# Handbook for sorting of plastic packaging waste concentrates

Separation efficiencies of common plastic packaging objects in widely used separation machines at existing sorting facilities with mixed post-consumer plastic packaging waste as input

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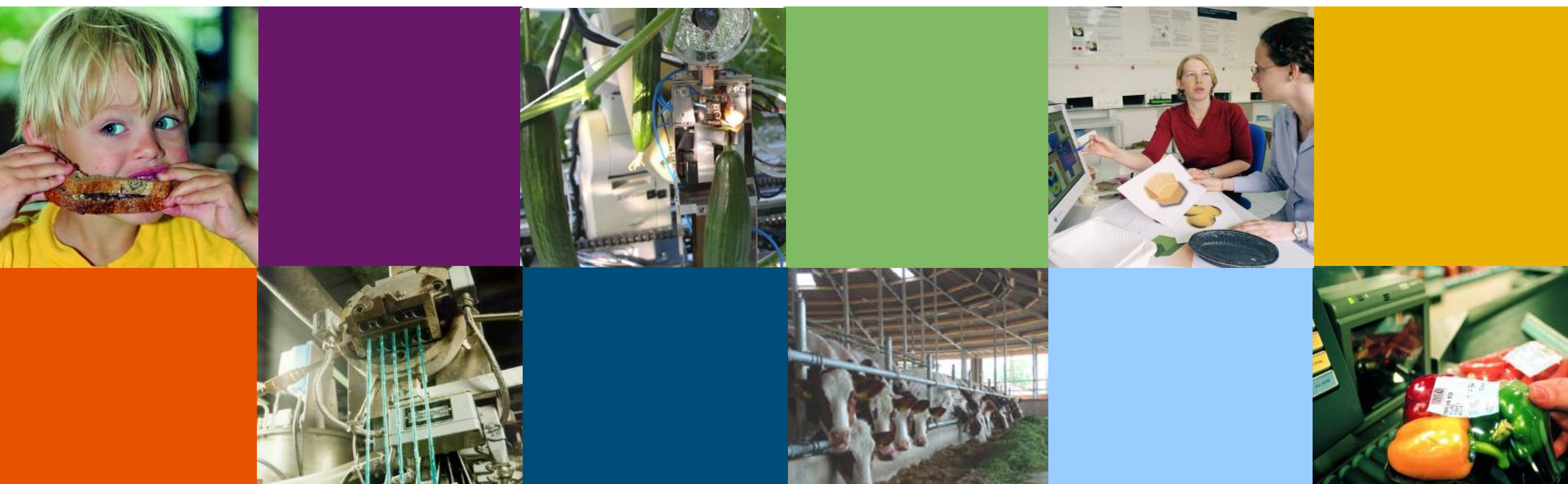
Rapport 1604



# Colophon

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## Abstract

Recycling of post-consumer plastic packaging waste is a complex chain of activities which generally involves three steps. The first step is the collection from households or the recovery from MSW[1] of plastic packages, then sorting and finally mechanical recycling to washed milled goods. This study focusses on the second step in which either separately collected plastic packaging waste or recovered plastic packaging waste is sorted into material fractions which are traded to recycling facilities. In Germany and the Netherlands the sorted fractions have to comply with the DKR specifications as minimum set of quality standards. Automatic sorting facilities vary in annual capacity, process scheme (configuration of sorting machines) and applied machines. Nevertheless, they are engineered in a similar manner; 1) bag opening, coarse milling and metal removal, 2) film removal by wind sifting or ballistic separation, 3) a cascade of NIR[2] machines to sort the rigid plastics in plastic types, 4) manual quality check and sorting, 5) bunkers and bale presses, 6) storage of baled products.

Since this business activity is juvenile and the process technology involved with separating plastic packaging objects is complex, there are few scientific publications on this topic. This hand book will disclose technical performance data of sorting facilities that has been collected over the past 7 years and in that respect form a scientific basis for understanding packaging sorting processes. The collected data will be analysed in terms of yields per packaging type and per polymer of sorting processes in general and of the machines involved in the sorting processes. This will allow for more realistic assumptions on how the sorting yields can potentially be raised in future studies. Data was collected by analysing seven full scale sorting trials with plastic packaging waste from the Dutch source separation and recovery system. This data was analysed overall on facility-level and was broken down and evaluated in the view of efficiency of screening, air classification, ballistic separation and near-infrared sorting. This analysis results in a database for the simulation of sorting processes or single stages that can be used to predict yields for certain packaging types (e.g. bottles) and for certain polymers (e.g. PE). It is shown that sorting of plastic packaging waste is subject to limitations in regards to yield of certain packaging types (e.g. films). This database can be used to design new sorting facilities although the precise composition of the input plastic packaging mixture should be considered.


[1] *Municipal solid refuse waste*
[2] *Near infrared sorting machines*

## Samenvatting

Hergebruik van huishoudelijk kunststofverpakkingsafval is een ingewikkelde keten die in het algemeen uit drie stappen bestaat; gescheiden inzameling bij de burgers of nascheiding uit het huisvuil, sorteren en opwerken tot gewassen maalgoed. Dit onderzoek analyseert de tweede stap, waarin of gescheiden ingezameld kunststofverpakkingsafval of nagescheiden kunststofconcentraat wordt gesorteerd in materiaalfracties die verhandeld kunnen worden met recyclingbedrijven. In zowel Duitsland als Nederland moeten de verhandelde fracties voldoen aan de DKR specificaties, die minimale kwaliteitseisen behelzen. Sorteerbedrijven verschillen van elkaar in grootte, processchema (configuratie van scheidingsmachines) en het soort machines. Desalniettemin kennen ze allemaal een soortgelijke opbouw; 1) voorbehandeling met zakkenopeners, grove maalmolens en metaalverwijdering, 2) folieafscheiding middels ballistische scheiders of windzifters, 3) een reeks NIR-machines voor het op kunststofsoort scheiden van de vormvaste kunststoffen, 4) menselijke controle en nasortering, 5) bunkers met een balenpers, 6) opslag van productbalen.

Aangezien deze bedrijfstak jong is en de betrokken procestechnologie lastig is, is er nog weinig over gepubliceerd. Dit handboek zal technische prestatiegegevens openbaren van sorteerinstallaties die in de afgelopen zeven jaar zijn verzameld en daarmee een wetenschappelijk basis vormen voor het begrijpen van sorteerprocessen van verpakkingen. De verzamelde gegevens werden geanalyseerd in termen van de haalbare opbrengsten op zowel installatieniveau als op machineniveau; waarbij de opbrengsten verder worden uitgesplitst naar kunststofsoorten en verpakkingsvormen. Dit levert realistische inzichten op aangaande de wijze waarop sorteeropbrengsten kunnen vergroot in toekomstige studies. De benodigde gegevens werden verzameld uit praktijkmetingen die verricht waren aan zeven sorteerinstallaties die werden gevoed met kunststofafval uit gescheiden inzameling of uit nascheiding. De opbrengsten werden berekend op overall installatieniveau. In een tweede stap werden de opbrengsten uitgesplitst op machineniveau, zodat er inzicht werd verkregen over de prestaties van zeven, windzifters, ballistische scheiders en NIR sorteermachines. Dit levert een database op van de scheidingsefficiënties van een reeks sorteermachines voor zowel verschillende kunststofsoorten als verpakkingsvormen. Aangetoond wordt dat de sorteeropbrengsten van kunststofverpakkingsafval beperkingen kennen, in het bijzonder voor bepaalde verpakkingstypes zoals films. Bij het ontwerpen van nieuwe installaties kan men deze database gebruiken samen met de juiste samenstelling van het ingaande mengsel.

 

## Content

# 1 Introduction

## 1.1 Context

Recycling of post-consumer plastic packaging waste is a complex chain of activities which generally involves three steps. The first step is the collection from households or the recovery from MSW[3] of plastic packages, then sorting[4] and finally mechanical recycling to washed milled goods. This report focusses on the second step in which either separately collected plastic packaging waste or recovered plastic packaging waste is sorted into material fractions which are traded to recycling facilities. Automated sorting of plastic packaging waste is an emerging business activity in Europe. Some member states started collecting, sorting and recycling plastic packaging waste more than twenty years ago; others started recently and others didn't start yet. Sorting plastic packaging waste is, however, not a standard activity, since the composition of the input material and legal constraints vary between countries. Additionally, advances in sorting technologies, like the introduction of NIR[2]-based sorting machines just before the turn of the century, have extended the options for sorting companies, changed the sorting processes and improved the quality of the sorted products. Automatic sorting facilities vary in annual capacity, process scheme (configuration of sorting machines) and applied machines. Nevertheless, they are engineered in a similar manner; 1) bag opening, coarse milling and metal removal, 2) film removal by wind sifting or ballistic separation, 3) a cascade of NIR[5] machines to sort the rigid plastics in plastic types, 4) manual quality check and sorting, 5) bunkers and bale presses, 6) storage of baled products.

The engineering of sorting facilities is greatly assisted by process technological modelling, which requires three types of data-input:

1. the expected composition of the input material,
2. a clear description of the type of sorting products that need to be produced, including the quality specifications for these sorting products that need to be attained,
3. the most recent technical parameters of contemporary equipment (yields for plastic packaging objects in commonly used separation machines with mixed plastic packaging waste as input).

The composition of separately collected plastic packaging waste is known to vary and the average composition of Dutch separately collected packaging waste has recently been reported. [Thoden van Velzen 2014]. In Germany and the Netherlands the sorted fractions have to comply with the DKR specifications as minimum set of quality standards. For the Dutch situation the following products are targeted: PET (DKR 328-1), PE (DKR 329), PP (DKR 324), Film (DKR 310) and mixed plastics (DKR 350). This report will present the yields of common plastic packaging

[3] *Municipal solid refuse waste*
[4] *Many different terms are used for sorting facilities, sometimes they are named 'light-weight packaging processing plants'* .
[5] *Near infrared sorting machines*

 

objects for widely used separation machines in sorting facilities, thus enabling process technological modelling of sorting facilities. This will allow to engineer better performing sorting facilities and give insights to stakeholders of what type of improvements would be technical feasible.

## 1.2 Objectives

This study aims to calculate and publish yields of the most common categories of plastic packaging objects for widely used separation machines in sorting facilities with an input of Dutch post-consumer plastic packaging waste. These yields are important engineering parameters that will allow to model sorting processes in a process technological manner. Since this business activity is juvenile and the process technology involved with separating plastic packaging objects is complex, there are few scientific publications on this topic. This study aims to provide a basic understanding of yields per packaging type and per polymer of sorting processes in general and of the machines involved in the sorting processes. This will allow for more realistic assumptions on how the sorting yields can potentially be raised in future studies.

## 1.3 Approach

These parameters were derived by process technological analysis of seven full scale sorting trials at three different sorting facilities with plastic packaging waste originating from source separation and automatic recovery schemes in the Netherlands between 2010 and 2012. This data was first analysed overall on a facility-level with the collected data regarding the mass and composition of all the sorting products. Subsequently, this data was broken down to the level of individual sorting machines and evaluated in the view of efficiency of screening, air classification, ballistic separation and near-infrared sorting. This analysis results in a database of yields for categories of plastic packaging objects and polymer groups per separation machine. This data can be used to model new sorting processes or exiting sorting processes with different input mixtures and to predict yields for certain packaging types (e.g. bottles) and for certain polymers (e.g. PE).

# 2 Methods

Three sorting facilities with three different full scale sorting processes were process technologically analysed with regards to the overall efficiency (transfer coefficient) of the whole process. The applied method for the technical assessment of the sorting facility is explained in a separate article.[Feil 2015] Some of these sorting facilities were analysed multiple times with different input mixtures of plastic packaging waste. In total seven sorting runs were analysed, see Table 1. In this chapter first the configurations of the sorting plants are shown in paragraph 2.1. Subsequently, the methodology that has been followed to derive sorting efficiencies per separating machine is discussed in paragraph 2.2 and 2.3.

**Table 1: Overview of analysed sorting facilities and the input plastic materials.**

| Sorting facility | Characteristics | Types of input mixtures |
|---|---|---|
| 1 | Large scale German LVP sorting plant | A Rigid plastic concentrate from recovery facility 1<br>B Rigid plastic concentrate from recovery facility 2<br>C Mixed rigid & flexible plastic concentrate from recovery facility 2 |
| 2 | Smaller German LVP sorting plant | D Separately collected plastic packages<br>E Rigid plastic concentrate from recovery facility 1 |
| 3 | Smaller German plastic sorting plant | F Rigid plastic concentrate from recovery facility 1<br>G Rigid plastic concentrate from recovery facility 2 |

## 2.1 Process flow sheets

Three sorting facilities were analysed. These sorting facilities all have a different process and configuration of separation machines. Two of the three sorting processes are designed to be suitable for sorting of German light packaging waste, a mixture of plastic packaging, metal packaging and beverage cartons. The settings of various sorting machines in the respective plants were adjusted to obtain a more efficient sorting process with only Dutch post-consumer plastic packaging waste as input. Additionally, the settings were also modified to obtain sorted fractions that would comply with the DKR specifications. It should be mentioned that settings of sorting machines are continuously adjusted in sorting facilities and that it is impossible to keep track of all the changes. Continuous changing machine settings should be regarded as normal industrial operation. The third process had been specifically engineered to sort Dutch post-consumer plastic packaging waste efficiently.

The flow sheet of the first sorting facility is presented in Figure 1. This is a high capacity facility for the sorting of German LVP which involves size classification, air classification, metal separation of ferrous and non-ferrous metals and paper and plastic separation by near-infrared sorting. The plastic fraction is split into the polymers PE, PET and PP.

 

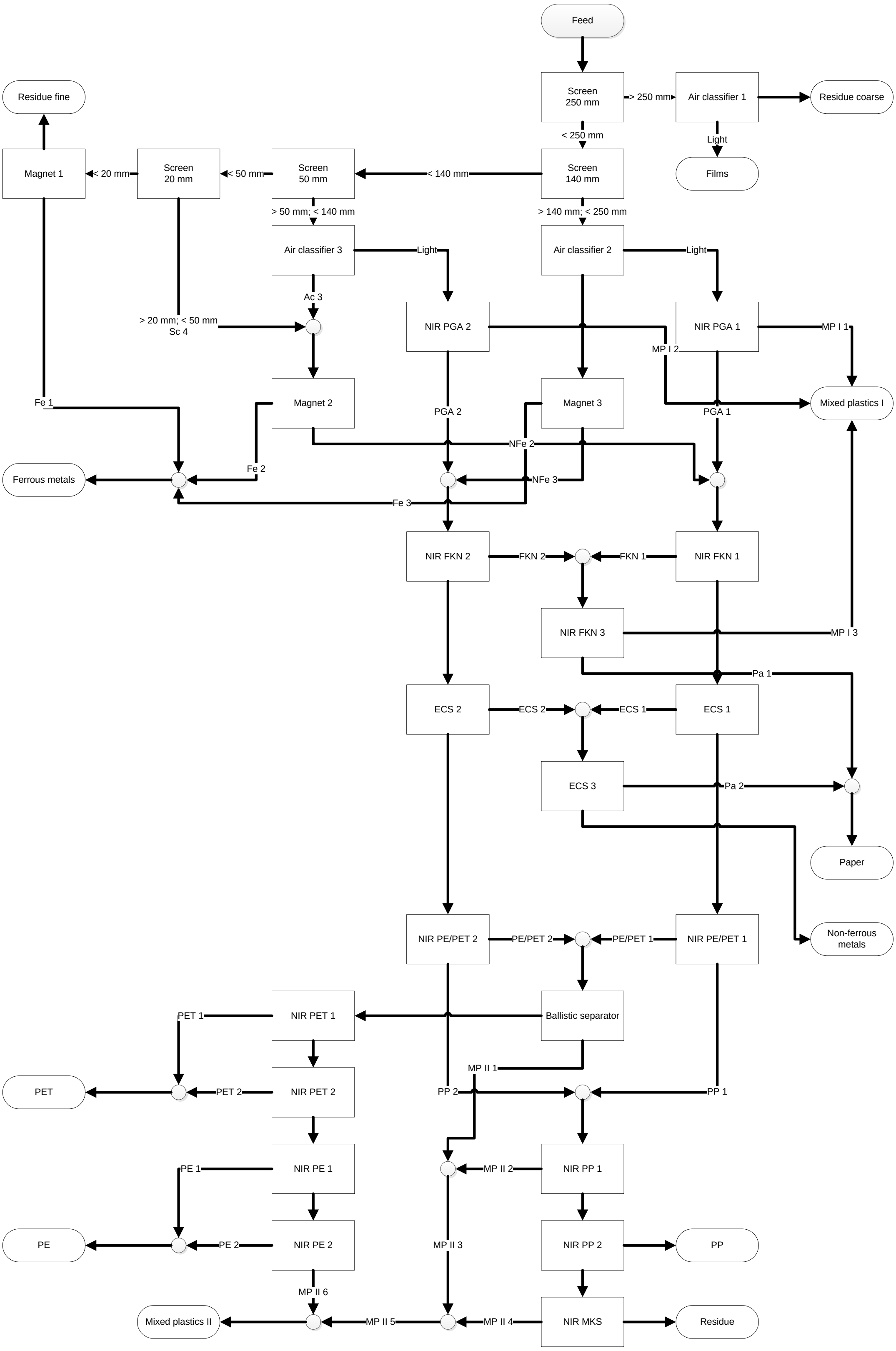


**Figure 1 Flow sheet of the high capacity sorting process for light weight packaging waste**

The process was studied during three trials with inputs originating from the Dutch recovery system (e.g. see (Thoden van Velzen & Jansen, 2011)). During every trial the sorting facility was fed with recovered input material from two different recovery facilities and with different mixes of recovered plastic concentrates (rigids and flexibles). This resulted in different input mixes both in respect to the types of polymers present (PET, PE, PP, etc.) and with respect to the packaging types (bottles, trays, films, etc.).

The process flow of the second sorting facility is shown in Figure 2. It involves similar process stages as the first process. The polymers are sorted with only four NIR sorting machines, of which one acts as a central distributor. This NIR machine is named the "two stages NIR machine" and it separates of PET and PE in a positive manner and retains a PP enriched negative sorted stream. These three streams of pre-NIR-sorted plastics are sent to three different NIR sorting machines, to obtain positively sorted PET, PE and PP streams. The residues of the PET and PE NIR sorting machines are fed back to the two stage NIR sorting machine.

 

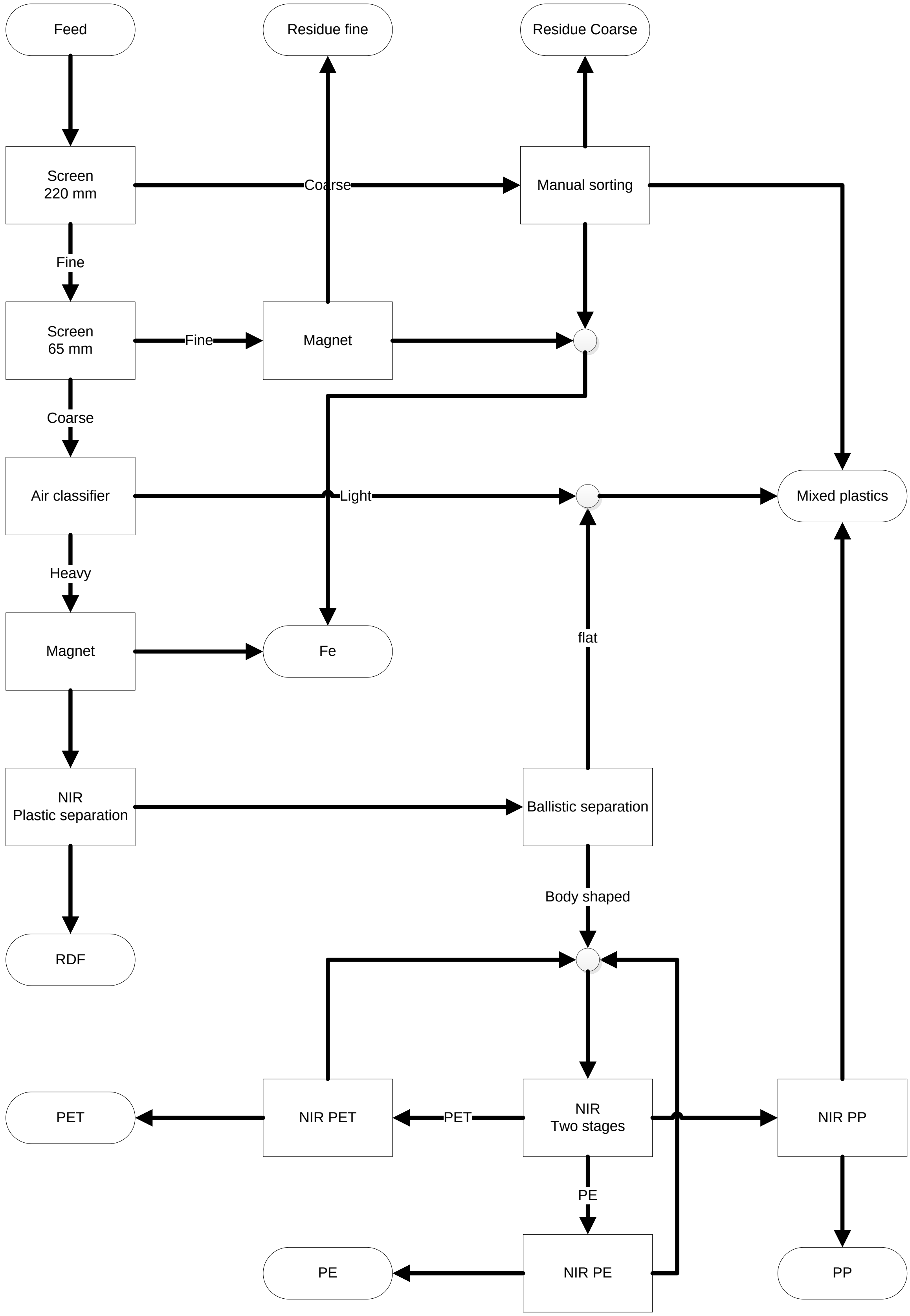


**Figure 2 Flow sheet of the low capacity sorting process for light weight packaging waste**

This process of the second sorting facility was studied in two trials. In one trial post-consumer plastic packaging waste from the Dutch source separation system was used as input; in the other trial similar material from a Dutch recovery facility was used. The inputs differed with regards to the polymer composition, the level of residual waste present and the amount of attached moisture and dirt present on the packaging object.

The process flow sheet of the third sorting facility is shown in Figure 3. It involves metal separation for ferrous metals and air classification as well as five stages of NIR sorting of which the first two stages consist of two parallel NIR sorters each.

 

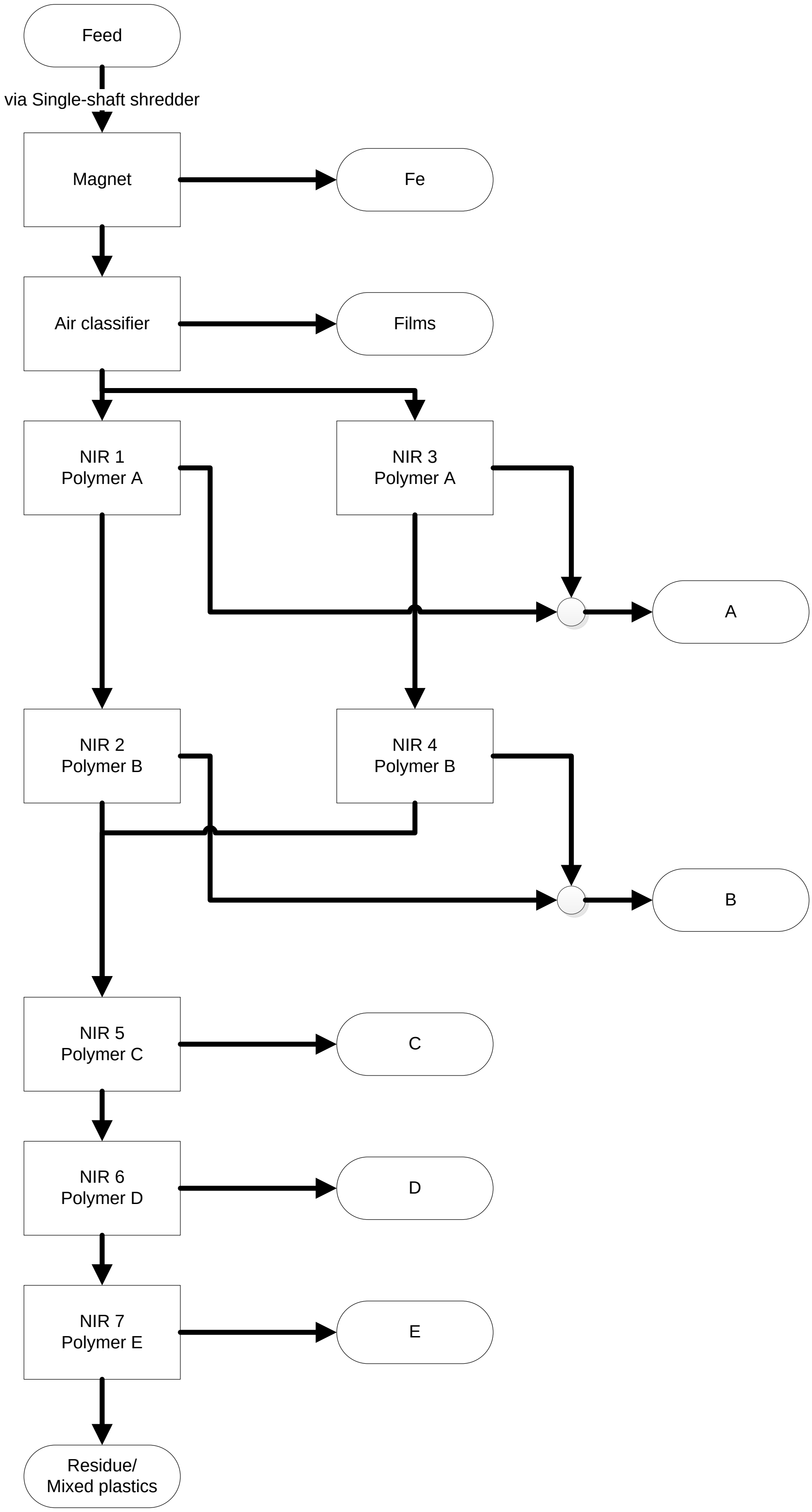


**Figure 3 Process flow sheet of the third plastic sorting facility**

The third process was studied in two trials; each with material from the same Dutch recovery facility but at different moments in time. The input composition differed slightly with regards to the amounts of non-packaging plastic objects and residual waste present.

## 2.2 Input data for the analysis: Mass balances and quality of the outputs

For each trial a mass balance was provided by the respective plant operator. The mass balances showed the mass of the input material fed to the sorting facility and the mass of every material fraction and residue formed in the sorting process. The composition and hence quality of each output stream was assessed by taking samples and sorting these samples. The volume of the sample of one output was around one cubic metre; one to four sub samples formed one sample. Data regarding the quality and the mass of the output streams were used to analyse most individual sorting machines within the overall process in terms of one input stream and two output streams. The sum of both outputs equals the input. And this calculated mass and composition of the input is eventually the output of another machine of which one output was already analysed by sampling, sorting and mass balancing. This methodology allows the calculation of the efficiency of each individual machine in a linear process. In case of non-linear processes additional assumptions or measurements are necessary to make these efficiency calculations. In some cases the output of a process was a mixture of outputs from various machines (see Figure 4). It is then not possible to directly calculate the efficiency of the respective machines. It has to be assumed how much mass of the output originates from which machine. In addition the composition of a stream has to be assumed. Here it was assumed that each stream which forms an output together with other streams has the same composition as the analysed output which collects the smaller streams.

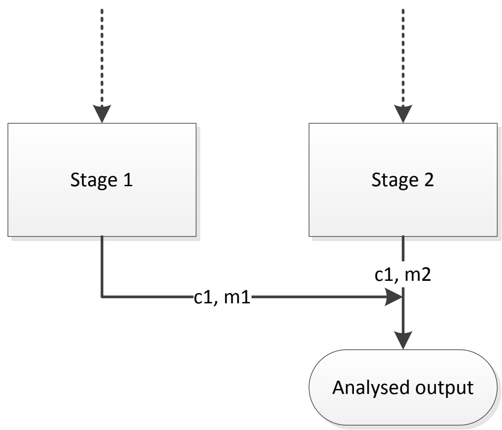


**Figure 4 Mixing of two different outputs; the composition of both outputs was assumed to be the same; the mass originating from stage one and stage two was assumed**

 

## 2.3 Process analysis in terms of similar stages

All the process flow sheets of the sorting facilities were analysed in terms of similar process stages. This enabled an equivalent comparison of the efficiencies of similar sorting machines in different sorting facilities. The following stages were identified to be relevant for plastic packaging waste sorting:

- **NIR sorting of the polymers PE, PET and PP:** these polymers can be found in large quantities in most plastic packaging waste mixtures and can be sold for positive prices in case the sorted products qualifies for the appropriate DKR specification. The extraction of these materials is state-of-the-art for most sorting plants.
- **Ballistic separation**: prior to sorting of PE, PET and PP all light weight flexible materials (films) should be removed to raise capacity of the NIR sorters. Additionally, films tend to cover other plastic objects which hinders the NIR sorting process and reduces the sorting efficiencies. Ballistic separation allows splitting a material stream into a stream of rigid body shaped objects ("three dimensional packaging") and a stream of flat and flexible objects ("two dimensional packaging"). In case rigid hollow shaped plastic articles have been compressed during collection or processing the chance that they will be lost to the flexible output stream increases.
- **Air classification**: an alternative process stage to remove films from the plastic packaging waste stream. Depending on the setting of the air classifier it is possible to extract a film product here, as well.
- **Size classification**: screening is often used to achieve a narrow[6] particle size distribution. This is done to raise the efficiency of following air classification stages. Additionally, larger plants tend to have several parallel processing lines. The volume stream is split by particle size to allow higher efficiencies during material conditioning.

Besides the previously mentioned sorting products PET, PE and PP which are the positively sorted products from the NIR machines and the FILM product which is formed as result of ballistic separation and air classification also two other products are formed: mixed plastics and sorting residues.

The largest product of all plastic sorting processes with Dutch plastic packaging waste is the fraction mixed plastics. This mixed plastic product is formed as a consequence of negatively sorting by NIR machines and by manual sorting. The mixed plastics product contains the residual plastic types (PS, PC, etc.), the packaging types for which there are compositional restrictions (only 10% PET trays allowed in the PET product DKR 328-1, so most of the PET trays are added to the mixed plastics) and also losses of fractions which should have been extracted can be found here (the faulty sorted packaging objects).

The sorting residues are formed by size classification, manual sorting and negatively sorted output from NIR machines. It contains undesired plastics like PVC and non-detectable plastics such as black coloured plastic packages, but also residual waste.

[6] *Ratio of size of the smallest and coarsest particle in the stream should be equal or less than 1:3.*

 

## 2.4 Calculations of the yield of recyclable material

The yield of recyclable materials is a key parameter to describe the efficiency of machines and processes. It describes how effective a process or process stage extracts a recyclable material from a given input. It can be described as in Equation 1.

$$Y_{i;j}=m_{i;j}/m_{input;j}$$

**Equation 1**

Where:

$Y_{i;j}$ Yield of the recyclable material j into the output I, [%]

$m_{i;j}$ Mass of the recyclable material j contained in the output I, [kg]

$m_{input;j}$ Mass of the recyclable material j contained in the input., [kg]

This yield of recyclable materials will be calculated for every process and separating machine for different polymers and packaging types. For a given process the yield of a recyclable material of one output is the product of the yields of all machines involved in forming this output.
Further considerations should be given to contaminants; the materials which are sorted into the product even though they should end up in the residue. The final quality of an output mainly depends on the yield of these contaminants into this output and of the faulty sorted packaging objects (e.g. PP packages that end up in the PE sorting fraction).
In the subsequent results section the yields per machine, packaging type and polymer are presented in a systematic order.

 

# 3 Results

The results of the study will be presented per process stage, in a logical sequence as is often found in sorting facilities. The yield of every process step is given per polymer and packaging type. Interesting findings and nuances are discussed for the results of every process stage.

## 3.1 Screening

Screening is widely applied in plastic packaging waste sorting plants. The screen aperture size varies from plant to plant. However, the general purpose of the screening is similar in most cases: the coarse material, especially films with a size coarser than DIN A4[7], has to be separated and the fine material which is too small for optical or manual sorting has to be removed. The respective screen aperture sizes are in the examples used in this study 220/250 mm and 50/65 mm. High capacity plants use another midsize screen to split the material stream according to its particle size distribution and process the material on two parallel lines.

A practical limitation to the interpretation of the screening results is that most trials were performed with baled input materials. During the baling process packages are deformed and some maintain their new deformed shapes after the bales are opened and the material is freed. This will affect the particle size distribution and hence the screening results.

Figure 5 shows how much material from the input to screening has been found in the coarse fraction (> 220/250 mm), the midsize-coarse fraction (140 - 220/250 mm), the midsize-fine fraction (50/65 - 140 mm) and the fine fraction (< 50/65 mm). The error bars show the 95 % confidence interval which has been deduced from the observed variations between the different trials.

[7] *The product specification 310 for plastic films from the DKR asks specifically for this size. This fraction can be extracted with a low amount of impurities and is therefore kept apart from the flexible mixed plastics fraction.*

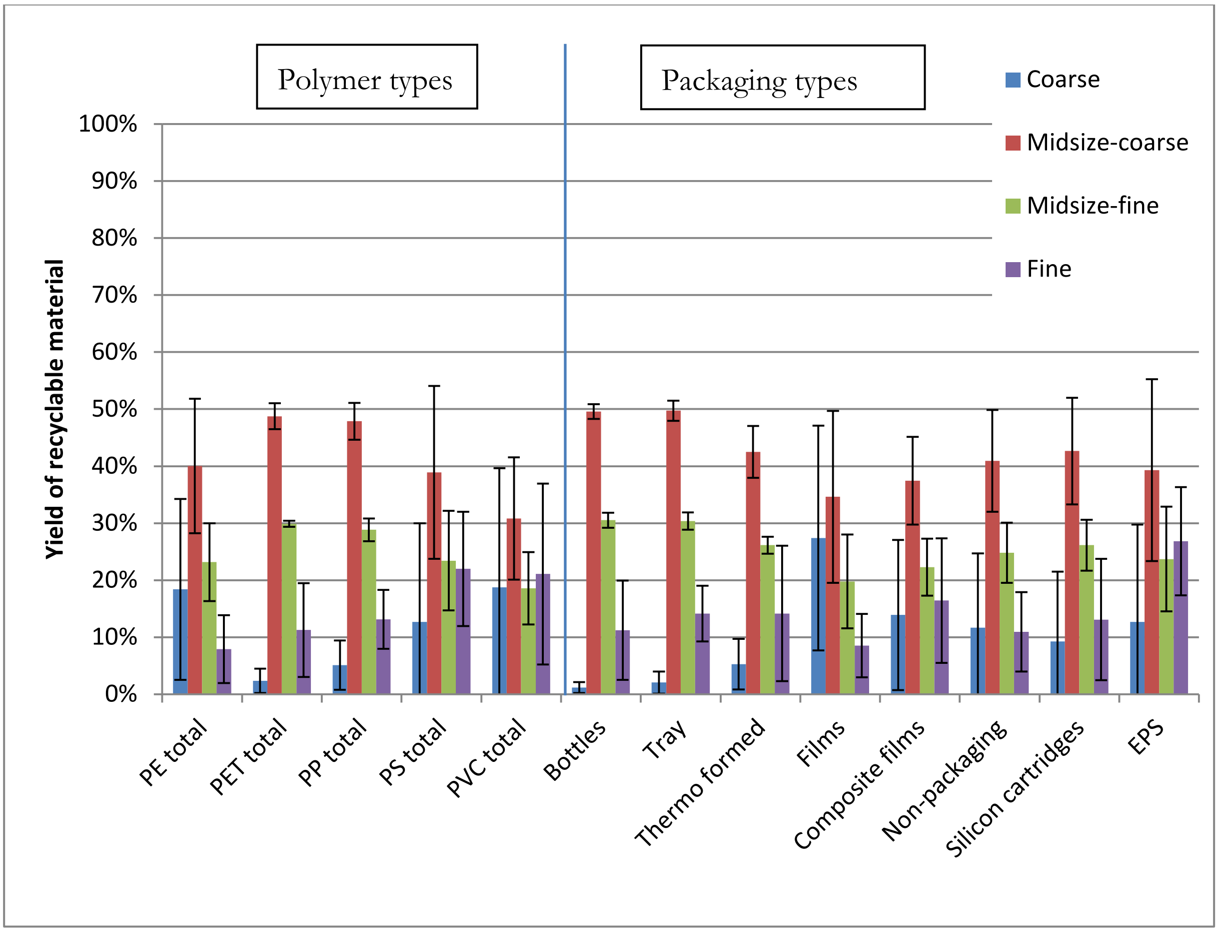


**Figure 5 Yield per polymer/packaging type for screening. The error bars relate to the 95 % confidence levels. (n=5;5;5;5;5;5;5;5;5;5;5;4;5)**

The screening process indeed does concentrate most polymers/packaging types in the midsize fractions. This intended enrichment helps the subsequent sorting processes further downstream in the overall process. One exception is the film fraction. The coarse films form a separate product of the sorting processes. The data for PS and PVC show high variations due to the small amounts contained in the input. It is therefore difficult to interpret this data. An additional aspect is that some of the present PS non-packaging objects tend to fracture during collection, baling and screening. This fracturing process is not a very well defined process and therefore adds to the broadening of the particle size distribution. Simulation of the screening process with PS and PVC packaging objects is not advised with this data. If simulation of PS and PVC packaging is needed similar pieces of other polymers should be taken into account for a comparison.

## 3.2 Air classification

Air classification is also a widely applied process step in the sorting of plastic packaging waste. An air flow is used to separate light-weight articles from denser heavier articles. In practise it is used to separate off flexible packaging materials in such a manner that the losses of the valuable rigid

 

packaging objects are still limited. These materials represent the major value in the plastic packaging waste and are intended to be sorted with the NIR equipment. Air classifying of plastic packaging waste prior to NIR sorting is important to keep the capacity of the NIR sorters elevated.
The summarised results of all the air classifiers in the studied sorting processes are shown in Figure 6. Also the 95 % confidence intervals are shown.

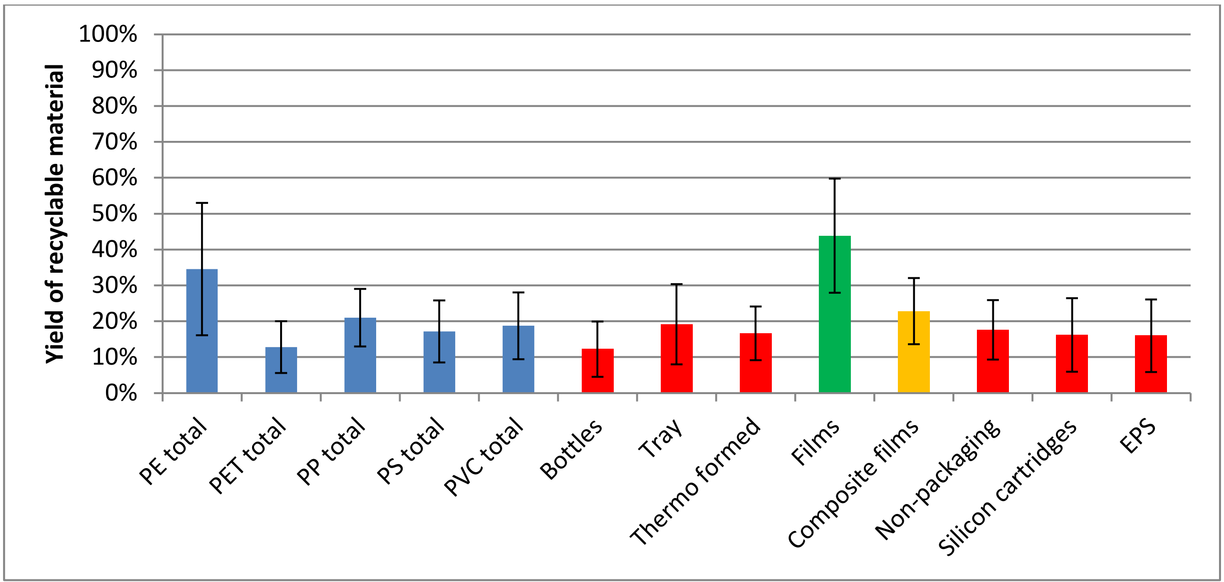


**Figure 6 Yield into the light fraction per polymer/packaging type for air classification. The error bars relate to the 95 % confidence levels. (n=12;12;12;12;11;11;12;11;12;12;12;8;10) Green bars represent intended objects, red bars are undesired objects and orange bars represent not intended objects. Blue bars represent polymer classes.**

Machine settings were found to influence the result of air classification step in the sorting process strongly. Air classifiers can be set to yield relatively pure film products with relatively few rigid packages in the product, but with also a smaller yield of flexible product. When the settings of the air classifier is changed relatively higher yield of flexible products can be obtained, but with some rigid packages as well. Hence, air classifiers with high yields of films will typically show high losses of rigid materials. Quantification of the above described effects is difficult due to the wide variety of air classifiers from different suppliers. Due to built-in devices like splitting rolls, splitting conveyors or similar the air classifiers show different responsiveness to flexible or rigid materials.

## 3.3 Ballistic separation

Figure 7 shows the yield and confidence interval for the ballistic separation.

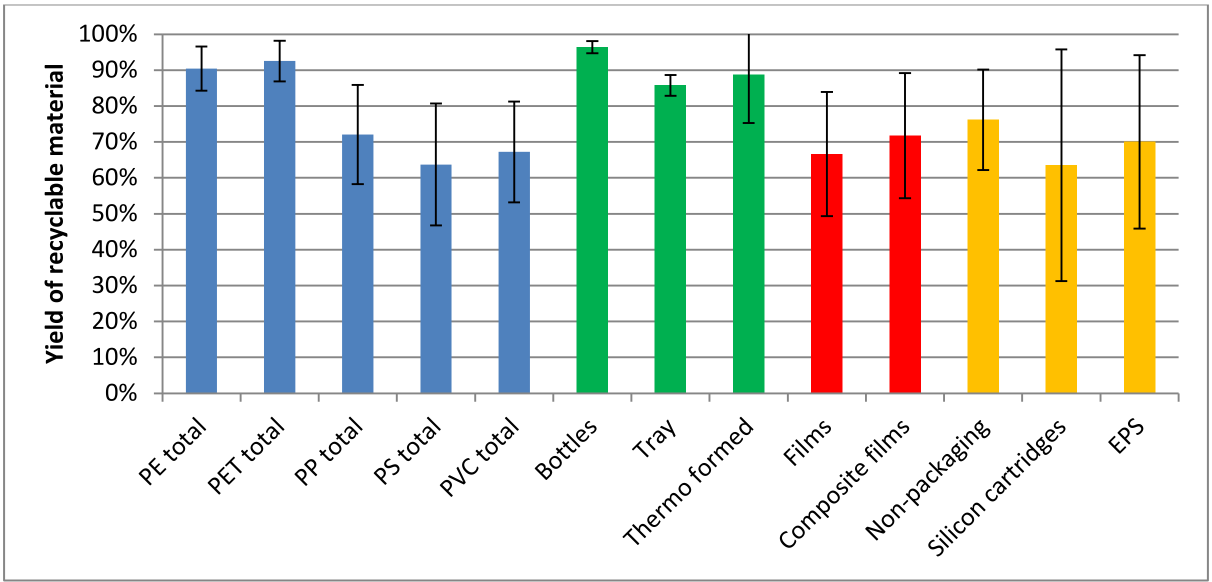


**Figure 7 Yield into the 3d fraction per polymer/packaging type for ballistic separation[8]. The error bars relate to the 95 % confidence levels. (n=5;5;5;5;5;5;5;4;5;5;5;3;4). Green bars represent intended objects, red bars are undesired objects and orange bars represent not intended objects. Blue bars represent polymer classes.**

Ballistic separators can successfully concentrate rigid plastic packages from mixed plastic waste streams, see Figure 7. Ballistic separation is therefore an effective technique to reduce the film content in the input to downstream process stages without causing losses of valuable materials. However, the difference between the yield of rigid objects and the yield of flexible objects is not much greater than 25 %. That means a considerable amount of films will remain in the input to downstream machines.

## 3.4 Near-infrared sorting of single polymers

The efficiency of NIR sorting devices was studied for three main packaging polymers (PE, PP and PET) separately. In one sorting facility the NIR sorting devices for PET and PE are partially fed by their own output, see Figure 2. Since this partial material circulation can't be enumerated, the results of this facility have not been analysed.

[8] *Ballistic separators are often equipped with screens of around 60 mm. As all processes which involved ballistic separation also involved screening of fine materials it was assumed that the amount of fine material removed during ballistic separation is negligible in comparison to the actual screening stage.*

 

### 3.4.1 PE

Figure 8 shows the yield and confidence interval for the PE NIR sorters.

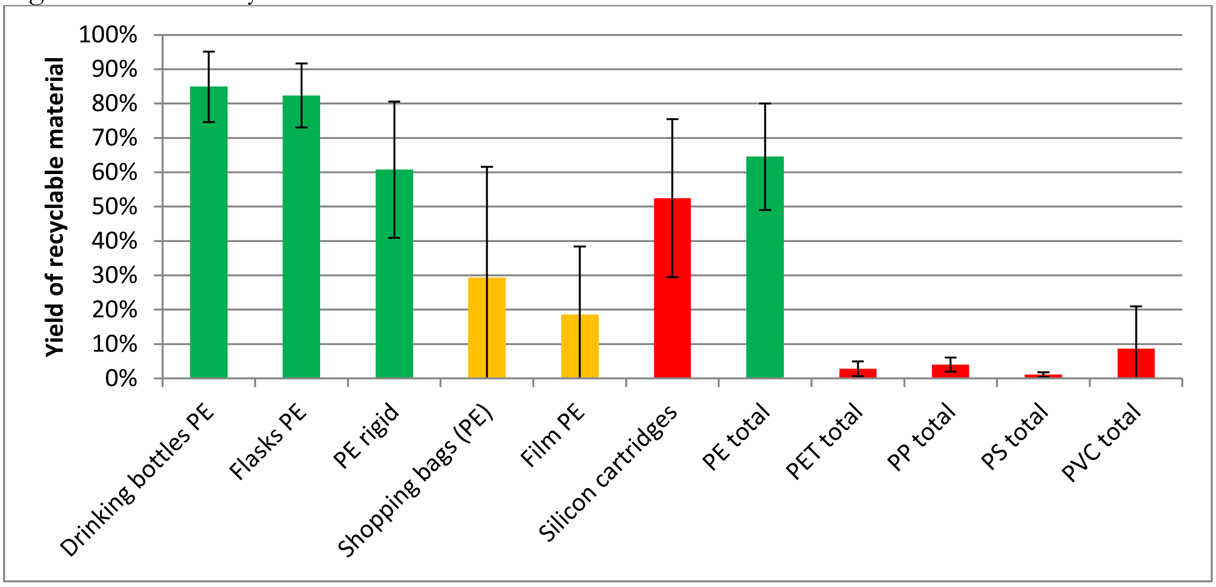


**Figure 8 Yield into the PE fraction per polymer/packaging type for NIR sorting. The error bars relate to the 95 % confidence levels. (n=7;7;7;5;7;4;7;7;7;6;4). Green bars are desired PE plastic packaging objects and red bars represent undesired plastic packaging objects and orange bars represent allowed but less desired objects.**

The studied NIR sorting machines sort PE bottles and flasks with high efficiencies into the PE product. It can be seen that the bottle fractions are sorted with high efficiency into the PE product. The sorting efficiency for the fraction residual rigid PE packages is slightly lower and shows a large variance, which corresponds to the heterogenic nature of this category (from small caps & closures to larger chewing gum pots). The sorting efficiency of flexible PE based packages (shopping bags and films) is much lower and this is desired, because the PE product should not contain more than 5% of flexibles (DKR 329). Flexible packages are being removed during the manual quality control of the outputs. As the applied methodology doesn't allow balancing of the manual quality control the lower yield of film can be seen as a result of that. That means NIR sorter do sort some of the flexible packages but they are removed during quality control. Some NIR sorters can distinguish between LDPE and HDPE and therefore selectively sort out PE bottles and flasks. However, some bottles are also composed of LDPE and would therefore be lost in the sorting process. The higher confidence interval for the films originates from the common analysis of NIR sorters which are used to concentrate all PE in one stream and NIR sorters which are used to selectively sort out PE which complies with the product specification. The first type of NIR sorters usually sorts out more film than the second type. The main impurities found in the PE product were silicon cartridges, which are not supposed to be in the waste at all, and PP packaging. The cartridges are composed of HDPE which makes it difficult to remove these with NIR sorters. They are typically removed during manual quality control of the products. PP packages that are present in the PE product as impurity are likely to originate from composed PE-PP packages (e.g. PP flasks with PE caps) and the regular sorting mistakes.

### *3.4.2 PET*

Figure 9 shows the yield and confidence interval for the PET NIR sorters. The sorting yields for PET bottles and flasks in a NIR machine dedicate for the sorting of PET is clearly less high than for PE bottles in a NIR device devoted to PE sorting, see Figure 9.

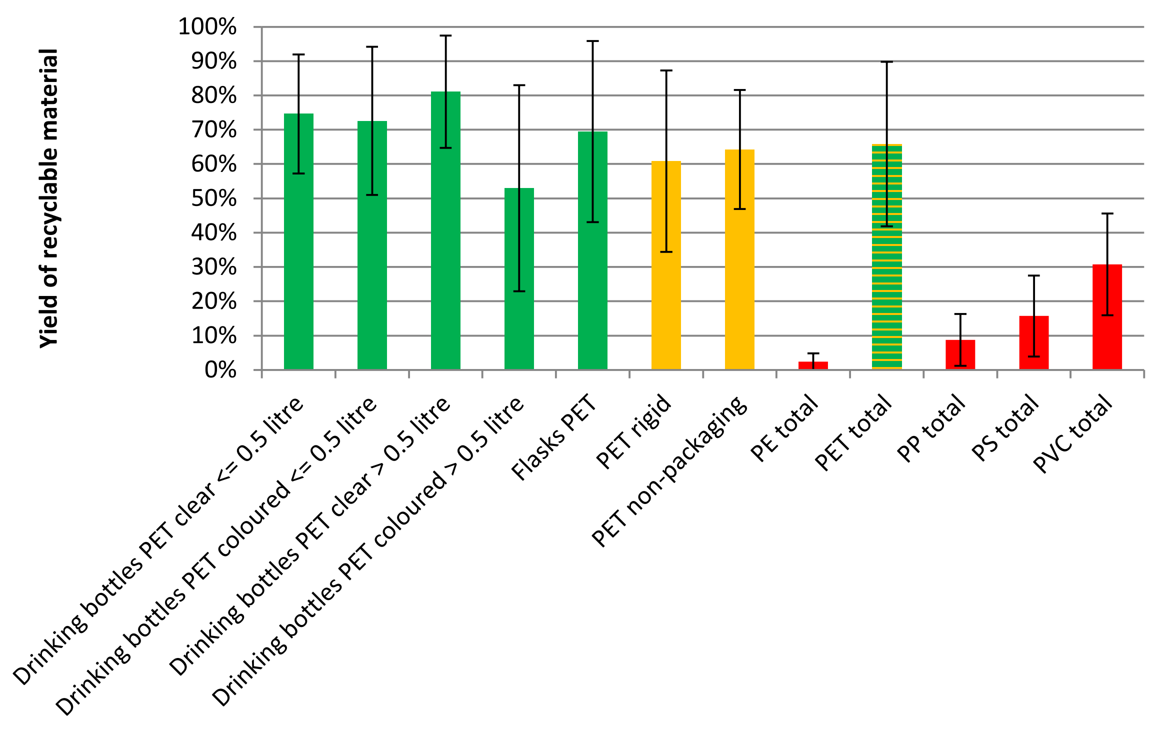


**Figure 9 Yield into the PET fraction per polymer/packaging type for NIR sorting. The error bars relate to the 95 % confidence levels. (n=6;6;6;5;6;6;3;6;6;6;5;4)**

Also the yield of impurities (PP, PS and PVC) into the product is higher. Several factors contribute to this lower sorting efficiency for PET. The PET sorting typically involves splitting of bottles from the remaining PET. If one tries to achieve this during NIR sorting, it will result in lower yield of PET bottles as the sorter hardly can distinguish between bottles and non-bottles (bottles and trays are usually composed of crystalline and amorphous PET respectively). Another influence factor is the presence of films in the input in combination with insufficient material conditioning. In one case baled input material with approximately one third of flexibles was delivered which couldn’t be unbaled properly due to the plant not being equipped to accept baled material. This resulted in very low (50 %) overall yield for most polymers. The high yield of impurities is due to the baling process of the unsorted plastic packaging waste. PET objects maintain their shape after bending. Impurities trapped in the bended object will be ejected with the PET object. However, depending on the material preparation, setting of the sorter and requirements to the product the sorting process can be as efficient as in the case of HDPE. The higher yield of PS packages is the result of one trial where the quality of the PET product didn't comply with any DKR specification. In all other trials the yield of PS packages into the PET product was found to be lower. The higher yield of PVC into the PET product is, as well, a result of the trial which resulted in a PET product of poor quality. Additionally the final concentration of PVC in the PET product was found to be approximately 0.05 % in the other cases. That indicates that the database doesn't allow a precise assessment of the sorting errors of PVC on NIR sorters which should sort out only PET.

### *3.4.3 PP*

Figure 10 shows the yield and confidence interval for the PP NIR sorters.

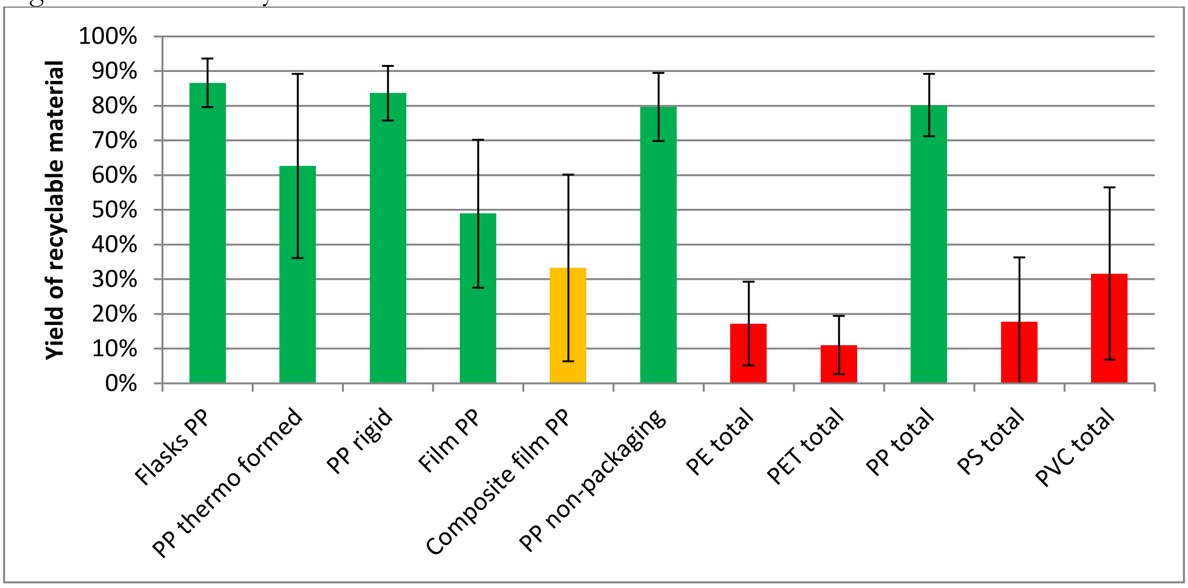


**Figure 10 Yield into the PP fraction per polymer/packaging type for NIR sorting. The error bars relate to the 95 % confidence levels. (n=9;7;9;9;7;7;9;9;9;9;7)**

The sorting yields for most PP fractions are roughly 85 %. However, some fractions show lower efficiencies combined with large variances. Thermoformed trays, film and composite film packaging can't be extracted as efficient as the other fractions. The ejection of films and composite films with pressurised air is difficult as the objects don't follow predictable trajectories once blown. The composite PP packaging films are composed of predominantly PP but also other polymers (PA, EVOH) and sometimes also of other materials such as thin aluminium films. These packaging objects are not intended to be sorted out into the PP fraction and the fact that their sorting efficiency is relatively low (about 30%) is positive for the quality of the PP product. The smaller amount of PP thermoformed trays in comparison to the PP rigid fraction also indicates that the results are less precise because of greater variations.

The PET objects ejected into the PP fraction are PET bottles or flasks with a PP label. The sorters scan the surface of an object to distinguish what polymer it is composed of. If a predefined area of the object's surface is e.g. PP it will be identified as PP. If on the surface of a deformed PET bottle more PP can be seen as PET as the label covers a certain part of the surface the object will be identified as PP even though it is mostly made of PET. Similarly, PE bottles often have PP caps and can therefore be sorted into the PP fraction. The higher yield of PVC into the PP fraction is a result of a two stage NIR sorting of PP in one plant where in the first stage PP is sorted negatively (see Figure 1). The sorter removes mixed plastics from the material stream. The non-mixed plastic fraction contains the PP and PVC. The PP is sorted out positively in the second stage. The trials in this sorting installation cause the higher yield of PVC. Generally, it is not expected that sorting of PP will cause frequent sorting errors related to PVC.

 

# 4 Data usage

The collected yields of recyclable materials per machine can be used to estimate the sorting results of new sorting facilities, but these estimations can only be used indicatively, due to the large variations in the observed yields.

## 4.1 Utilisation of the data to calculate facility's yields

To estimate the sorting results of future sorting facilities a precise description of the input mixture is required and a process flow sheet which describes the configuration of the sorting machines. For a simple sequential process flow sheet of several machines in-line the facility's yield for a polymer or a packaging object can be estimated by multiplying the yields for that polymer of object for all sorting machines involved. Due to the fact that the variation found between similar sorting machines at different sorting facilities is relatively large, the variation of the final estimated yields for the complete facility is relative large and these estimated yields on a facility level can only be used indicatively.

## 4.2 The large variation in the observed yields and factors involved

To be able to utilise the gathered data it is necessary to assume certain parameters of the simulated process. The confidence interval as a measure of central tendency gives information regarding the overall average of yields of a process stage. The actual yield in one case can be lower or higher. Therefore one has to assume parameters which might influence the yield negatively and positively and adjust the yield according to the assumed parameters.
The throughput of a stage influences its efficiency. A too high throughput will cause high losses of recyclable material into the residue fraction. However, it is not possible to give precise figures for optimum throughputs. Depending on the capacity of a single machine, the composition of the input to the machine, the concentration of recyclable material in the input to the machine and various other factors higher or lower throughputs can be realised.
The composition of the input is especially important for streams showing high film contents which are to be sorted with NIR sorters. The input material has to be fed as a layer of non-overlapping objects to the machine. Thin films cover large parts of the conveyor belt used to feed the machine. The lower ratio of weight per surface area results in a lower throughput.
Near-infrared sorting is sensitive to upstream near-infrared sorting. A positively sorted material stream, i.e. objects which already got identified and sorted by a NIR sorter, are more likely to be sorted with high yields (>90 %) into the products.
The particle size distribution is important for air classification of plastic packaging waste streams. Air classifiers split a material stream depending on particle size, density of the material and shape of the particle. As most plastic packaging have similar densities the splitting process can be most efficient if most of the objects have also a similar size. It is then possible to sort the waste

depending on the shape of the objects, i.e. flat objects like films versus three dimensional objects like bottles.
One has to take into consideration that this data was gathered by studying mixtures of various packaging objects. A simulation of one specific type of packaging, e.g. a PET water bottle of a certain manufacturer is not possible. This particular type of bottle might behave different to the average, e.g. it can't be identified with NIR sensors at all due to shrink sleeves, labels, etc. Therefore the actual result might deviate strongly from the simulation of the behaviour in the process chain.

 

# 5 Conclusions

The database provided allows for the simulation of plastic packaging waste sorting processes. The stages screening, air classification, ballistic separation and near-infrared sorting have been analysed per packaging type and per polymer. Each packaging type which is part of a simulation of a process can be assigned to either a polymer fraction or a packaging type fraction. Therefore, for the given process it is possible to predict the yield of this packaging type into the various outputs of the process.

It has been shown that the sorting of plastic packaging waste is subject to variations. Depending on the throughput of a stage, composition of the input material, particle size distribution of the material and other factors the yield of the stage varies. An important variable is for example the concentration of flexible packages in the input material, in case this concentration is high the yields of the rigid packages will be reduced in most sorting facilities.

This database will improve the understanding of which packaging objects can be sorted into products for material recycling and which objects are more likely to end up in the sorting residues and hence will be incinerated. Environmental calculations which consider the correct end-of-life destinations of a certain product group, e.g. HDPE shampoo bottles, can be refined in a way that a material recycling quota for this specific group can be taken into account instead of relying on general numbers such as a nationwide material recycling quota for all plastic packaging. However, calculations regarding one single type of product, e.g. a shampoo bottle of one manufacturer might strongly deviate from the average of this product group, since too small shampoo bottles are more likely to end-up in the fine residues and HDPE-shampoo bottles with large PS shrink wrap labels are more likely to end up in the mixed plastics.

# 6 Recommendations for further research

The sorting of plastic packaging waste is one of three process stages in the recycling chain. As a first step plastic packaging waste has to be collected from the household as a separate fraction or has to be separated from the municipal solid waste in a mechanical-biological treatment plant. The sorted products are processed in re-processing plants to produce washed milled goods or re-granulates which can then replace other materials.

Both stages, the separation in the mechanical recovery facilities and the re-processing are vital steps in the plastic recycling chain and technical parameters per polymer type and packaging type are still lacking for these processes. It is suggested that similar research on process and machine efficiency is performed for these stages to complete the database.

 

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