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CIRCULAR
FoodPack

D2.6 REPORT ON TBS SORTING EFFICIENCY AND SORTING TRIALS

WORK PACKAGE 2

Associated Task(s): T2.4
Development of TBS sorting machine
for conventional NIR sorters and TBS trials

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PUBLISHABLE EXECUTIVE SUMMARY

The use of recycled materials in plastic based products of any kind is growing in importance in light of global problems and EU-imposed regulations targeting recycling content in freshly produced plastic packaging items. Packaging material in contact with sensitive goods such as food is required to match at least 25% of recycling content by 2030. As of now, only Polyethylene-Terephthalate (PET) fullfills the strict regulations on recycling-infeed-material's origin, due to its unique collection scheme and intrinsic material properties regarding non-intentionally added substances in the recycling process.

With Polyethylene (PE) making up a significant part of food-grade plastic packaging items in the market, a solution for PE-based material must be developed. Furthermore, there is another challenge: ensuring the recycling process waste input material's origin as food-grade. As there are no instrinsic material properties deployable to tell for separating the food-grade from non-food-grade packaging, tracers are implemented in the packaging items and used as a sorting criterion in the state-of-the-art sorting machines for flexibles. The entire process only requires minor adaptations to the detection system in place by adding a tracer excitation source.

A total of 315 kg freshly produced, traced food-grade mono PE-based multilayered flexible packaging material has been produced by AMCOR and pouches thereof have been produced at NESTLE for food packaging. These pouches were then mixed with household PE-rich flexible packaging waste at a ratio of 1:1 and sorted in a state-of-the-art flexible packaging sorting line at the Steinert Technical Center in Cologne, Germany, at industrial conditions of 4.5 m/s conveyor belt speed and 30% belt coverage, resulting in a material throughput of 1.0 tons / hour / meter-belt-width. In a two-step-sorting-process, a purity of over 97% in food-grade packaging items has been achieved, while maintaining a sorting efficiency as high as 89%.

This report demonstrates an industrially viable and relevant sorting process, paving the way towards circular use of food-grade mono PE-based multi-layered flexible packaging material by using Polysecure's tracer-based-sorting technology adapted to state-of-the-art NIR-sorting lines.

ABBREVIATIONS

Abbreviation	
PET	Polyethylene-Terephthalate
PE	Polyethylene
LDPE	Low-density Polyethylene
NIR	Near infrared
MDOPE	Machine direction oriented Polyethylene
VFFS (machine)	Vertical form fill seal machine
VOC	Volatile organic compounds

1. INTRODUCTION

The EU-funded project CIRCULAR FoodPack comprises different loops, demonstrating the circular use of plastic packaging material. One of those loops aims for the circularity of mono PE-based multi-layered flexible food-grade packaging items, running two cycles of packaging production, sorting, and recycling. Figure 1 displays a schematic view of the entire process chain: First, PE-based multi-layered laminates are produced by AMCOR and NESTLE. During the lamination process, Tracers provided by Polysecure are integrated into the food packaging items as part of the printing ink. This artificially produced flexible packaging material (representing flexible packaging waste marked with tracers) is then mixed with the real, un-washed, and un-treated household waste from Poitiers, France, provided by SUEZ. In a potential future scenario with tracer-based sorting being implemented in industrial sorting lines, one sorting stage could be specifically dedicated to a category "PE-based food-grade packaging". In such a sorting stage, the traced food-packaging items used in this trial would have to be sorted out of a waste stream like the one given here. Tracer-Based-Sorting (TBS), a process developed by Polysecure, will serve as the sorting protocol. In this trial, the sorting itself takes place at the Steinert Technical Center in Pulheim, Cologne, Germany. Minor adaptions on the Steinert UniSort Film EVO 5.0 sorting line with laser installation for tracer excitation are performed on site, while using common NIR-sorters which blow out the waste items by air jets.

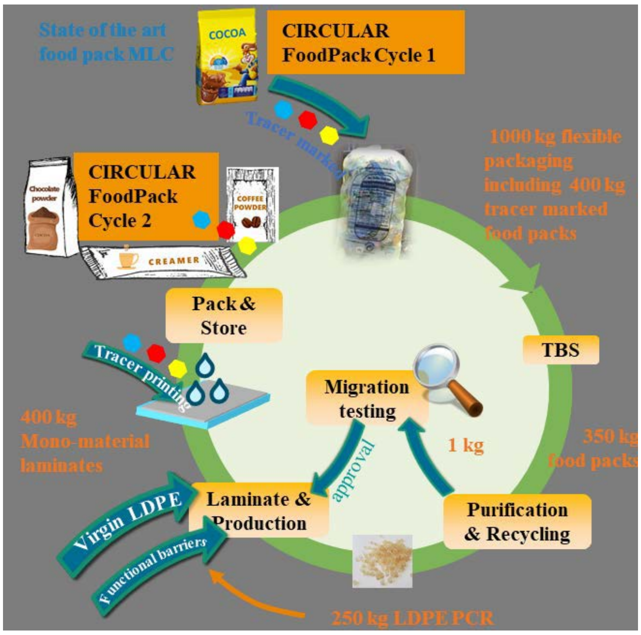

Figure 1 Overview of Loop 3 as performed in CIRCULAR FoodPack

After the sorting, the food-packaging material will be subjected to cleaning steps, recycling process, and migration tests. The recyclate's quality will be assessed and incorporated into laminate structures sandwiched in between functional barriers and virgin LDPE, forming a mono PE-based multi-layered flexible food-grade packaging item with high PE-recyclate content. The entire resulting packaging will then be examined and gauged with respect to EU-regulatory norms.

From that packaging material with recyclate content, a second recycling loop will be initiated, repeating the cycle as described earlier (tracer implementations, tracer-based-sorting and recycling), demonstrating the true circularity for PE-based multi-layered food packaging items containing meaningful concentrations of the recycled PE material.

The report at hand focuses in depth on the sorting step of the loop. One scope within the project lies on establishing a reliable and efficient process, capable of sorting industrially relevant sample sets at typical throughput rates with minimal adaptions to the systems used today. Therefore, the development of this process itself is regarded as the first major output and will hence be described thoroughly throughout the report.

The second contribution of the underlying deliverable to the overall project is the specific outcome of the sorting trials and the results themselves: Which sorting quality can be achieved under which process conditions. The latter part of the report will go into detailed discussion thereof.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101003806.

2. SORTING TRIAL SETUP

2.1 INPUT MATERIAL

2.1.1. Tracer-based PE food grade packaging

The first part of the sorting input is made of specifically produced PE-based multi-layered food packaging pouches with tracers inside the printing ink. This material serves as the targeted fraction. First, reels of 385 mm width, consisting of the vertical structure 25 µm MDOPE / SiO_x / printing / 2K adhesive / PE 60µm, were produced at the AMCOR plant in Ghent, Belgium. A pattern of white and blue ink as depicted in Figure 2 have been reverse printed along the entire reel. Prior to printing, tracers from Polysecure have been dispersed into the white printing ink. Finally, a lamination step with a PE sealing web was applied, sandwiching the ink layer between 2 PE-based layers.

Figure 2 (left) single pouches (12.6 g and 6 g, nominally as produced) and (right) specific area weight measurement for drop of the first sorting step to determine the mass throughput values.

At Nestlé Institute of Packaging Sciences in Lausanne, CH, two different types of packaging formats were produced out of the provided PE laminate structures on a Vertical form fill seal (VFFS) machine: A pillow bag with 190 x 180 mm^2 and gusseted bag with 300 x 130 mm^2, with total mass output of 209 kg and 260 kg, respectively. Altogether, 469 kg PE food-grade mono-material has been produced.

The traced fraction as an interim product after the first sorting step has been characterized for its specific area weight, identical to the background waste stream. Here, a specific area weight of 0.21 kg / m^2 was extracted according to Figure 2, right picture. The specific area weight after sorting step 1 (to be described later on in Chapter 3.1) enables the calculation of the overall material throughput and gives an indication of the response to the blow-out-valve technology deployed in the sorting trials.

The freshly produced food-grade packaging items were contaminated, one week prior to the sorting trials, by mixing these with the background waste (i.e. the real, un-washed, and un-treated household waste from Poitiers, France, provided by SUEZ) and leaving the mixture loose in big bags, allowing VOC migration due to the background waste with only minor mechanical wear-off during the mixing process.

2.1.2 Background waste stream

The background stream for the sorting trial is current post-consumer flexible packaging waste withdrawn from the Poitiers sorting site in France, without being subjected to any form of additional treating such as washing or cleaning prior to the sorting trials. It consists of food- and non-food packaging. Within the framework of CIRCULAR FoodPack, this waste stream has been extensively examined and characterized by SUEZ, resulting in a detailed description of the composition, being published in the Deliverable D2.1 "Analysis of current multi-layer food packaging in the waste streams in Europe" submitted in month 9 by SUEZ. Within this characterization it was found that especially the food packaging consists mainly of heavily printed multi-layered multi-material laminate, whereas the non-food packaging is less printed and less multi-material.

Figure 3 Background waste provided by SUEZ, originating from the flexible packaging waste stream of the sorting site in Poitiers

A picture of the bale received from Poitiers with low compress ratio is given in Figure 3, left. More pictures of the waste stream and overall sorting process can be found in Annex A to demonstrate its condition. The background waste stream comprises of ~15% food and ~85% non-food packaging waste. The latter, dominant fraction contains significant portions of large flexible coherent structures, such as secondary packaging films, collection bags, and carrier bags, as well as bags above 25 liters of capacity. Figure 3 right, gives a visual impression of this background waste. The specific area weight was calculated to be around 0.14 kg / m².

A general challenge for the sorting itself via blow-out-valve technology is posed by the size of coherent objects among the background stream. With single items partially exceeding 1 meter in length, overlapping of objects cannot be avoided for industrially relevant degrees of conveyor belt coverage, thus posing a threat of impairing the purity of the sorted fraction.

Figure 4 Black and/or huge bags inside background stream

Color wise, the background waste fraction consists of mainly transparent or light-colored objects. Exceptions are found such as the large black garbage bag-type samples, as shown exemplarily in Figure 4. As the sorting in the trials will be a two-step sorting with "tracers" as criterion, black colored objects might impose serious concerns, as no color-sorting step is performed, and black objects cannot be recognized in NIR-reflection spectrometry.

In total, 13 loosely filled bags of sample material at a ratio of ~1:1 background waste to food-grade packaging items were used adding up to 650 kg of input material for the sorting trials in a state-of-the-art sorting machine in the Steinert Technical Center in Pulheim, Cologne, Germany.

2.2 SORTING MACHINE / TECHNICAL CENTER

The sorting trials were performed in the Steinert Technical Center in Pulheim. The entire system optimized for thin film samples comprises of the following subsystems:

1. Bunker for introducing material into the circulating system
2. Metal scrap eddy-current filter system
3. Ballistic separator
4. Air-flow guided, 1.4 m wide conveyor belt for detection and sorting
5. Steinert UniSort Film EVO 5.0
6. Air-nozzle blow-out-valve system at 5 bar
7. Drop and Eject separation, modes: circulation, output
8. Feeding system to step 3., in case "circulation" is chosen
9. Drop-Out system into Bins for final product, in case "output" is chosen

The testing center of Steinert and the sorting line for flexible packaging have not been cleaned prior to the trials. It is regularly used for sorting trials and demonstration purposes with common household waste and showed a corresponding degree of contamination. However, the fact that it is a testing center instead of an industrial sorting line (as stated in the DOA by subcontracting) allows experiments on industrial-scale sorting machinery without the need to interrupt regular operation of a sorting facility. The input waste from France has not been washed, it was delivered directly from the SUEZ sorting site.

Figure 5 General overview of the Steinert technical center in Pulheim

As the initial step, the big bags were cut open and fed into the bunker, conveying material at a constricted rate by tumbling up a steep slope. After passing the eddy-current metal filter, the sorting good passed the system's ballistic separator and was dropped onto the conveyor belt for detection and sorting. During the feeding process, the Drop and Eject belts were operated in the circulation mode, leading back to the ballistic separator and eventually back to the detection/sorting step. This procedure is schematically represented in Figure 6.

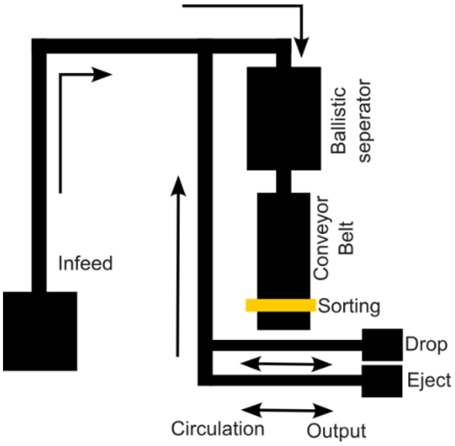

Figure 6 Schematic representation of the sorting process flow in use

As a result, conveyor belt coverage – as measured by the detection unit – could be controlled and adjusted to the desired value, while homogenizing the material flow throughout the system. The desired value of belt coverage was 30 % to be close to industrial standard according to SUEZ and Steinert team. The amount of material introduced into the system added up to ~50 kg of flexible packaging waste per sorting process.

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After reaching the homogenously distributed desired belt coverage, the detection/sorting step's mode was changed to "output", leading the sorted material flow into big bins instead of circulating the material further.

Figure 7 Steinert UniSort Film EVO 5.0, the state-of-the-art sorting machine by Steinert (schematic view)

The conveyor belt for detection/sorting was operated at 4.5 m/s belt speed and aimed towards 30% conveyor belt coverage, to provide typical operation conditions in state-of-the-art sorting sites for flexible packaging waste. With the given specific area weights of the input material, a throughput rate of ~1.0 tons / (hour x meter-belt width) was achieved, equating to 1.4 tons / hour for the given belt width of 1.4 meters. Although the belt width in industrial sorting plants can be wider (up to 3 meters), the performance of the sorting trial was not affected by this scalable parameter. Coverage and belt speed are more critical for the scalability and comparison, which were both in line with SOA sorting lines.

As the sorting criterion was the distinction between tracer-based and untraced material, with this information being encoded into the packaging items via the use of tracers, tracer detection had to be enabled for the state-of-the-art detection unit of the Steinert sorting machine.
Polysecure's tracers show strong and specific response to NIR-laser excitation, emitting in a confined wavelength range in the NIR spectral regime. Therefore, the detection unit had to be slightly adapted by installing lasers with the respective wavelength suitable for tracer excitation, producing a laser curtain in the plane-of-view of the NIR hyperspectral imaging system of the Steinert detection unit. Figure 8 shows the adaption of the detection unit both schematically and as a real image of the lasers being implemented, spanning an excitation curtain for objects passing by. For operation, a laser line density of ~140 W/m conveyor belt width is used.

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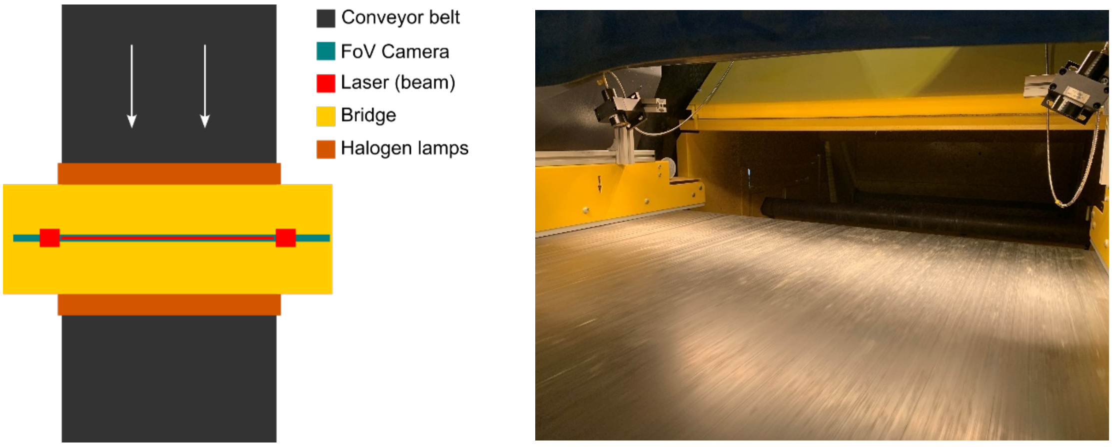

Figure 8 Laser adaption (left) schematic and (right) real image. The lasers span a curtain in the detection system's field of view.

2.3 TRACER DETECTION QUALITY

As stated in section 2.1, Polysecure's tracers were dispersed into the white printing ink and transferred into the food-grade packaging items via a lamination process. Once excited with the proper NIR-laser irradiation, the tracers emit efficiently in the NIR spectral region, as well as performing a so-called up-conversion effect, emitting additionally in the green. Figure 9 shows traced samples inside the laser curtain in the detection unit. The left half of the conveyor belt is illuminated with NIR laser light having the tracers respond with NIR-signatures as well as luminescence in the green, the right half deploys the adjustment laser system, thus resulting in a red line.

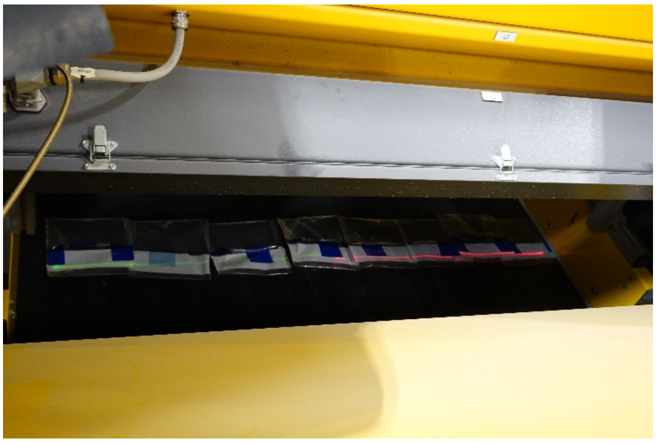

Figure 9 Samples in Laser line, illustrating the emission of the tracers inside the packaging goods. Right part in red due to adjustment laser, left part with green emission due to the tracer specific up-conversion illumination around 550 nm wavelength

The tracers inside the food-grade PE-based multi-layered packaging results in an overlay of typical PE-diffuse reflection spectra caused by the polymer and broadband halogen illumination and a sharp and distinct tracer signature in the NIR. This new type of spectrum is taught to the sorting algorithm as a new category of material and can be sorted accordingly.

The spectral signatures originating from the tracers is clearly detectable despite the high halogen broad band background and yields for unique and distinct classification results due to the

Steinert Sorting Algorithm. In fact, detection quality has been assessed after material teaching and 200 out of 200 objects were classified correctly with very high accuracy, far from any resemblance of ambiguity in the classification results.

Demonstrating this high level of detectability of the tracers inside the food-grade packaging items, sorting fraction purity would be limited by aero-mechanic properties of the general sorting approach itself: Overlapping of objects belonging to different fractions, mainly due to large scale objects at 30% conveyor belt coverage, and aerodynamic issues of blown out objects not landing in the desired pathway. Contamination of the packages on the other hand would only affect the traceability, if heavily contaminated with dark intransparent dirt. This is not necessarily a standard condition for food packaging, as can be seen on the pictures of the background waste provided. As long as a traced area of a minimum of 1cm^2 is uncovered of contamination, the item can be detected.

Trials regarding the minimal tracer concentration in the packaging items have been reported in the confidential deliverable D2.4.

2.4 SORTING PROCEDURE AND SORTING PARAMETERS

The sorting procedure follows an industrial process, consisting of two sorting steps, both run at 4.5 m/s but with differing throughput values and blow-out target fractions:

2.4.1 Sorting step 1 – Densification

Step one will select for the traced fraction by blowing out (Eject) this part of the stream, effectively densifying at high throughput and material efficiency, but at mediocre purity. All items belonging to any other fraction will end in the dropped fraction (Drop) – displayed in Figure 10, step 1 (green). The aim is to densify the input stream for a cleaning step with the relevant sorting fraction, which is in this case the traced food-grade packaging item fraction. The material throughput of ~1.0 tons / hour / meter conveyor belt width could be achieved in this step, well in accordance with industrial standards for sorting of flexible packaging waste. The purity after this step lies in the range of ~80% traced material at ~90% material sorting efficiency. All outputs were weighted.

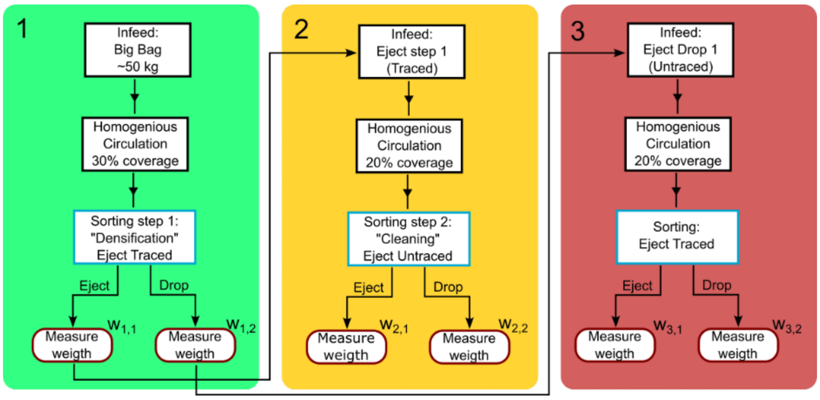

Figure 10 Schematic sorting procedure and measurement of weights after each step

In Figure 11 the output for sorting step 1 is exemplarily shown for one sorted big bag. On the left side, the Drop with the sorted background stream is shown, on the right, the densified, yet to be cleaned Eject fraction with tracers as blowing-out criterion can be seen.

Figure 11 Sorting result after Step 1: Densification, showing good first sorting results

2.4.2 Sorting step 2 – Cleaning

The Eject-fraction of step 1, Densification, will be subjected to an additional sorting step, the so-called Cleaning. Here, the aim is clearly set on a purity as high as possible, while maintaining industrial relevance in throughput and efficiency. Conveyor belt coverage for the cleaning step was kept at ~15%. The procedure of introducing and homogenizing the sorting goods of step 1 is repeated likewise. As traced material making up the majority of the new infeed stream, all untraced items are being blown out within the cleaning step. This is depicted in Figure 10, middle (yellow). With the traced fraction being dropped this time, black items will unavoidably be dropped as well, as they are unseen by NIR-sorters and hence not actively blown out. These big black bags, which were initially blown out within Step 1 due to overlapping with traced objects and dropped in Step 2 due to their NIR-invisible nature are suspected to make up most of the impurities in the sorting trials for Tracer-Based-Sorting in conventional state-of-the-art NIR-sorting machines. The tracer containing Drop-fraction was weighted, and, additionally, the remaining impurities were handpicked and measured likewise.

Figure 12 presents the final product after cleaning with very low amounts of impurities remaining inside, while maintaining a high overall material efficiency at relevant operating conditions.

Figure 12 Final Product after Step 2: Cleaning. High purity in traced food-grade material achieved

2.4.3 Sorting step 1 & 2 – Analysis

The Drop fraction of Step 1, mostly un-traced material, is subjected to an additional sorting step with lowered conveyor belt coverage to determine its composition of traced and untraced material, shown schematically in Figure 10, right panel (shown in red). This additional step was performed for four of the 13 big bags for sake of viability.

This way, the overall material efficiency η and purity ρ could be calculated per sorting step, according to the following equations:

$$\eta = \frac{w_{2,2}(traced)}{w_{2,2}(traced)+w_{3,1}(traced)}$$

$$\rho = \frac{w_{2,2}(traced)}{w_{2,2}(traced)+w_{2,2}(untraced)}$$

Here, w indicates weights, first subscript denotes the sorting step of Figure 10 and the second subscript whether the Eject (1) or the Drop (2) is referred to. In brackets, the hand-picked fraction of traced or untraced material is given.

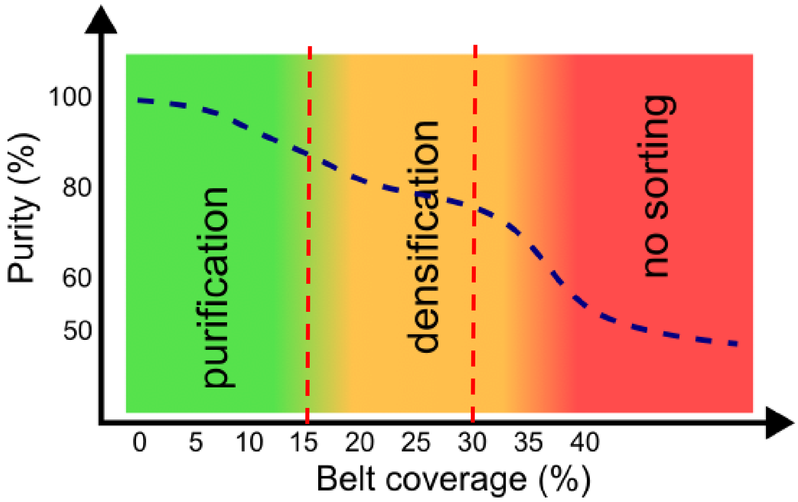

Figure 13 Purity vs Conveyor belt coverage indication. Red dashed line indicates targeted operations conditions at industrial relevance

3. DISCUSSION OF THE RESULTS

3.1 SORTING EFFICIENCY AND PURITY

The overall outcome in terms of Efficiency and Purity of the sorting trials of ~650 kg input material is shown in Table 1 for every big bag separately. As there is a certain variance in the individual mass of input material per bag, the averaged values at the end of the table are not deducible from the results of the individual bags due to weighing factors.

BigBag ID	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	Ø
Step 1 – Densification														
Coverage indication	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟥	🟨	🟥	🟩	🟩	🟩	
Purity	78.9	84.6	81.3	82.4	85.3	81.8	82.7	72.2	83.3	63.6	86.1	86.4	90.9	
Step 2 – Cleaning														
Coverage indication	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Purity	98.6	94.6	96.7	97.6	98.3	97.4	96.8	98.2	96.2	97.4	97.9	96.8	99.7	**97.4**
Efficiency	84.9	-	89.5	-	-	-	90.2	-	-	-	91.8	-	-	**90.2**

Table 1 Results of the sorting trials of all big bags, Conveyor belt coverage according to Figure 13

Within the first step, the densification, an overall purity in the range of ~80% was achieved at 4.5 m/s belt speed and ~30% conveyor belt coverage. Big bag #10 is a negative outlier with 63.6% purity of the densified Eject fraction. This is due to a very high conveyor belt coverage in excess of 40%, clearly exceeding the sorting machines operating range and running into overlapping issues.

The Cleaning step was able to demonstrate a high degree of purity of overall $\rho \sim$ 97.4% while maintaining a material efficiency of η ~90.2% at industrially typical conditions. Big bag #13 is a positive outlier in this regard. Being the last big bag and thus filled with less than typical overall sorting material, conveyor belt filling degrees were lower than typical, resulting in higher purities.

Subsequently, several exemplarily taken images of some of the big bags' impurities are shown in Figure 14. Clearly, big black overpack bags are the main remnant of non-traced material present in the sorted, traced fraction. Being invisible to the NIR-sorter as black items, while offering an item size prone to be overlapping with traced food-grade items, the overall purity seems greatly limited by this type of flexible packaging waste.

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Figure 14 Example impurities in the Cleaned final product: Mainly large and black bags

3.2 OUTLOOK ON FURTHER MATERIAL TREATMENT

The TBS sorted packaging items coming out of the sorting process as described before will be subjected to recycling processes and optimized pre/post-treatments (Figure 1) within WP3 in the project, aiming towards the demonstration of PE PCR implementation in PE-based multi-layered flexible food packaging applications of WP6.

4. CONCLUSIONS

This section reviews the results according to the formulated main goals of Deliverable D2.6, being the development of an efficient sorting process for food-grade flexible packaging waste. First step of this process was to design and fabricate large amounts of PE-based multi-layered packaging items with tracers blended into the ink layer to enhance the sorting efficiency. A total of 315 kg traced packaging material was mixed with the household background waste stream from Poitiers, France sourced by SUEZ at a ratio of 1:1.

The sorting plant in which the trials took place was the Steinert Technical Center in Pulheim, Cologne, which uses a Steinert UniSort Film EVO 5.0. The system consists of an NIR-based detection system with blow-out valve technology and air-flow guidance, designed for high-speed efficient flexible packaging waste sorting. Operation was at standard two-step sorting comprising of a densification and cleaning step. The conveyor belt speed at the detection and sorting step was at industrial levels: 4.5 m/s, at 30% belt coverage, resulting in a material throughput of 1.0 tons / hour / meter-band-width. For the 1.4 m wide sorting machine, 1.4 tons / hour was the overall achieved throughput.

The overall process showed regimes of conveyor belt coverage, in which the feasibility of the presented sorting process becomes compromised due to both aerodynamic effects and geometric overlapping of items belonging to different sorting categories. 30% belt coverage was extracted as suitable for the densification step, 20% was identified as an upper limit for the cleaning step. The sorting efficiency was 90.2%. An overall purity at the given process parameters as high as 97.4% could be achieved.

Observed factors impacting the sorting purity was overlapping of objects and precision in the blowing-out process due to the air turbulence and objects diverting from their coordinate on the belt after detection – well known problems in state-of-the-art NIR sorting systems. Especially large black LDPE bags were prone to those problems and could not be recognized as impurities in the cleaning step due to their invisibility in NIR-reflectometry. A manual pre-sorting step, color-sorting for black items or size dependent systems could alleviate the main impurity of the presented sorting process, increasing the purity even further, while maintaining excellent efficiencies.

Excluding this type of packaging formats from the sorting product in one of the proposed ways, the overall sorting process purity of Tracer-Based-Sorting adapted State-of-the-Art NIR-flexible packaging waste sorting machine would exceed 99%, as confirmed via manual weighing of big black bags. Therefore, by adding a color sorting process prior to the presented sorting step for Tracer-Based-Sorting, it would be possible to achieve an efficient, easy-to-adapt and industrially relevant sorting process exceeding purities of 99% for flexible packaging waste, while maintaining both high throughput and high material efficiency.

ANNEX A

Pictures of the background waste stream used for the large scale sorting trials can be found in the figures below.

Figure 15: Decompressed bale of flexible French packaging waste used as background for sorting trials

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Figure 16: Tracer-based pouches in front of the sorting line in Steinert Sorting Center in Pulheim

Figure 17: Sorting line in Steinert Sorting Center Pulheim with backgorund waste and tracer-based pouches on the conveyor belt (the conveyor seen on the right side is not used during actual sorting. It can be used to circulate the material on the conveyor system to increase or decrease the belt coverage within the system)

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Figure 18: Tracer-based pouch contaminated in French post-consumer background waste

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Figure 19: Bale with French post-consumer packaging waste used as background material for sorting trials, before opening the bales

Figure 20: left: end of conveyor belt towards ballistic separator; right: infeed container with French waste and tracer-based pouches

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Figure 21: end of conveyor belt and ballistic separator with background waste and tracer-based pouches

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