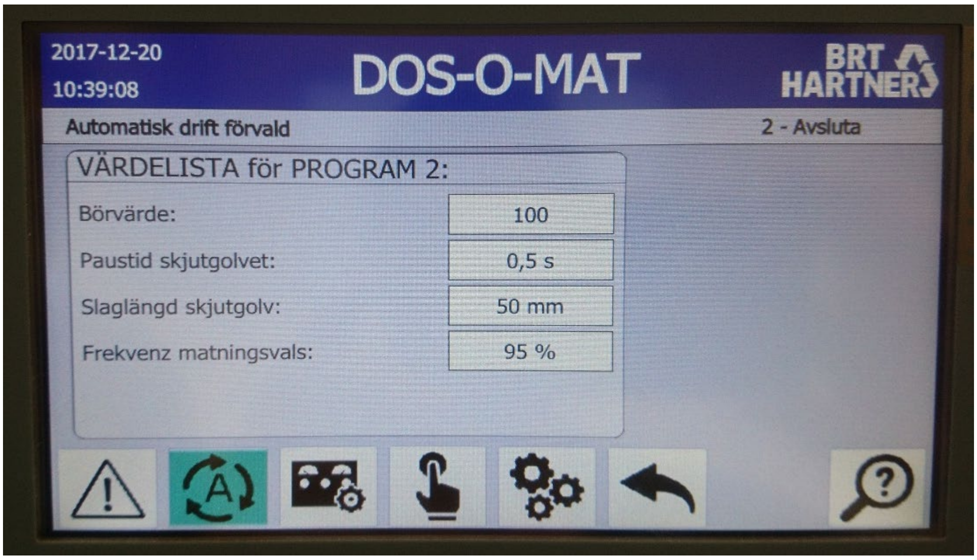

figure 5 Control panel of the Feeding Bunker with adjustable parameters for optimized feeding of different textile wastes.

4.1. movements of the moving floor conveyor

The moving floor conveyor was made of rugged steel and consisted of numerous side-by-side, longitudinally-movable conveyor slats. Each slat was 0.15 meters wide and the full width of the moving floor 1.8 meter. The objective of the moving floor conveyor was to transport textile waste material towards the rotary drum feeder enabling a constant and optimal material flow.

Every third slat was interconnected, forming tree groups of slats (1-3), see figure 6. All slats within one group moved simultaneously.

figure 6 Every third slat was interconnected resulting in three groups of slats (1-3). All slats within one group moved simultaneously.

The feeding process of the movable floor conveyor was that all groups of slates (hydraulically) moved forwards one step and that, subsequently, each one of the groups separately moved backwards one step resulting in the following movement pattern:

- groups 1+2+3 forwards
- group 1 backwards
- group 2 backwards
- group 3 backwards
- groups 1+2+3 forwards
- group 1 backwards
- etc.

While one group moved backwards, the friction of the textile waste on the surface of the remaining two groups (not moving) secured that the textile waste did not move backwards, resulting in a forward movement of the textile waste towards the rotary drum feeder every time all groups were moved forwards.

Two parameters were adjustable regarding the moving floor conveyor:

1. The individual length of one step could be adjusted from 0-0.15 m
2. The time delay between two movements (stokes) could be adjusted

4.2. height of loaded material

To operate efficiently, i.e. producing a steady flow of textiles onto the subsequent conveyor belt with short distances between individual items but without creating heaps and overlapping material, the rotating feeding drum needed a steady flow of textiles. The moving floor conveyor created a pressure of textiles on the rotary feeding drum. Too low pressure resulted in too little textile waste fed onto the subsequent conveyor belt per unit time. Too high pressure increased the risk for heaps and overlapping textiles on the subsequent conveyor belt.

Two sensors above the rotary feeding drum measured the height of the loaded material from the bottom of the Feeding Bunker, see figure 7.

The height (fill level) was adjustable from 0-1.2 meter. Once the desired fill level was reached (or exceeded) the movements of the moving floor conveyor were automatically stopped until the fill level was below the desired fill level.

figure 7 Two sensors over the rotary feeding drum (marked with yellow circles in the picture to the left) measured the height (fill level) of the loaded material (picture to the right).

4.3. shape and placement of tappets on the rotary drum feeder

Three different shapes and sizes of tappets could be mounted to the rotary drum feeder in different patterns. figure 8 shows the three different types of tappets available in the project (large, medium and small).

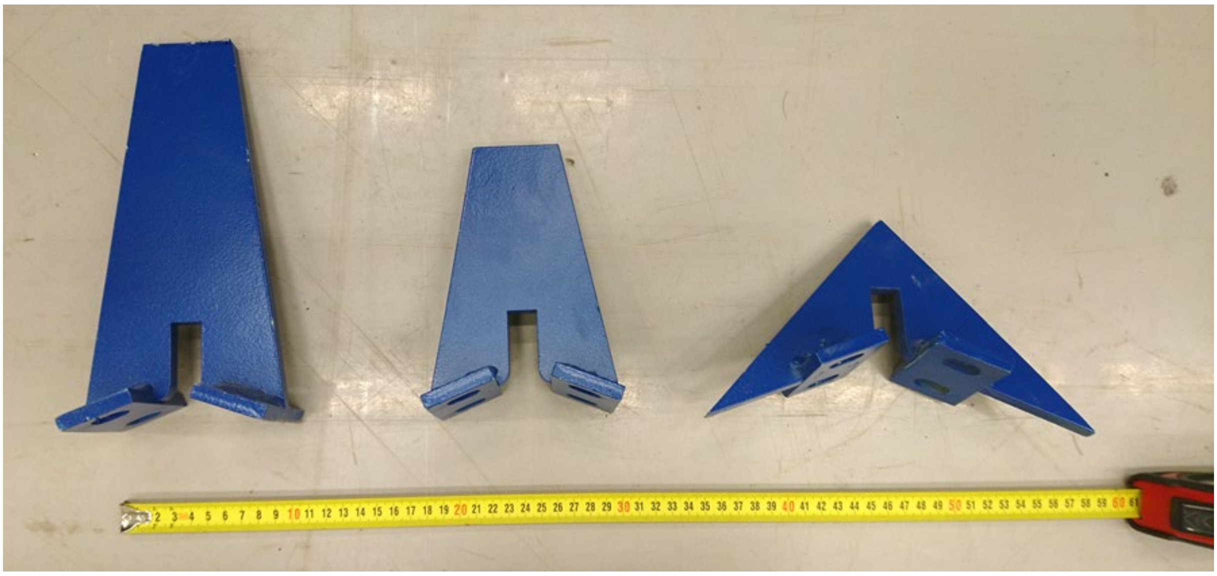

figure 8 Three differently shaped and sized tappets were used in the Feeding Bunker (from left: large, medium and small).

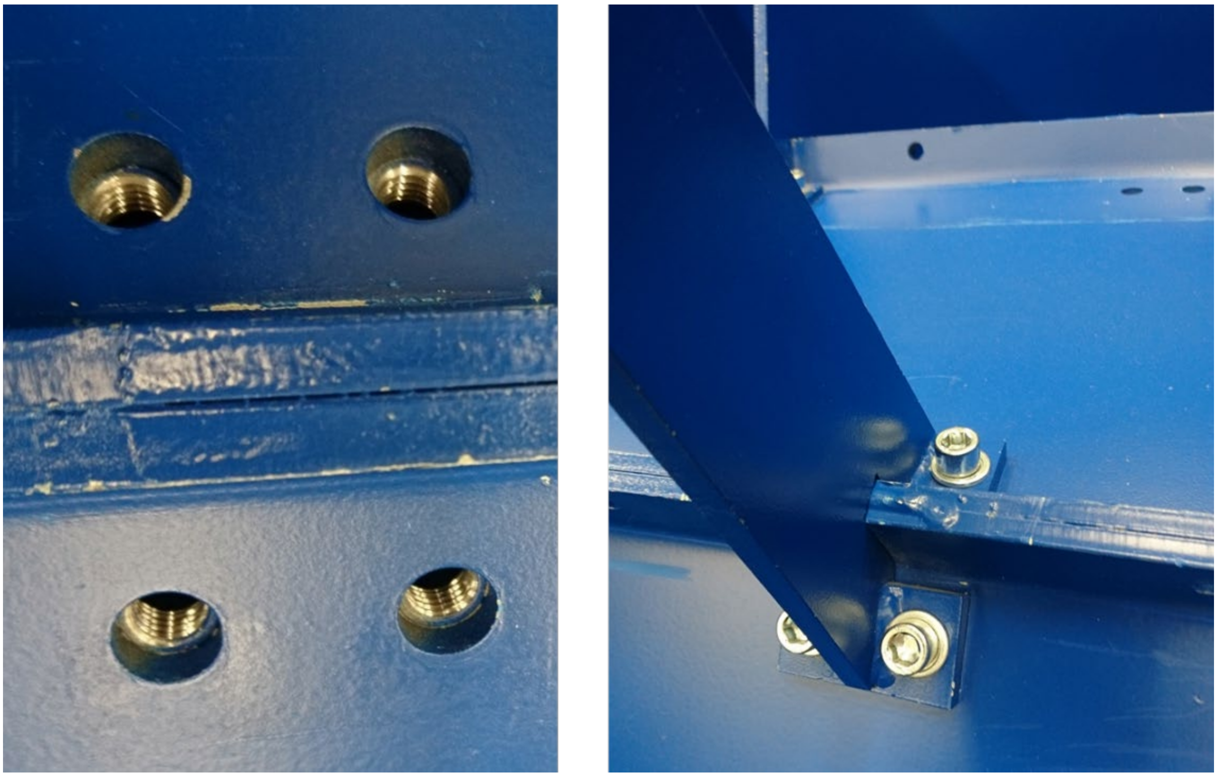

figure 9 The tappets were mounted onto the rotary drum feeder using bolts and could be exchanged by the machine operator.

The tappets were mounted onto the rotary drum feeder using bolts, see figure 9.

The positioning of the tappets was adjustable. The rotary drum feeder had in total 42 places to place tappets, see figure 10. The machine operator could exchange both the size of the tappets and the positioning of them at any given time.

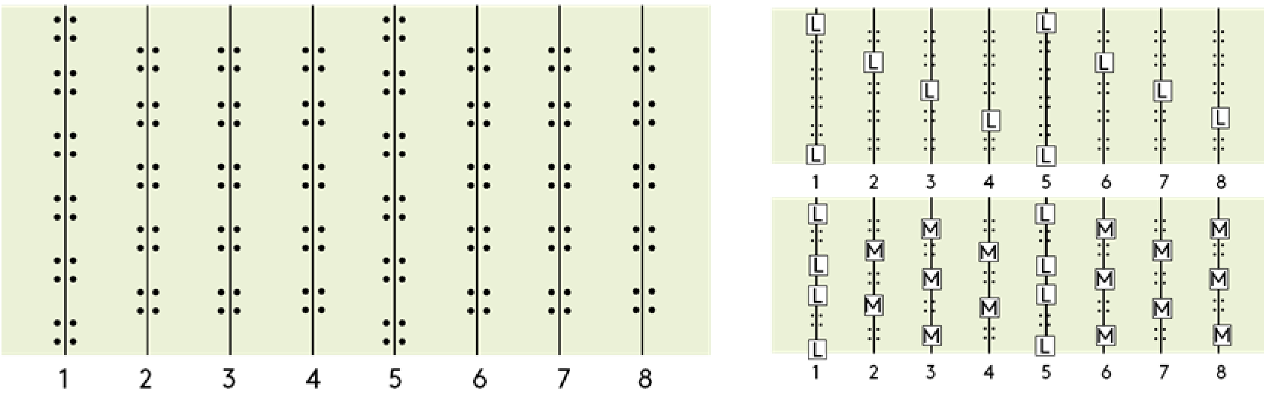

figure 10 The rotary feeding drum had 42 places to mount tappets (left), resulting in a very large number of possible combinations of size (large, medium, small) and positioning of tappets (two examples to the right).

4.4. rotation speed of the rotary drum feeder

The rotating speed of the rotary drum feeder could be adjusted between 0-100 percent of the maximum speed of the drum.

5. experiences and results

The practical tests of the FITS-equipment in direct connection with the subsequent SIPTex-equipment provided valuable insights for creating efficient material flows in automated textile sorting. The technology used in the Feeding Bunker is considered suitable for automated feeding of textile waste and the tests carried out in pilot scale as part of the FITS-project are promising in terms of scalability for industrial use. The following sections summarize experiences and results for different aspects respectively.

5.1. inbound material

Five out of six inbound materials tested in the Feeding Bunker were pre-sorted (see Table 2). The pre-sorting increases the homogeneity of the textile waste within one category of inbound material. The most extreme example was "Broken jeans" that almost exclusively included jeans and trousers in adult sizes. Also "Knitwear" predominantly included garments of approximately the same size and weight. The wipers categories included both garments and household textile waste (sheets, towels etc.) and were a bit more heterogenous. "Woolen clothing" included garments of varying size and weight, e.g. blazers and long johns.

The mixed textile waste comprised a large variety of textile waste, of different sizes and weight. In addition, the mixed textile waste in the trials included a higher share of items that were hard to feed with the Feeding Bunker, for example rolled up balls of cut textiles (for rag rugs), balls of socks and small items such as crocheted oven mittens and cuddly toys. These items were generally not grabbed by the tappets, passed through underneath the rotary drum feeder and were collected in front of a row of steel "teeth" (see underneath the rotary drum feeder in figure 2) where they eventually fell down onto the subsequent conveyor belt or had to be removed manually.

The feeding of textile waste generally worked better for pre-sorted textile waste than for mixed textile waste as the parameters in the Feeding Bunker could be optimized for the most common size and weight of items included in a specific inbound material category.

Large items, especially items with elastic bands such as e.g. fitted sheets but also lengthy items such as e.g. cut textiles (for rag rugs) and jeans, pose a risk for tangling and twining around the rotary drum feeder. Sometimes the tangled items fell of the drum feeder after some time, but generally they had to be removed manually. Large tangled and twined items tend to also cause tangling of other, smaller items getting caught between the item and the drum feeder. When tangled and twined items were released from the drum (on their own or manually) they tended to create heaps of material on the subsequent conveyor belt.

The Feeding Bunker was not tested for baled material entering the moving floor conveyor (see p.13). However, also for the to some extent pre-loosened material a certain "stickiness" was observed, i.e. separate items were still pressed together from the large pressure in the bale. Depending on inbound textile waste, "sticking" items were sometimes grabbed together by the tappets on the rotary drum feeder posing a risk for overlaps and (smaller) heaps on the subsequent conveyor belt.

5.2. movements of the moving floor conveyor

The experiences with the moving floor conveyor was very good. The friction of the material was for all inbound materials large enough to prevent materials being dragged backwards in the feeding process (see p.16).

The optimal step length for creating a constant flow of textile waste towards the rotary drum feeder and the subsequent sorting process varied from 30 mm for larger (and heavier) items, e.g. sheets and denim, to 50 mm for smaller items. Larger step lengths were used at the start of each test batch to initially move the material towards the feeding drum and reach sufficient height of the inbound material in front of the drum feeder. Larger steps were also used in the end of each test batch, i.e. when the Feeding Bunker was not filled, to create enough pressure of inbound material onto the feeding drum.

The time delay between two movements (stokes) varied depending on the fill level of the bunker but was generally set to 0.6 second delay for all materials.

Larger steps and shorter time between two stokes resulted in that the optimal height of loaded material was reached and the forward movements stopped until the height of the loaded material was reduced.

5.3. height of loaded material

The optimal height of evenly loaded material in the Feeding Bunker varied between 30-50 cm from the moving floor conveyor (see Figure 7) in the SIPTex pilot plant. Less height resulted in too little material on the subsequent conveyor belt (lower feeding capacity) and larger height in heaps of material on the subsequent conveyor belt.

5.4. shape and placement of tappets on the drum feeder

All three different shapes and several different positioning of the tappets were tested. The small tappets were shown less suitable for feeding of textiles as they did not grab enough textiles onto the rotary drum feeder. The medium size tappets were primarily used in combinations with the large tappets, that most efficiently pulled separate items apart and grabbed them onto the rotary drum feeder.

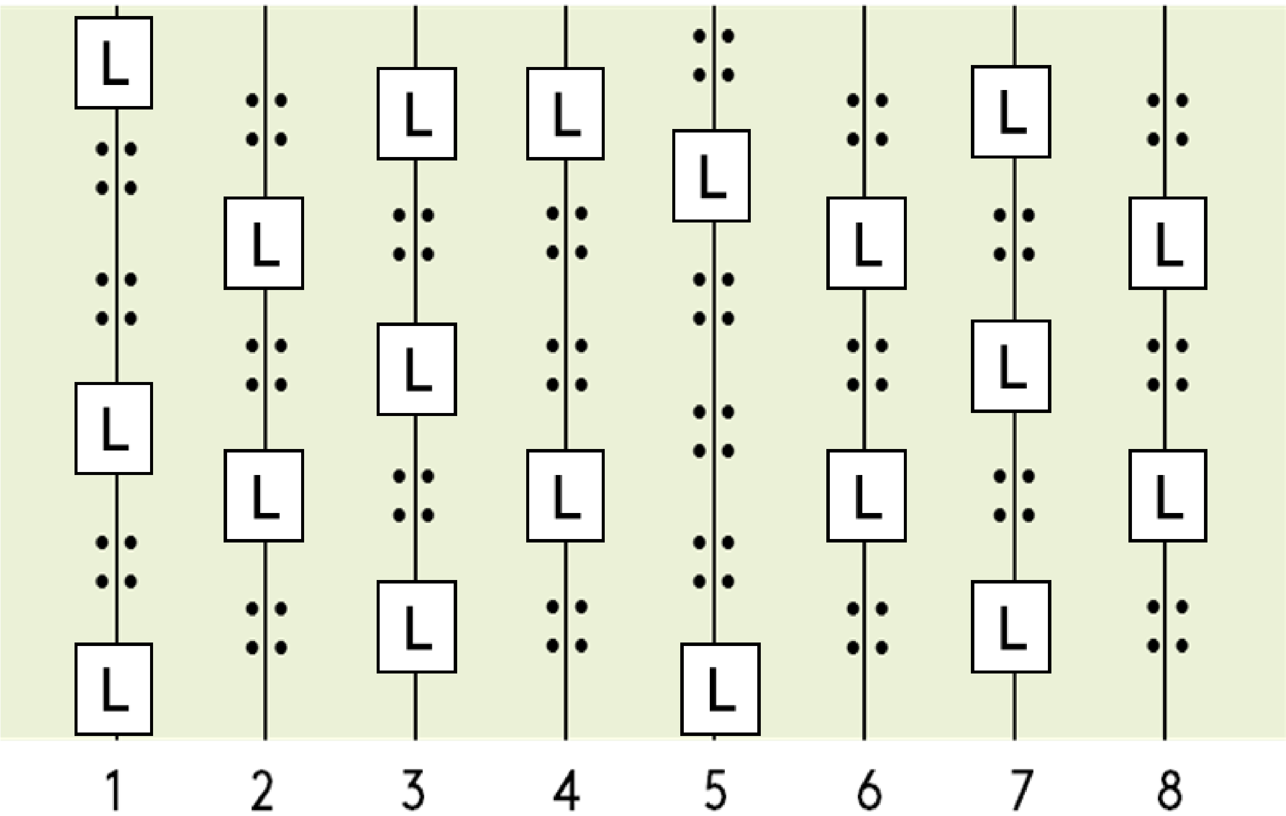

figure 11 The most commonly used size and positioning of tappets on the rotary drum feeder during the reference tests in the SIPTex pilot plant.

5.5. rotation speed of the rotary drum feeder

With the other adjustable parameters set as described above the rotation speed of the rotary drum feeder could be held at 90-95 percent of full speed in the SIPTex pilot plant. Higher speeds resulted in heaps of items on the subsequent conveyor belt and lower speeds in too few items dropped down onto the belt.

5.6. feeding capacity (throughput)

Given the right adjustments of the parameters of the Feeding Bunker, the feeding capacity or throughput rate, i.e. throughput of material per unit time, typically varied depending on the characteristics of the inbound materials. Heavier (higher density) inbound materials, e.g. denim jeans, generally had higher throughput rates than lower density inbound materials, e.g. knitwear. In addition, the tendency of tangling and twining also influenced the throughput rate as it increased the risk of inefficient feeding and, in some cases, interruptions of the feeding process. Finally, the size of the test batches influenced the throughput rate. The individual size of the test batches fed and sorted in the SIPTex pilot plant ranged from 750 kg to 2 200 kg. The Feeding Bunker worked best when properly filled. In the beginning and in the end of one test batch the throughput rate was reduced due to insufficient pressure on the rotary drum feeder, see figure 12.

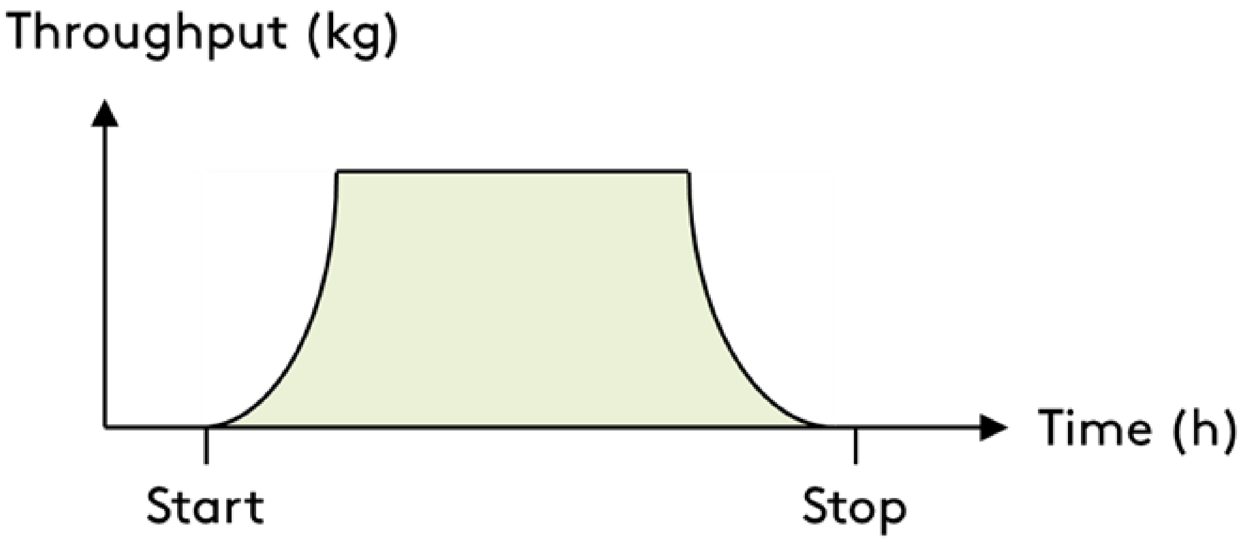

figure 12 The throughput rate was reduced in the beginning and end of each test batch

The achieved throughput rates for different pre-sorted inbound materials varied between 1 000 and 1 950 tons per hour (including reduced throughput rates in the beginning and end of the test batches respectively), see table 3. The highest achieved throughput rate for mixed textile waste was 1 050 kilograms per hour.

table 3 Average throughput rates for different pre-sorted inbound materials during full test runs in the Feeding Bunker.

Inbound material	Throughput rate (kg/h)
Broken jeans	1 650-1 950
Woolen clothing	1 000-1 350
Knitwear	1 050-1 300
Wipers white	1 000-1 100
Wipers colored	1 000-1 250

The lower throughput rate in the beginning and end of a test batch was estimated to lower the average throughput rate by at least 10 percent, i.e. the average throughput rate in continuous operation would have been at least 10 percent higher.

Another limiting factor for the throughput rate was that heaps of textile waste on the subsequent conveyor belt had to be kept to a minimum to secure a good spread of textile waste entering the NIR-sorting. The conveyor belt directly after the Feeding Bunker did not have variable speed. A higher speed of this conveyor belt would have allowed for increased height of loaded material in the Feeding Bunker as well as for increased or maximum speed of the drum feeder, resulting in an estimated at least 30 percent increased throughput rate.

6. conclusions and recommendations

The design and function of the Feeding Bunker worked well for automated feeding of textile waste. It worked best for pre-sorted materials with more homogenous textile waste in terms of size, weight and quality of individual items, but can also be used to feed mixed textile waste at a somewhat reduced throughput rate.

Some items/garments were hard to feed and/or caused problems in the feeding process. table 4 gives an overview of items/garments that were considered problematic in the test runs and recommendations on how to deal with them to create an efficient feeding process.

The importance of a close dialogue with inbound material supplier for avoiding potentially problematic textile waste items in inbound material is stressed, as is the need for additional steps spreading the textile waste between the Feeding Bunker and the (first) NIR-sorting unit. The latter is standard procedure in automated sorting facilities. The need for additional steps spreading the textiles is particularly important for baled (pressed) inbound material items/garments that tend to stick to each other. To further reduce the risk of items sticking to each-other, measures for pre-loosen baled inbound material in connection with the loading of the Feeding Bunker could be considered.

The throughput rate of the Feeding Bunker during the test runs in the SIPTex pilot plant typically varied between 1 000 and 1 950 kilograms of textile waste per hour. This throughput rate secured sufficient spread of the textile waste on the conveyor belt leading to the NIR-sorting unit in order to sort and separate individual items/garments. In the SIPTex pilot plant higher throughput rates caused heaps of materials on the conveyor belt and increased shares of wrongly sorted items/garments.

table 4 Overview of items less suitable for feeding using the Feeding Bunker and recommendations on how to deal with them.

Type of items in inbound material	Identified problem	Recommendation
Large items, e.g. sheets	Large items tend to tangle and twine around the rotary drum feeder, reducing throughput rate and, when released from the drum feeder, cause heaps of textile waste on the subsequent conveyor belt. The problem particularly occurs when the items include elastic bands, e.g. fitted sheets.	The problem can either be avoided by close dialogue with material suppliers that such large items are not accepted in inbound material or by cutting (large) items into smaller pieces (e.g. 0.4 meters times 0.4 meters) before filling them into the Feeding Bunker, e.g. with a so-called guillotine
Long items, e.g. yarns and cut textiles (for rag rugs)	Long items tend to tangle and twine around the drum feeder, winding additional items around the drum and causing balls of textile waste around the drum feeder that reduces throughput rate and requires process stops for manual removal.	Avoid items by close dialogue with material suppliers regarding the problematic items that may not be included in the inbound material
Small, and potentially round, items, e.g. balls of socks, crocheted oven mittens and cuddly toys	The tappets have difficulties to grab small items, particularly small round items, and feed them onto the subsequent conveyor belt. The small items tend to slip underneath the drum feeder, get caught in front of steel "teeth" and either eventually drop down on the subsequent conveyor belt or having to be removed manually. When they drop down on the conveyor belt there is a risk of them getting caught under larger items and that they are not separated before reaching the NIR-sorting.	In the test runs, most of the small items eventually dropped down onto the subsequent conveyor belt without manual handling and there is no need to avoid the items in the inbound materials. To reduce the risk of smaller items getting caught under larger items all the way to the NIR-sorting it is recommended to introduce an additional conveyor belt with varying speed between the end of the Feeding Bunker and the (first) NIR-sorting unit.
Jeans and trousers	In inbound material predominantly containing jeans and trousers there is a risk that the trouser legs of separate jeans/trousers intertwine and form heaps of textile waste on the subsequent conveyor belt.	To reduce the risk of intertwined jeans/trousers entering the NIR-sorting it is recommended to introduce an additional conveyor belt with varying speed between the end of the Feeding Bunker and the (first) NIR-sorting unit.

The two main limitations for the throughput rate were the fact that the Feeding Bunker was operated batch-wise with reduced throughput rate in the beginning and in the end of each batch and that the speed of the subsequent conveyor belt was too low and not variable. All in all, at least a 40 percent increase in throughput rate is considered realistic:

- Continuous operation is estimated to increase throughput rate by at least 10 percent.

- The maximum height in the Feeding Bunker was 120 cm, i.e. up to three times the optimal height in the test runs in the SIPTex pilot plant. The optimal rotary speed of the drum feeder during the test round was only 90-95 percent. By introducing additional steps for separation of textile waste items on the conveyor belts between the Feeding Bunker and the (first) NIR-sorting unit, e.g. by an additional conveyor belt with variable speed directly after the Feeding Bunker, both the height of the loaded material and the rotation speed of the rotary drum feeder can be increased. It was estimated that this will increase the throughput rate by at least 30 percent.

It could be interesting to experiment with additional sizes and shapes of tappets for the rotating drum feeder and e.g. analyze how small hooks in the end of the tappets might influence the throughput rate.

7. outlook

The experiences from automated feeding of textile waste in the FITS-project fed into the business plan for automated textile sorting that was developed as part of the SIPTex-project. Specifically, the results from the FITS-project in terms of throughput rates were used in the process of designing and recommending annual sorting capacity for an industrial-scale automated textile sorting facility.

In April 2019 Vinnova granted 22 MSEK in innovation support for building and operating the world's first industrial-scale automated textile sorting plant (SIPTex) in Sweden (Vinnova, 2019b). The objective is to create opportunities for increased high-quality textile recycling and introduce automated textile sorting as a new step in a more circular textile value chain. SIPTex strengthens Sweden's role as frontrunner in the areas of circular economy and transition to more sustainable textile and fashion industry. The project includes Swedish textile and fashion companies with global value chains and cooperates actively with Swedish and international companies to create an ecosystem of actors jointly creating efficient and circular textile flows.

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Mistra Future Fashion is a research program that focuses on how to turn today's fashion industry and consumer habits toward sustainable fashion and behavior. Guided by the principles of the circular economy model, the program operates cross disciplinary and involves 60+ partners from the fashion ecosystem. Its unique system perspective combines new methods for design, production, use and recycling with relevant aspects such as new business models, policies, consumer science, life-cycle-assessments, system analysis, chemistry, engineering etc.

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