RECYCLABLE PACKAGING

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03-07-2015

The project Sustainable Packaging of TI Food and Nutrition and Kennisinstituut Duurzaam Verpakken (KIDV) would like to have guidelines for design of the project's packages. The project focusses on nine different packages. This report describes a research to find the compositions of packages, the market share, how the packages are recycled and as a result guidelines for design.

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July 2015, Wageningen

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S1378023

Pages: 74
Appendices: 10

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ABSTRACT

This research project is executed on behalf of Wageningen UR. The project participates the project SD002 Sustainable Packages. The project originated by a collaboration between TI Food & Nutrition and the Kennisinstituut Duurzaam Verpakken (KIDV). The research project was conducted in three months time. The aim of this project is to collect technical and marketing data from a 3x3 matrix of packages that are available on the Dutch market, see table 1. The technical data is the levels of attached moisture and dirt material composition and the average weight of those packages. The results includes the average and extreme values. Besides, a goal is to determine the significance of this data for the recycling of the 3x3 matrix's packages. This is done by describing the general recycling system and making an estimation of the efficiency of mechanical recycling facilities with the results of the composition research. Finally, the problems of the recycling will be described and the aim is to determine guidelines for designing recyclable packages.

Product	Packaging material options			
Soups	Metal can	Pouch	Liquid carton	Glass (optional)
Shower gels	HDPE bottle	PET clear rigid bottle	Aluminium pressurized can	
Non-carbonated beverages (≤ 0.5 litre)	PET bottle	Metal can	Beverage carton	Glass non-refill (optional)

Table 1 - 3x3 matrix of the project Sustainable Packaging

A composition research is conducted of randomly selected packages of the 3x3 matrix. The weights are measured with a scale and the materials are defined by a NIR scanner, magnet or the data per package. The most present material per packaging option is shown in table 2. Also a detailed composition is determined. In further research the glass could be included. Also the ratio of coating and aluminium of metal cans could be measured exactly. As well as the ratio of the multiple layers in pouches and aluminium pressurized can's bags. These ratio's are estimated in the report.

The composition of the 3x3 matrix packages is input for the efficiency of mechanical recycling calculation. First the recycling system is explained. The collection of packages is done by municipalities. This could be source separation or municipal solid waste. Municipal solid waste is going to recovery plants where the recyclable waste is separated from the packages which are going into refused derived fuel. The recyclable packages are transported to sorting facilities and the remaining waste will be incinerated. The sorted waste of recovery plants and the source separation waste will be input in sorting facilities. Sorting facilities are separating bigger waste streams into smaller waste streams. For example the plastic waste stream into polymer types. Afterwards the materials needs to be purified in mechanical recycling. In this part of the process packages turn into reusable material.

To recycle all packages of the 3x3 matrix as good as possible the different materials needs to follow their own specific path through the sorting, recovery and mechanical recycling facilities. The efficiency of mechanical recycling facilities is calculated. Some assumptions are made which makes the calculation an estimation of the recycled packages. The percentages of mechanical recycled packages can be seen in table 2. PP and PE are processed together into PO-mix. The amount of PS is pollution of the PET. In this research is not taken into account the ratio in beverage cartons of plastic foil which stick to the carton and PE foil which stick to the aluminium because this ratio is not known.

As a total result the guidelines for recyclable packages are made. The guidelines are divided into general packaging guidelines and plastic packaging guidelines. The general guidelines are:

- The goal of improving the recyclability cannot compromise product safety.
- Minimize the use of different materials
- Preferable dimensions of all parts between 70 and 200 mm. Otherwise it will be separated at the screens of the recycling system.
- Use a wall thickness of more than 0.1 mm so the packages cannot be sorted at the air classifiers of the recycling system.
- Minimize the volume of material
- The different materials should be separated easily.
- Minimize the product residue
    - Design the package with a wide neck
    - Consider using a package that can be stood inverted to ease empting
    - Consider or investigate in use of non-stick additives to reduce the product residue stick to the package. This should not affect the recyclability of the package.

The guidelines for recyclable packages are made to have a better recycling of the packages. The guidelines for designing recyclable packages can be applied to the current packages of the 3x3 matrix. In a further research the packages of the 3x3 matrix could be re-designed into recyclable packages.

	Soups			Shower gels			Non-carbonated beverages (≤ 0.5 litre)		
	Metal can	Pouch	Liquid carton	HDPE bottle	PET bottle	Aluminium pressurized can	PET bottle	Metal can	Beverage carton
Material	Tin plate	Plastics	Carton	PE	PET	Aluminium	PET	Aluminium	Carton
Percentage	75.7%	90.2	72.0%	82.4%	74.4%	78.1%	84.0%	79.8%	70.1%
Percentage recycled	81.5%	0%	41.1%	55.7%	56.1%	63.1%	66.7%	65.7%	55.7%
Pollution	-	-		11.7% PP	0.1% PS	-	0.4% PS	-	

Table 2 - Most present material per packaging option and percentage recycled material in mechanical recycling

SAMENVATTING

De opdrachtgever van de bachelor opdracht is Wageningen UR. De opdracht valt binnen het project SD002 Sustainable Packages . Het project komt voort uit een samenwerkingsverband tussen TI Food & Nutrition en het Kennisinstituut Duurzaam Verpakken (KIDV). Het doel van deze opdracht is het projectteam van Sustainable Packaging meer inzicht te verschaffen in de verpakkingen die binnen de 3x3 matrix vallen welke te zien is in tabel 3. Dit kan gerealiseerd worden door het verzamelen van data van bestaande verpakkingen uit de 3x3 matrix beschikbaar op de Nederlandse markt. Binnen deze data valt hoeveel van deze verpakkingen er op de markt zijn en wat de gemiddelde/extreme samenstelling per verpakkingstype is. Deze data moet duidelijk gepresenteerd worden zodat deze in verschillende onderdelen van het project als input kunnen dienen. De technische data kan worden geanalyseerd waarbij gezocht wordt naar verbetering mogelijkheden van deze verpakkingen in de recycling keten. Dit resulteert uiteindelijk in ontwerprichtlijnen voor deze verpakkingen. Dit alles zal binnen een tijdsbestek van drie maanden plaatsvinden.

Product	Verpakking (materiaal) opties			
Soep	Blik	Zak	Drankenkarton	Glas (optioneel)
Shower gel	HDPE fles	PET fles	Aluminium spuitbus	
Niet-koolzuurhoudende dranken (≤ 0.5 liter)	PET fles	Blikje	Drankenkarton	Glas (optioneel)

Tabel 3 - 3x3 matrix uit het project Sustainable Packaging

Een onderzoek naar de samenstelling is uitgevoerd van random geselecteerde verpakkingen uit de 3x3 matrix. Het gewicht van de verpakkingen is gemeten met een weegschaal en de materialen zijn gedefinieerd door een NIR-scanner, magneet of de gegevens op een verpakking. Het meest voorkomende materiaal per verpakking is te zien in tabel 4. Daarnaast is ook een gedetailleerde samenstelling bepaald. In een verder onderzoek kan van het verpakkingstype glas ook de samenstelling bepaald worden. Daarnaast zou de verhouding van aluminium en coating in blik exact gemeten kunnen worden. Van deze verhouding is in dit rapport een schatting gemaakt. De verschillende lagen kunststof in soep in zak en de zak in een aluminium spuitbus zouden ook exact gemeten kunnen worden. Hiervan is de samenstelling niet verder bepaald dan kunststoffen.

De samenstelling van de verpakkingen uit de 3x3 matrix input voor een berekening over de efficiëntie van mechanisch recyclen. Hiervoor is de recycling keten toegelicht. De inzameling van verpakkingen wordt gedaan door de verschillende gemeenten. De inzameling kan zijn bron gescheiden inzameling of restafval. Het restafval gaat naar nascheidingsinstallaties waar het recyclebare materiaal uit het afval wordt gehaald, het overgebleven afval wordt verbrand in de verbrandingsoven. Het recyclebaar materiaal wordt naar sorteerbedrijven gebracht. Hier worden grote afval stromen gescheiden naar kleinere afvalstromen. Bijvoorbeeld plastic afval scheiden op de verschillende polymeren. Na het scheiden moet het materiaal gezuiverd worden. In dit deel van de keten wordt er herbruikbaar materiaal gemaakt van de verpakkingen.

Alle verpakkingen uit de 3x3 matrix hebben een ideale recycling route door sorteer, nascheiding en mechanische recycling installaties. De efficiëntie van de mechanische recycling installaties is berekend. In deze berekeningen zijn een aantal aannames zijn gedaan waardoor de berekening een schatting wordt van de gerecyclede verpakkingen. De percentages van de mechanisch gerecyclede verpakkingen kan gezien worden in tabel 4. PP en PE kunnen samen verwerkt worden tot PO-mix. In het PET materiaal treed het PS op las vervuiling. In dit onderzoek is de verhouding van het plastic folie wat gehecht is aan het karton en wat gehecht is aan het aluminium in drankenkartons niet meegenomen. Dit is omdat de verhouding is niet beschikbaar is.

Als eindresultaat zijn de ontwerprichtlijnen voor recyclebare verpakkingen gemaakt. De richtlijnen zijn verdeeld in algemene ontwerprchtlijnen voor recyclebare verpakkingen en ontwerprichtlijnen voor recyclebare kunststof verpakkingen
De algemene ontwerprichtlijnen zijn:

- Het doel om de recyclebaarheid van verpakkingen te verbeteren mag niet de veiligheid van het product in de weg staan.
- Minimaliseer het gebruik van verschillende materialen
- De verschillende materialen moeten eenvoudig te scheiden zijn.
- Bij voorkeur hebben alle onderdelen een afmeting tussen 70 en 200 mm. Anders zullen deze gescheiden worden door de zeven in het recyclingproces.
- Gebruik een wanddikte van meer dan 0.1 mm zodat de verpakkingen niet worden gesorteerd door de windsorteerders.
- Minimaliseer het volume materiaal
- Minimaliseer het product residu
  - Ontwerp een verpakking met een grote opening
  - Overweeg een verpakking die binnenstebuiten gekeerd kan worden om het legen eenvoudiger te maken.
  - Overweeg of doe onderzoek naar het gebruik van materialen waar het product niet aan vast kan blijven plakken. Dit zou de recyclebaarheid van de verpakking niet moeten beïnvloeden.

De richtlijnen voor recyclebare verpakkingen zijn gemaakt om de verpakkingen beter te kunnen recyclen. The richtlijnen kunnen worden toegepast op de huidige verpakkingen uit de 3x3 matrix. In een toekomstig onderzoek kunnen deze verpakkingen herontworpen worden in recyclebare verpakkingen.

	Soepen			Douchegels			Niet-koolzuurhoudende dranken (≤ 0.5 liter)		
	Blik	Zak	Dranken-karton	HDPE fles	PET fles	Aluminium spuitbus	PET fles	Blikje	Dranken-karton
Materiaal	Dunstaal	Plastics	Karton	PE	PET	Aluminium	PET	Aluminium	Karton
Percentage	75.7%	90.2	72.0%	82.4%	74.4%	78.1%	84.0%	79.8%	70.1%
Percentage gerecycled	81.5%	0%	41.1%	55.7%	56.1%	63.1%	66.7%	65.7%	55.7%
Vervuiling	-	-		11.7% PP	0.1% PS	-	0.4% PS	-	

Tabel 4 - Meest voorkomende materiaal per verpakking en het percentage gerecycled materiaal in mechanische recycling

CONTENT

1. INTRODUCTION

This research project is executed on behalf of Wageningen UR. The project participates the project SD002 Sustainable Packages. The project Sustainable Packages is originated by a collaboration between TI Food & Nutrition and the Kennisinstituut Duurzaam Verpakken (KIDV). The goal of the project is getting academic knowledge of the environmental impact of product-packaging industry. This is input to create tools and methods for preservation of packaging supply, from design to recycling. Multiple knowledge institutions are collaborating to succeed the project: Rijksuniversiteit Groningen, Universiteit Twente, Wageningen UR, Technische Universiteit Delft, TNO en RWTH Aachen. All institutions have their own specialism. The project Sustainable Packages focusses on packages of the 3x3 matrix as shown in table 5.

Besides the project Sustainable Packages also the packaging industry is interested in the results of the project Sustainable Packages. The packaging industry consist of packaging companies, sorting companies and recyclers which are working with the packages of the 3x3 matrix as mentioned in table 5. They will use the results to improve the sustainability of packages inside the company. Currently there are in the packaging industry too many questions and too little knowledge to achieve this. There will be looked at sustainable packaging, retrieving materials, material chain, consumer research and the environmental impact of the packages of following 3x3 matrix. The project Sustainable Packaging's results are academically researched knowledge.

The aim of this report is to collect technical and marketing data from a 3x3 matrix of packages that are available on the Dutch market. The technical data are the levels of attached moisture and dirt material composition and the average weight of those packages. The results includes the average and extreme values. The data could be input for different parts of the Sustainable Packaging project. The technical data will be analysed. In the analysis the question: what does these data mean to the recycling process of packages? needs to be answered. With the analysis there will be searched for improvements of these packages. The final result of this report is guidelines for designing sustainable packages.

Firstly, in chapter 2 the package of the 3x3 matrix are described. What are the different packages and what is the market share of the packages. A description is made of the difference in shape and volume, the general parts of the packages how are the packages used and the intersections are shown. Secondly, a research is done to the composition of the packages in chapter 3. The main result of this research will be the ratio of the composition. Besides, there will be looked at the interface between the materials and the percentage of product residue in the package. The results of this research will be input into the chapter 4. The packages of the 3x3 matrix needs to follow their own specific path through the recycling process. With the results of the composition research a efficiency of the mechanical recycling facility can be made. In chapter 5 the problems of recycling are described and guidelines for designing packages are made. At last, the conclusions and recommendations are made of the total report.

Product	Packaging material options			
Soups	Metal can	Pouch	Liquid carton	Glass (optional)
Shower gels	HDPE bottle	PET clear rigid bottle	Aluminium pressurized can	
Non-carbonated beverages (≤ 0.5 litre)	PET bottle	Metal can	Beverage carton	Glass non-refill (optional)

Table 5 - 3x3 matrix of the project Sustainable Packaging

2. PRODUCTS OF THE 3X3 MATRIX

In the project Sustainable Packaging is focused on three different types of products; soup, shower gel and non-carbonated beverages (≤ 0.5 litre). Three packaging options are studied per product category as shown in the 3x3 matrix. The optional package glass is not included in this study. What are the different types of packages and what are the different parts of these packages? There is also looked at the market share of the packages of the 3x3 matrix. To get an insight of the product's shares into recycling and the completeness of the matrix.

2.1 PRODUCTS

Firstly a market analysis is done to see which packages belong to the products and packaging options. Several retail stores of different price ranges were visited: Coop, Albert Heijn, JUMBO, Lidl and HEMA. The price range in stores is included to see if there is a difference in packaging. All packages are described in appendix 1 with brand, variations, volume or/and weight and the selling stores. The goal of this analysis is not to be complete but to give an impression of which different types of packages are on the market. The analysis also includes the packaging options which do not belong to the matrix according to the five stores.

By means of this analysis and other additional information about the products and packaging options descriptions are made of the difference in shape and volume, the general parts of the packages, how the packages can be used and the intersections of packages is shown.

Soups - metal can

Commonly a metal can consist of tin plate cylindrical can as illustrated in figure 1. The analysis shows that different metal cans have almost the same shape which differ when the volume changes. Generally a paper label is glued to the outside of the curved surface. Some packages have also a label printed on top of the can. Also a pull tab can be added to open the can easily. For those without a can opener is needed to open the can. Afterwards the soup can be poured out. Additional layers in the can are used for the preservation of the soups which can be seen in figure 2. The polymeric lacquers protect the food and prevent undesirable interactions between the metal from the can and the food. Common types are epoxyphenolic, PVC organosol and polyester phenolic (Goodson, Summerfield, Cooper, 2001). Epoxyphenolic is used mostly for metal cans. However each coating is made for a specific type of soup (de Olde, ter Morsche, 2015). For example mushroom soup has a different coating than tomato soup even when they are of the same brand. This has multiple reasons; First it could be the preference of the manufacturer. Some prefer a white metal can in stead of a gold metal can. This also has to do with the appearance of the product. Tomato soup in an white metal can gives a pink lacquer. This is unattractive for the consumer. Secondly, the products with a low PH value needs a firm lacquer or more lacquer than usual. This are acid products for example tomatoes. Thirdly, when the metal can is shaped a lot in the manufacturing process the lacquer needs to be flexible. Fourthly, sulphur containing proteins inside a product can react with the thin layer and cause a darkening in the lacquer. This can be counteracted to use a dark colour of lacquer or prevented with an specific type of lacquer. At last, some products are tasting better when they have reacted with the thin layer of the metal can (van Dijke, 2015).

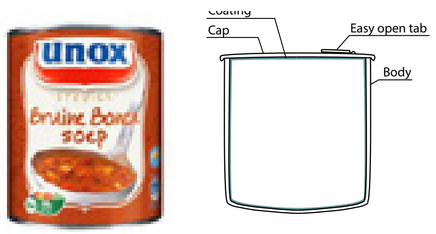


Figure 1 and 2 - Soups metal can and intersection metal can

Soups - pouch

Pouches are flexible, laminated packages that can withstand thermal processing temperatures. A typical pouch is illustrated in figure 3. Pouches does not have many different shapes and volumes. The pouches contain mostly 570 ml soup. Most pouches are constructed with a four-ply laminate consisting of a polyester outside layer, a nylon second layer, an aluminium foil third layer and a polypropylene inner layer which can be seen in figure 4. Polypropylene has a melting point between 130 ˚C and 170 ˚C. This temperature is higher than the commonly applied sterilisation temperature of 121 ˚C. Each layer performs a specific function that is critical to the shelf stability and container integrity (Jun et al., 2006). A notch on top of the pouch can be used to tear off the sealed top edge from the pouch the pouch easily.

Figure 3 and 4 - Soups pouch and intersection pouch

Soups - liquid carton

Liquid cartons consist of cardboard, aluminium and PE which can be seen in figure 5 and 6. The packages contain mostly 1 Litre soup but there are also small 300 ml packages. The cardboard layers gives the package its strength and shape. The aluminium layer prevents air, light and micro-organisms to reach the food. The inner and outside layers are made of PE. This way the food does not come into contact with the aluminium or cardboard (Pasqualino et al., 2011). The consumer needs to cut off a corner piece of the package after which the soup can be poured out.

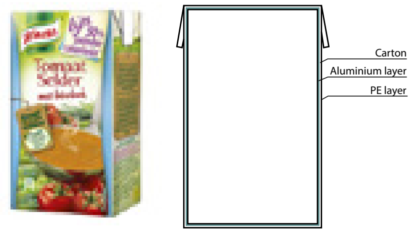


Figure 5 and 6 - Soups liquid carton and intersection liquid carton

Shower gels - HDPE bottle

HDPE shower gel bottles have many different volumes and shapes. The appearance of HDPE bottles are wax-like, lustreless and opaque. A typical HDPE bottle is shown in figures 7 and 8. Most bottles have a cap on the top side of the bottle but some bottles have a cap at the bottom side. Besides bottles there are also HDPE tubes. The HDPE bottles have generally two labels: one in front of the bottle and one at the back. By squeezing the package the shower gel will come out.

Figure 7 and 8 - Shower gels HDPE bottle and intersection HDPE bottle

Shower gels - PET clear rigid bottle

PET clear rigid bottles are recognizable by the transparency but sometimes the bottles are coloured. For example red, green or opaque. The PET bottles are in many different volumes and shapes. This can be a travel package or a family package. Caps are mostly placed on top of the bottle which can be seen in figures 9 and 10. This could be a screw cap or a click cap. The label is placed in front and in the back of the bottle or around the bottle. The shower gel will come out by squeezing the package.

Figure 9 and 10 - Shower gels PET bottle and intersection PET bottle

Shower gel - Aluminium pressurized can

All Aluminium pressurized cans have the same shape which differ when the volume changes. An aluminium pressurized can consist of an aluminium or tin plate can which is closed by a valve on which a multilayer film bag is affixed or welded. A typical aluminium pressurized can is shown in figure 11. The multiple parts of the aluminium pressurized can can be seen in figure 12. The film bag is containing the shower gel. The propellant, liquid gas or compressed gas (nitrogen, air), is contained inside the can outside the bag and squeezes the bag to release the product through the valve. This way it is possible to dispense the product in whatever position the can is held (Coster BOV, n.d.). A large range of standard actuators are available depending on product demands. A section of the shower gel is pentane. Pentane has a boiling temperature of 36.1 ˚C so it boils when it comes in contact with the skin (Ten Klooster, 2015). This causes the foaming effect. The multiple parts in the valve allows filling the bag with shower gel and the can with propellant. The label is printed on the can itself.

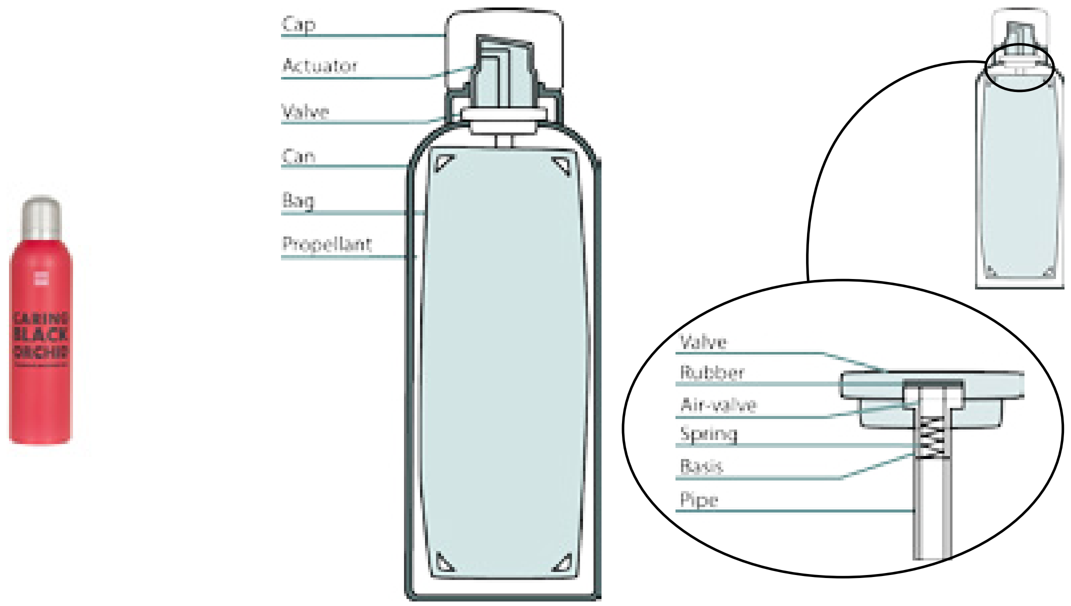


Figure 11 and 12- Intersection aluminium pressurized can

Non-carbonated beverages - PET bottle

The body of the PET bottle can be compared to a shower gel PET bottle. The non-carbonated beverages PET bottles have many different shapes. The caps of these PET bottles are mostly screw caps but also some “sport caps” (see figure 19.A) or click caps. Some cap have an inside cap which is illustrated in figure 19.B. The labels are generally around a part of the body and sometimes the body is completely wrapped. Some of the bottles are provided with a barrier. This is an additional layer inside the bottle to protect the food. The currently most favoured coatings in this industry are diamond-like carbon (DLC) and silicon oxide (Shirakura et al., 2006). Besides coatings also oxygen scavenger layers inside the PET material are used to protect the food such as ethylene vinyl alcohol (EVOH) (Cruz et al. 2012). A typical PET bottle is shown in figure 13 and 14.

Non-carbonated beverages - metal can

Metal cans for non-carbonated beverages can be compared to soups metal cans (see figure 15 and 16). In stead of tin plate the non-carbonated beverage cans are mostly made of aluminium. Chiefly found on the market are two shapes of cans: small and long and wide and short. The differences between the cans are mostly in volume. There are also some special metal cans, cans with a different shape, but this is a niche of the market. All non-carbonated beverage metal cans have an easy open tab. The product can be poured out when the package is opened. Gas is added inside the can to create pressures of about 2 times atmospheric pressure. The gas which is added are nitrogen. Because of the internal pressure the can is very strong despite its thin walls (Hammack, 2015).

Non-carbonated beverages - beverage carton

The layers of the beverage carton can be compared to liquid cartons of soups. Only some additional parts are added. There are two types of beverage cartons. First a package which can be straw sipped (see figure 17 and 18) and second a package which will be poured out when the consumer wants to drink. At the top of the beverage with a straw a small circle is made of a thin aluminium layer. A straw can be put through this layer when the consumer wants to drink. The straw is

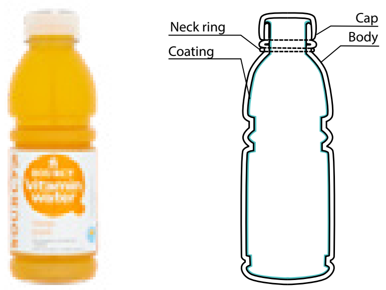


Figure 13 and 14 - Non-carbonated beverages PET bottle and intersection PET bottle

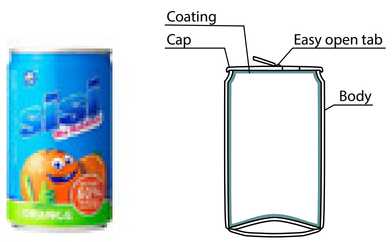


Figure 14 and 16 - Non-carbonated beverages metal can and intersection metal can

mostly packed in a flow pack at a side of the package (see figure 18). The second package type has a cap on top. There are two cap options. One with teeth inlay which cuts the aluminium layer when twisting the cap (see figure 19.C). Which can be found on small juice packages. And a second cap without teeth inlay. These caps are mostly on 0.5 litre milk packages which does not have an aluminium layer (see figure 19.D).

All different packages can be seen in appendix 1. This information is used to formulate a good method for the composition of packages research (see chapter 3). The terms used in this information will also be used in the research.

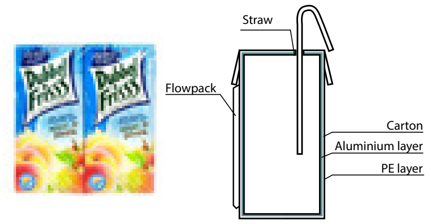


Figure 17 and 18 - Non-carbonated beverages beverage carton and intersection beverage carton

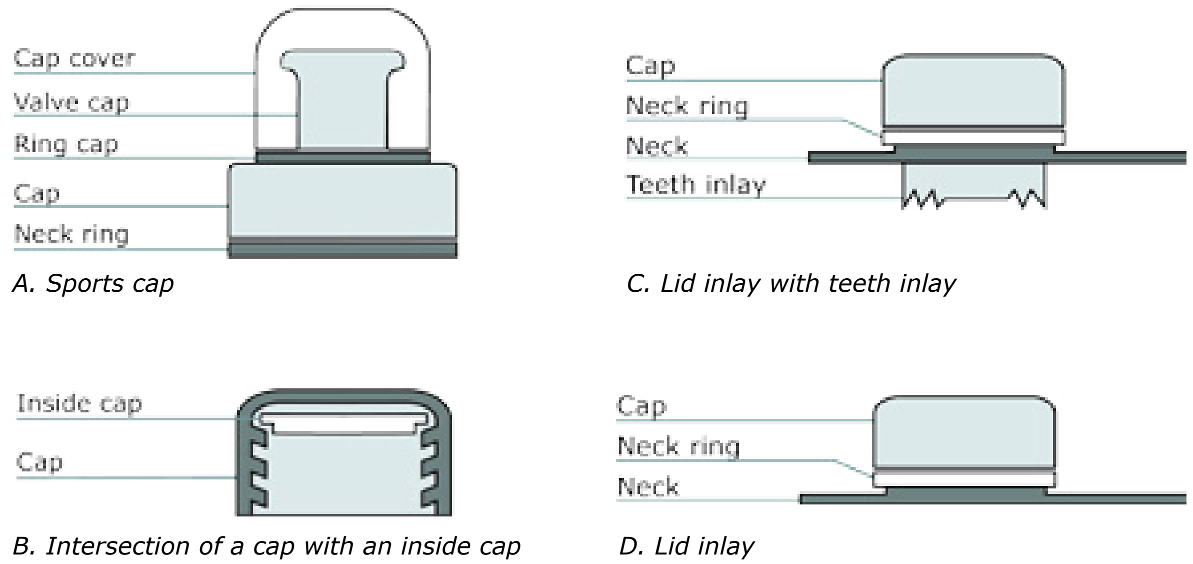


Figure 19 - Different types of caps.

2.2 MARKET SHARE

The market share of the products' packaging options in 2014 is found in the database Euromonitor. The data is based on the retail and off-trade volume of packages. Retail are companies that sell goods and services directly to the consumer. The off-trade means sales to food retailers like supermarkets etc. The percentages of soup, shower gels and non-carbonated beverages packages is based on the amount of packages and are shown in figure 20. Some percentages of categories are combined so it corresponds with the packaging options of the 3x3 matrix. The original data can be found in appendix 2.

Soups

The data of soups includes canned/preserved soup and UHT soup. This includes all varieties of soup in ready-to-eat or condensed (with water to be added) form which is not in chilled cabinets. Dried soups are not included in the analysis of Euromonitor. The total amount of soup packages are 164,10 million in the Netherlands. The 3x3 matrix covers over 99% of the packages volume. Only the group 'other plastic bottles' are not included in the matrix. This is corresponding with the data of the market analysis (see chapter 2.1).

Shower gels

The body wash and shower gel packaging is shown in figure 14. The total amount of packages in 2014 were 62,20 million. The majority of the packages are a HDPE bottle. In the data two categories are combined: 'HDPE bottles' and 'Squeezable Plastic Tubes'. Practice showed that the plastic tubes are made of HDPE. In the research to find the composition of packages these categories are also combined. Only 1.60% of the packages are not included in the 3x3 matrix. These are the categories ' Folding Cartons' and 'Glass Bottles'. In the market analysis these packages were not found. In the composition of packages research there were found some PP bottles which are not included in the data of Euromonitor.

Non-carbonated beverages

The amount of non-carbonated soft drink packages is 2496 million. This includes Asian specialty drinks, water bottles, concentrates, juice, sports and energy drink, Ready-to-drink (RTD) Coffee and RTD ice tea. Euromonitor's data does not specify on packages ≤ 0.5 litre but it is a sub-category. Additionally, in the market analysis alcoholic drinks are included which is not in the data of Euromonitor. Although the percentages are not complete it gives insight in the different packaging options and approximately the percentages. The matrix covers 93% of the total packages. The category beverage carton contains 'Brick Liquid Cartons', 'Gable Top Liquid Cartons' and 'Shaped Liquid cartons'. 'Metal Beverage Cans' and 'Metal Bottles' are took together in the category of metal cans. A lot package options are not included in the 3x3 matrix: 'HDPE bottles', 'Stand-Up Pouches', 'Other Plastic Bottles', and 'Thin Wall Plastic Containers' are taken together.

Non-carbonated beverages ≤0.5 litre is a very big and divers category. The content of these packages differ from juices and yogurt drinks to smoothies and wine. A recommendation is to specify the category of non-carbonated beverages. This gives probably a bigger coverage of the market share of that specific category. Further it will give more consistent results in the research. The market share of packages gives an good impression of the amount of packages on the market and the most commonly used packaging type per product. This is also input into the efficiency of mechanical recycling (see chapter 4.3).

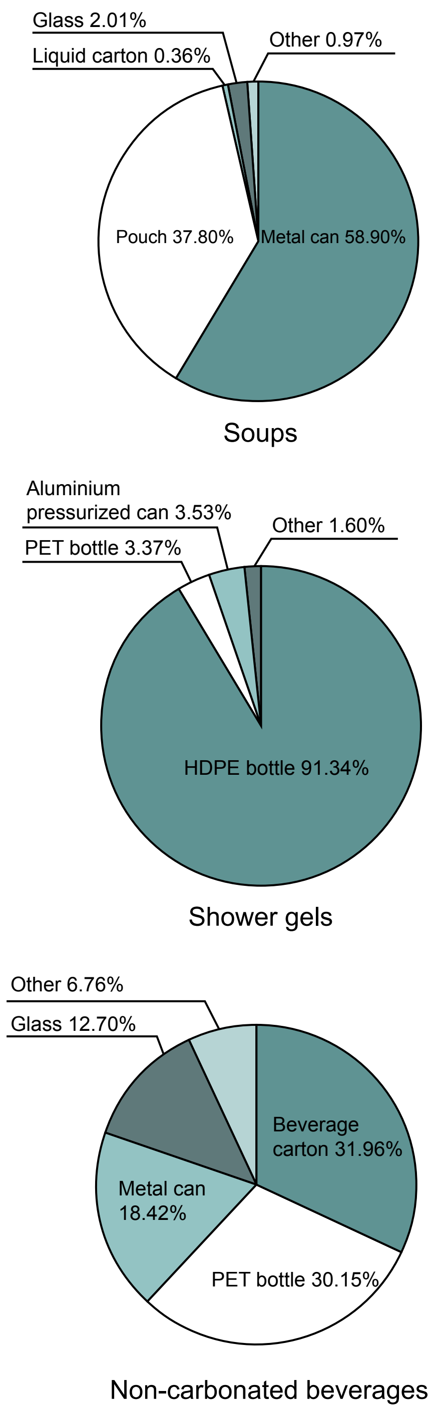


Figure 20 - Market share of soups, shower gels and non-carbonated beverages

3. COMPOSITION OF PACKAGES

In this research the composition of packages and the product residues are going to be measured. This will be an interesting research because the average composition of packages can be calculated. The product residues are also taken into account in this calculation. Another result of this research will be the extreme compositions of packaging. This will be input for making design guidelines but also for most of the work packages in the project Sustainable Packaging. The aim of this project is to measure the composition and product residues of the 3x3 matrix (see table 6). Glass is not included in this research.

Definition of the problem

i. What is the average and extreme composition of the 3x3 matrix?
ii. What is the percentage of the materials per packaging option of the 3x3 matrix?
iii. What is the interface between the materials? Can the materials easily been separated?
iv. What is the percentage of the product residues per packaging option of the 3x3 matrix?

3.1 METHODS AND MATERIALS

The material composition of every category of the following 3x3 matrix are determined by measuring the material content of at least ten, randomly selected, packages of that category. Data of PET bottles and beverage cartons are already available from previous researches of Wageningen UR Food and Biobased research. Some additional data is going to be added. Of these two packaging options there is more data collected.

People are asked to collect the packages of the matrix at home. In this way the packages have product residues inside and the outside of the packages are clean because the packages are collected directly after consumption. This gives insight to the dependent variable the residue inside the packages. The environment variable time between emptying the packages and measuring the packages is determined to be a maximum of one week. The aim is to test the packages as soon as possible after consumption. This because the residues will evaporate and dry in. The dependent variable materials are going to be measured on dry matter and described as a percentage of the total dry weight of the packages. All parts are going to be disassembled and weight independent from each other. The independent variables of this research are the packages of the 3x3 matrix.

Product	**Packaging material options**			
Soups	Metal can	Pouch	Liquid carton	Glass (optional)
Shower gel	HDPE bottle	PET clear rigid bottle	Aluminium pressurized can	
Non-carbonated beverages (≤ 0.5 litre)	PET bottle	Metal can	Beverage carton	Glass non-refill (optional)

Table 6 - 3x3 matrix of the project Sustainable Packaging

General test method:

The packages are studied indoors in a laboratory condition. In this research all packages have a general test method and each packaging option has its specific method. This because of the different materials and parts of each packaging option. The general test method and the specific test methods can be seen in appendix 3. Of all packages the trade name, manufacturer and the type product and volume are described. This information can be found at the label of the package. Besides the general information of the products the weight of the packages is measured with a scale. Next, the dirt and moisture are rinsed off. The clean packages are put in the oven at a temperature of 60°C degrees until dry. The dry weight is measured with a scale. The data found by weighing the packages are used to calculate the average the product residue per category of the 3x3 matrix. This will be calculated as shown in equation 1. Further all detachable parts of the packages are detached. The separate parts are dried and weighted. To check the measurements the total weight of the separate parts and the total dry weight is compared. If there is an difference of more than one percent, new measurements are done. The materials per category of the 3x3 matrix are calculated as described in equation 2. The calculation is based on the weighted arithmetic mean percentage over the weight per sample. This take into account the weight of the materials per sample in stead of only the average weight or the average percentage. For each category of the 3x3 matrix also a specific test method is made which can be seen in appendix 3 tables 1 to 6. The equations to calculate the average weight, standard deviation weight, minimum and maximum can be seen in appendix 4 equation 4.1 to 4.3.

$$PR = \sum Dirty - \sum Dry$$

Equation 1: Product residue

PR	Weight product residue [gram]
Dirty	Weight dirty packages [gram]
Dry	Weight dry and clean packages [gram]

$$WAM = \frac{\sum_{i=1}^{n}(t_i * d_i)}{\sum_{i=1}^{n} t_i}$$

Equation 2: Weighted arithmetic mean material content for a division

WAM	Weighted arithmetic mean material content for a division [%]
t_i	Weight of package [gram]
d_i	Percentage of material found in a division [%]

Soups – metal can

The test method of soups metal can can be seen in appendix 3 table 2. Metal cans can be separated in three parts: label, top and body. The body consist of the cylindrical can and the coating inside the can. The total dry weight of the body is weight with a scale. The weight of coating and metal is going to be calculated with additional information about the proportion of the market. The ratio of metal cans is in general 99,7% steel or aluminium and 0,3% is tin and coating (ter Morsche, de Olde, 2015). Because of the many different coatings only an average proportion is not available on the market. The calculation of the aluminium layer's weight can be seen in equation 3. The material of the body and the top is measured with a magnet. There are two different materials of the metal cans: aluminium and thin plate. The aluminium is not magnetic and the thin plate is. The labels are weighted and the material is defined. The top consist of the top, coating and, if present, an easy open tab and it is in total weighted with a scale.

$$m = A * h * \rho$$

Equation 3: Weight aluminium layer

m	Mass aluminium layer [gram]
A	Surface aluminium layer [cm^2]
h	Thickness (height) aluminium layer [cm]
ρ	*Density aluminium layer [gram/cm^3]*

Soups – pouch

The total weight of the pouch rinsed and dried is measured in the general test method of packages. A pouch does not have detachable parts which are made of other material. The ratio of the multiple layers in pouches is not available on the market. The solution First is looked if the aluminium is metallized or a layer. Aluminium foil cannot been seen through and through a metallized layer is this possible. The thickness of the aluminium foil layer is known: 7 µm (Thoden van Velzen, 2015). With the total weight of the package, thickness of the package, the package's surface and the density of the aluminium (2,702 g/cm^3) the weight of the aluminium layer can be calculated. The calculation of the aluminium layer is shown in equation 3 and 4. The remaining weight is of multiple plastic layers. With merely this information the weight of the individual plastic layers cannot be defined.

Soups – liquid carton

The total weight of the pouch rinsed and dried is measured in the general test method of packages. Liquid cartons do not have detachable parts which can be measured separately. The weight of the PE, aluminium and carton layers are going to be calculated with additional information about the proportion based on a previous study of Wageningen UR Food and Biobased research (Thoden van Velzen, 2013). This can be found on the market. Beverage cartons are made by several manufacturers. This is another manufacturer which makes the product inside of the beverage carton. The manufacturers are making different types of beverage cartons. Although liquid cartons does not have detachable parts a specific test method (see appendix 3 table 3) is made to identify the type of liquid carton. The proportion of the layers is determined by SEM imaging and disintegration in combination with sieving (Thoden van Velzen et al., 2013). These calculations are done for several beverage cartons of common brands, types and volumes. The percentages are generalised and are used to calculate the masses of all similar beverage cartons. A random survey is done to check if the product residues were measured right. In the cardboard there is usually moisture which evaporates when put in the oven. In the random survey the packages are dried at room temperature after which the package is weighted. After put in the oven the amount of natural moisture extra weight in dry weight beverage cartons can be calculated with equation 4. This percentage of the dry weight can be added to the dry weight to get the weight of natural moisture.

$$NM = \sum RT - \sum Dry$$

Equation 4: Weight of natural moisture in dry weight beverage cartons

NM	Weight of natural moisture in dry weight beverage cartons [gram]
RT	Weight room temperature dry packages [gram]
Dry	Weight dry and clean packages [gram]

Shower gels – aluminium pressurized can

Aluminium pressurized can consist of many detachable parts. The test method of the aluminium pressurized cans are shown in appendix 3 table 4. The cap, bag and valve are going to be weight. The proportion of the bag is defined the same as described in soups pouches (see equation 3).The can also consist of a coating which can be calculated with the proportion described in soups metal cans. Furthermore the weight and material of the packaging components are measured with a scale and NIR scanner.

Shower gels and non-carbonated beverage – PET bottle and HDPE bottle

The test methods of HDPE bottles and PET bottles are equal to each other and is shown in appendix 3 table 5. These bottles mostly have three different parts: label, cap and body. The dry weight of the body is measured with a scale. The colour of the body is described because the colour has influence in the recycling process described in chapter 5.1. The expire date could also have influence on the recycling process. The amount of packages with ink on body will be calculated (see equation 6) Currently is studied in the project PET recycling (Thoden van Velzen et al, 2015) that the expire date is printed with ink which could deteriorate the quality of the colour of recycled PET or HDPE. Of all detachable parts the material and weight are determined. Some bottles have a barrier to protect the product inside. In the project 'PET recycling' (Thoden van Velzen et all., not published yet) is tested if these packages discolour when exposed to high temperature. This to test if the bottles have a barrier. All bottles which discolour at high temperature have barriers but not all barriers discolour at high temperature. The results of this test will be taken into account in the results (see equation 7). All non-carbonated beverages are split up in 6 categories: Juices, sports drinks, water, coffee, ice tea and milk. The waters includes also the vitamin waters. Coffee includes all kinds of ice coffees. Among the milk category are the yoghurt drinks and chocolate drinks. This will be observed in the research and calculated with equation 8.

$$PIB = \frac{\sum IB}{\sum Total}$$

Equation 6: Amount packages with ink on body [%]

PIB	Amount packages with ink on body [%]
IB	Amount found in the division
Total	Total amount of packages

$$CB = \frac{\sum Coloured}{\sum Total}$$

Equation 7: Barrier test

CB	Amount of coloured bottles [%]
Coloured	Amount found in the division
Total	Total amount of packages

$$CT = \frac{\sum Division}{\sum Total}$$

Equation 8: Amount of content type [%]

CT	Amount of content type [%]
Division	Amount found in the division
Total	Total amount of packages

Non-carbonated beverage – metal can

The weight of the non-carbonated beverage rinsed and dried is measured in the general test method of packages. The metal cans do not have detachable parts which can be measured separately. The coating of the metal can is measured with the body. The weight and material of the coating is going to be calculated with additional information about the proportion. The same proportion is used which is described in soups metal can.

Non-carbonated beverage - beverage carton

The test method of non-carbonated beverage - beverage carton can be seen in appendix 3 table 6. There are two types of beverage cartons. First a beverage carton with a cap and a neck or second a beverage with a straw and a flow pack. The weights and materials of all detachable parts are determined. The composition of the body part is going to be calculated in the same way which is described in soups liquid carton. Also the amount of natural moisture is going to be calculated.

3.2 IMPLEMENTATION OF THE RESEARCH

The implementation of the research describes the execution of the research. All packages are tested according to the test methods described in methods and materials. Some unexpected things appeared which are described below. Pictures of conducting the research can be found in appendix 5.

Firstly the collection of some packages did not went well. People did not bring in enough soups packages, aluminium pressurized cans shower gels and metal cans of the non-carbonated beverages. A solution to this problem was to buy the products and hand out to people. An advantage of this solution is that the weight of the package with the content can be measured so the density of the product can be calculated. With this information the percentage of product residue is calculated.

A metal can with a neck, cap and inside cap is found in the non-beverage metal can products group. This was not expected in the test method. The weight of the cap and neck are determined with a scale. Also an aluminium pressurized can without a bag is found. In this package the propellant and the gel are combined and put in the can itself.

The NIR scanner did not recognize small and/or black plastic material. A few steps can be done to define the plastic material of the part. Firstly, a float- and sink test is done. PET has a density of 1.38 g/cm^3, PE of 0.90 g/cm^3 and PP of 0.92 g/cm^3. PE and PP float when put in water and PET sinks. This way the PET can be filtered out. Afterwards the PE and PP are put in the oven at 130˚C. PE got an average melting point of about 129˚C and PP of about 163˚C (CES EduPack, 2014). At a temperature of 130˚C the PE is melting and PP is not. An IR spectrum is made of the small pieces to see of which material it is made. A spectrum can be seen in figure 22 and all spectra made of the small pieces can be seen in appendix 6.

For some specific beverage cartons there are no data for material composition of the body generated. In such cases the data of the most similar beverage carton is used to calculate the composition or when more data is available of the same manufacturer the composition is calculated

In the end a total of 329 packages are measured. An overview of the amount of the individual packaging options can be seen in figure 21. The measured double packages are between parenthesis.

SOUPS	
Metal can	20 (0)
Pouch	10 (0)
Liquid carton	10 (0)
SHOWER GELS	
HDPE bottle	23 (2)
PET bottle	9 (0)
Aluminium pressurized-can	8 (0)
NON-CARBONATED BEVERAGES	
Metal can	18 (0)
PET bottle	102 (10)
Beverage carton	58 (69)

Figure 21 - Amount of measured packages.

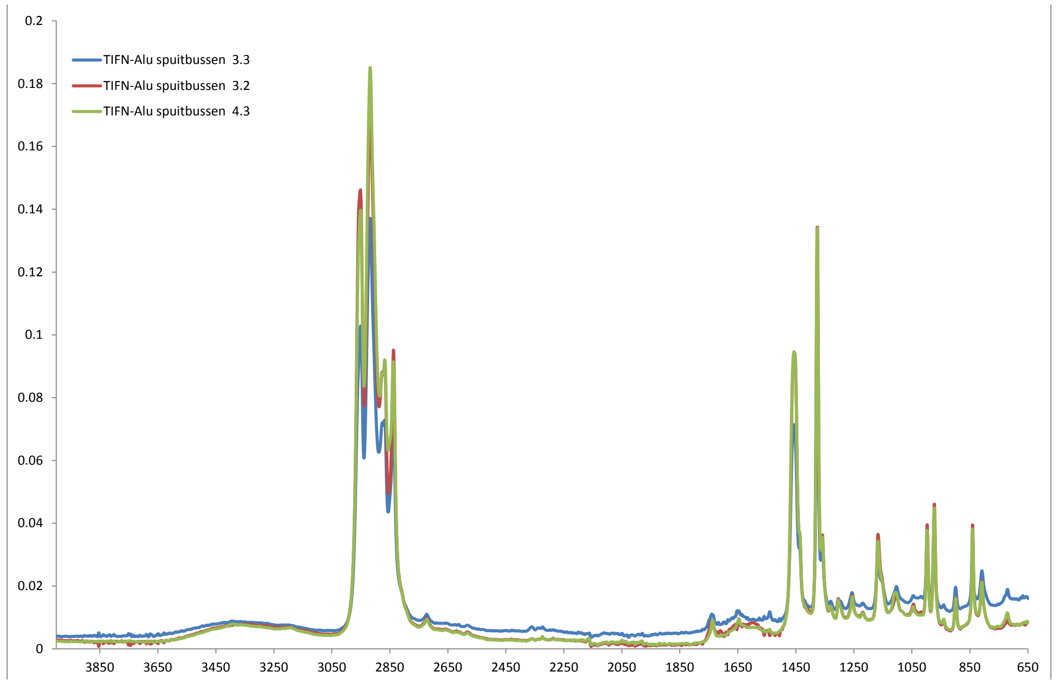


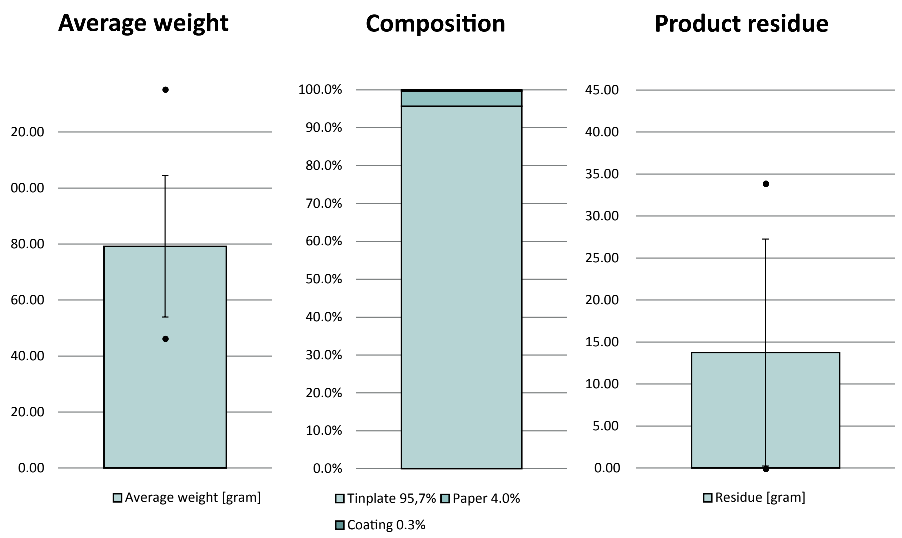
Figure 22 - NIR-spectra three parts of Polypropylene (PP)

3.3 RESULTS

All data is collected and analysed. The results of the data will be described here. The results of all packaging options includes at least the average weight, the average composition of packages and the average product residue. The composition is based on the weighted arithmetic mean per packaging type. The product residue is the weight of residual product. The double measured packages only will be taken into account to calculate the product residues. The graphs includes the standard deviation and the minimum and maximum.

Soups - metal can

In total twenty metal cans packages are measured. An overview of the results can be seen in figure 23. The average weight of metal cans is 79.2 gram. The average composition is 95.7% tin plate, 4.0% paper and 0.3% coating. The standard deviation, minimum and maximum can be seen in table 7. The ratio of coating and tin plate is assumed 0.3% and 99.7%. The product residue is measured at 19 packages and has a average of 13.74 gram. This is the percentage of residual product. The average density, measured over nineteen packages, is 1.16 gram/ml.



Assumptions:

Average weight
- n=20

Composition
- n=20
- Ratio coating and tin plate 0.3% and 99.7%

Product residue
- n=19
- Density content ρ=1.16 {n=19}

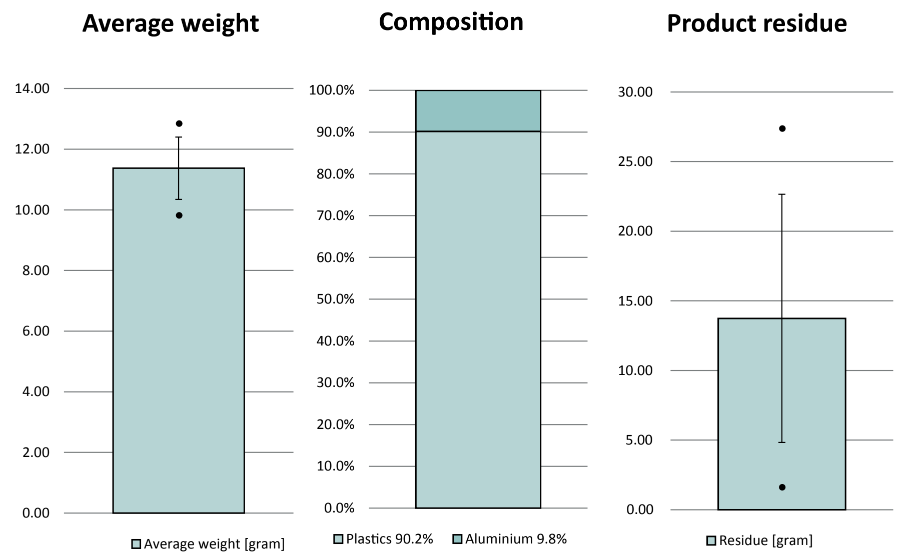
Figure 23 - Overview of the results soups metal can

Soups metal can	Total weight [gram]	Tin plate [gram]	Paper [gram]	Coating [gram]
Average	79.17	75.75	3.19	0.23
Standard deviation	25.24	24.17	1.05	0.07
Minimum	46.87	45.12	1.61	0.14
Maximum	134.59	128.31	5.89	0.39

Table 7 - Average, standard deviation, minimum and maximum of the soups metal can composition

Soups- pouch

In total ten packages are measured packages. The average weight of pouches is 11.4 gram. Also the average composition of packages is calculated. It is assumed that the thickness of the aluminium is 7 µm and a density of 2.7 gram /ml. The composition is 9.8 % aluminium and the remaining 90.2% are plastics. The plastics are not more detailed in this research. The standard deviation, minimum and maximum are shown in table 8. Two packages did not exist of an aluminium layer so this declares the large standard deviation and low minimum. The average product residue is 11.08 gram. This is calculated with a measured density of 1.03 gram/ml (n=10). An overview of the results can be seen in figure 24.



Assumptions:

Average weight
- n=10

Composition
- n=10
- Thickness of the aluminium layer 7 µm.
- Density aluminium ρ=2.7 gram/cm^3

Product residue
- n=10
- Density content ρ=1.03 gram/ml {n=10}

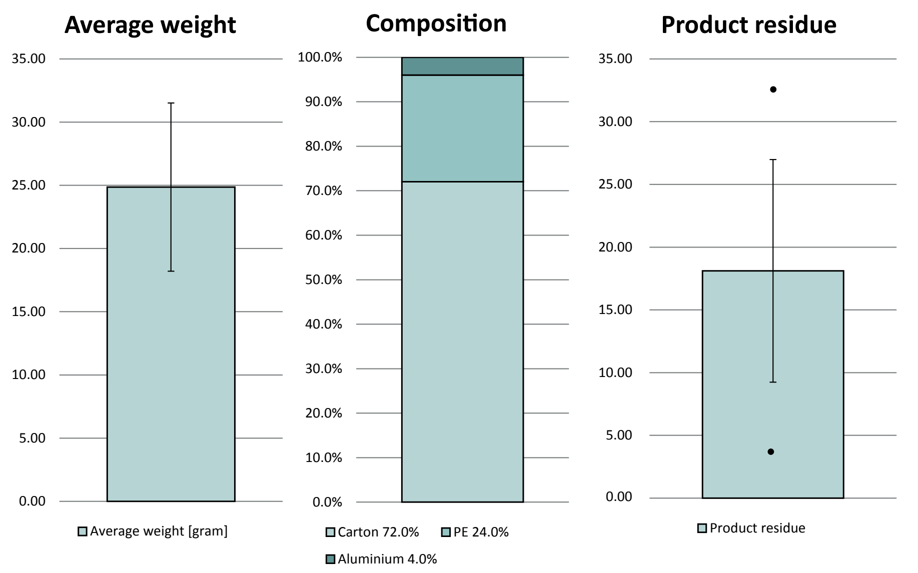
Figure 24 - Overview of the results soups pouch

Soups pouch	Total weight [gram]	Weight aluminium [gram]	Weight plastics [gram]
Average	11.37	1.12	10.25
Standard deviation	1.03	0.59	0.57
Minimum	9.54	0.00	9.54
Maximum	12.87	1.40	11.47

Table 8 - Average, standard deviation, minimum and maximum of the soups pouch composition

Soups- liquid carton

In total ten packages are measured. An overview of the results can be seen in figure 25. The average weight is 24.9 gram. The composition of liquid carton is based on a previous research of the Wageningen UR (Thoden van Velzen et al., 2013). The average composition of a liquid carton is 72.0% carton, 24.0% PE and 4.0% aluminium. The average weight, minimum and maximum per material type are shown in table 9. The product residue and the density of 1.08 gram/ml is measured at eight packages. The average leftover in a liquid carton package is 18.11 gram. Besides, at two packages the natural moisture is calculated. 1.00 gram of the dry package weight is natural moisture.



Assumptions:

Average weight
- n=10

Composition
- n=10
- Ratio packages: carton, aluminium and PE. (Thoden van Velzen et al. 2013)

Product residue
- n=8
- Density content ρ=1.08 gram/ml {n=8}

Natural moisture
- n=2

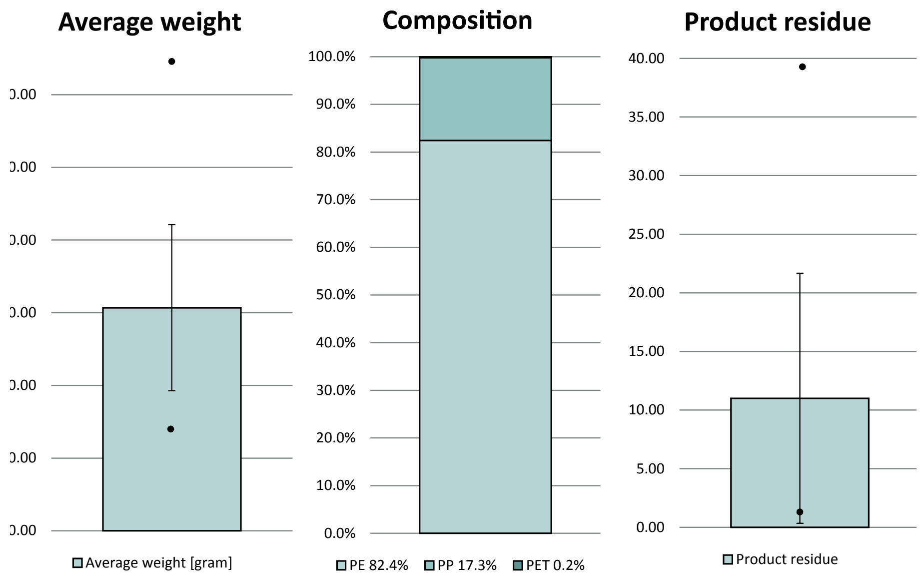
Figure 25 - Overview of the results soups liquid carton

Soups liquid carton	Totaal weight [gram]	Weight carton [gram]	Weight PE layer [gram]	Weight aluminium layer [gram]	Natural moisture [gram]
Average	24.86	17.91	5.95	0.99	1.00
Standard deviation	6.67	4.86	1.63	0.27	0.13
Minimum	11.90	8.53	2.90	0.48	0.91
Maximum	28.54	21.38	7.14	1.14	1.09

Table 9 - Average, standard deviation, minimum and maximum of the soups liquid carton composition

Shower gels - HDPE bottle

A total of twenty-five HDPE bottles are measured of which doubles. An overview of the results are shown in figure 26. The average weight of the packages is 30.7 gram. In the twenty-three composition measurements bottles is assumed that these bottles does not have coatings or barriers. The ratio of materials is in HDPE shower gel bottles 82.4% PE, 17.3% PP and 0.2% PET. The PET percentage is one label of a HDPE bottle. The remaining material is only PP or PE. The average weight, minimum and maximum per material type are shown in table 10. The product residue is calculated with an density of 1.16 gram/ml. This is measured at two PET bottles which will have the same sort of content as HDPE bottles. An average of 11.01 gram will be residue. This amount is a result of measuring twenty-five packages.



Assumptions:

Average weight
- n=23

Composition
- n=23
- No coating

Product residue
- n=25
- Density content ρ=1.16 gram/ml {n=2 shower gel PET-bottle}

Figure 26 - Overview of the results shower gel HDPE bottle

Shower gel HDPE bottle	Total weight [gram]	PP [gram]	PE [gram]	PET [gram]
Average	30.69	5.32	25.30	0.07
Standard deviation	9.23	3.69	10.96	0.34
Minimum	14.15	0.00	9.93	0.00
Maximum	64.70	9.28	64.70	1.62

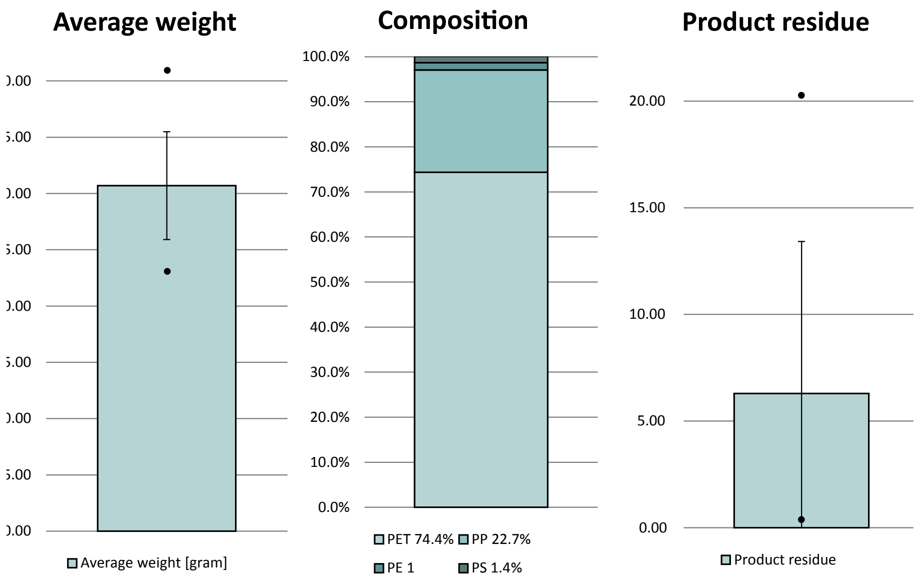
Table 10 - Average, standard deviation, minimum and maximum of the shower gel HDPE bottle composition

Shower gel - PET bottle

A total of nine packages are measured. An overview of the results can be seen in figure 27. The average weight is 30.7 gram. In the composition measurements is assumed that the PET bottles do not exist of a coating or a barrier. The average composition of the PET bottle is 74.4% PET, 22.7% PP, 1.6% PE and 1.4% PS. The standard derivation, minimum and maximum composition can be seen in table 11. The PS percentage are two decorative lids at the cap. The PE material only shows op in some labels. The caps are mostly made of PP. Two PET shower gel bottles are emptied by myself. This could influence the product residue. The average product residue is 6.29 gram.

Shower gel - Aluminium pressurized can

In total eight aluminium pressurized cans are measured. An overview of the results can be seen in figure 28. The average weight is 40.6 gram. In the composition measurements it is assumed that the thickness of the aluminium is 7 μm and a density of 2.7 gram /ml. The average composition of the aluminium pressurized can is 78,1% aluminium, 11.6% PP, 1.3% PE, 0.1% POM, 0.3% PA, 1.2% rubber, 0.5% metals and 6.7% plastics. The plastics of the bags inside the can is not detailed in this research. The standard deviation, minimum and maximum composition are shown in table 12. One bottle did not have a bag inside the can. In this can the gel and propellant was mixed. The product residue was measured at nine aluminium pressurized cans of which I emptied five by myself. The average product residue is 9.69 gram.



Assumptions:

Average weight
- n=9

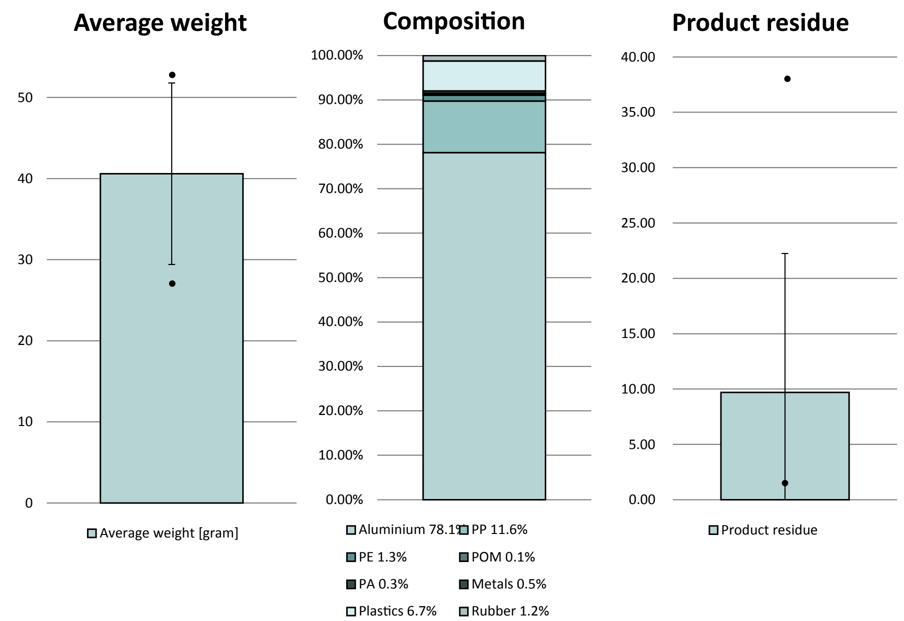
Composition
- n=9
- No coating

Product residue
- n=9
- Density content ρ=1.16 gram/ml {n=2}
- Emptied two packages by myself

Figure 27 - Overview of the results shower gel PET bottle

Shower gel PET bottle	Total weight [gram]	PET [gram]	PP [gram]	PE [gram]	PS [gram]
Average	30.70	22.82	6.96	0.49	0.43
Standard deviation	4.79	4.28	1.19	0.61	0.85
Minimum	23.74	18.93	4.81	0.00	0.00
Maximum	40.73	32.95	8.44	1.29	1.95

Table 11 - Average, standard deviation, minimum and maximum of the shower gel PET bottle composition



Assumptions:

Average weight
- n=8

Composition
- n=8
- Thickness of the aluminium layer 7 µm.
- Density aluminium ρ=2.7 gram/cm³

Product residue
- n=8
- Density content ρ=1.25 gram/ml {n=5}
- Emptied five bottles by myself

Figure 28 - Overview of the results shower gel aluminium pressurized can

Shower gel aluminium pressurized can	Total weight [gram[	PE [gram]	PP[gram]	POM [gram]	PA [gram]	Aluminium [gram]	Rubber [gram]	Metal [gram]	Plastics [gram]
Average	40.59	0.53	4.72	0.05	0.14	31.71	0.51	0.20	2.74
Standard deviation	11.19	0.45	0.53	0.05	0.19	10.07	0.04	0.12	1.48
Minimum	27.80	0.00	4.24	0.00	0.00	19.89	0.42	0.08	0.00
Maximum	52.29	0.97	5.53	0.10	0.54	42.67	0.54	0.32	4.28

Table 12 - Average, standard deviation, minimum and maximum of the shower gel aluminium pressurized can composition

Non-carbonated beverages ≤0.5 litre

The content of non-carbonated beverages ≤0.5 litre are very divers. The content type is also observe in the analysis. The contents can be split up in six different categories: Juices, sports drinks, water, coffee, ice tea and milk. The waters includes also the vitamin waters. Coffee includes all kinds of (ice) coffees. Among the milk category are the yoghurt drinks and chocolate drinks. The division of contents in the different packaging options can be seen in figure 29. In the research the alcoholic drinks are excluded.

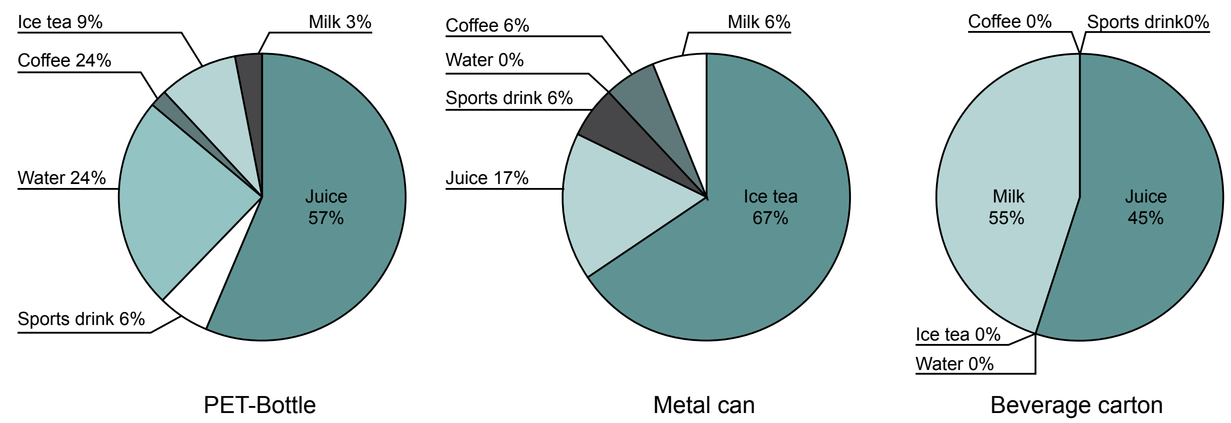
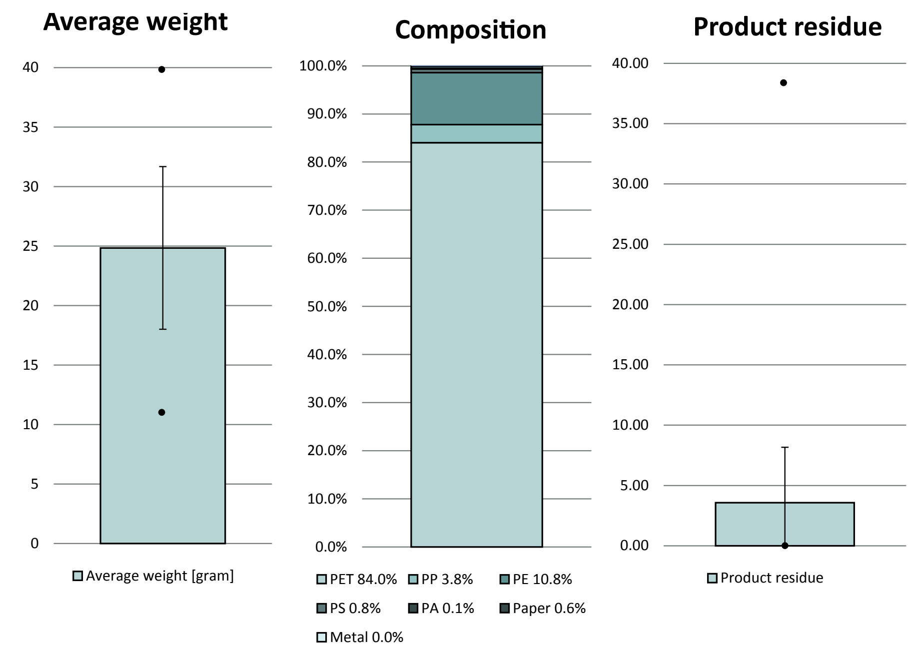


Figure 29 - Contents of non-carbonated beverage cartons ≤0.5 litre

Non-carbonated beverage - PET bottle

A total of 112 bottles are measured of which 10 doubles. An overview of the results can be seen in figure 30. The average weight is 24.8 gram. This is calculated on basis of 102 measurements. The average composition of non-carbonated beverages PET bottles is 84.0% PET, 3.8% PP, 10.8% PE, 0.8% PS, 0.1% PA, 0.6% paper and 0.0% metal. The measurements of the composition is also done at 102 bottles. The standard deviation, minimum and maximum composition are shown in table 13. The percentage of bottles with ink on the body is 47%. In the remaining percentage the ink is placed at another place or/and the expire date is printed with a laser. The volume and intensity of the ink is not tested. The percentage of ink on body could influence the recycling process. A further study to this subject could be interesting. In the project 'PET recycling' (Thoden van Velzen et al., not published yet) is tested if these packages discolour when exposed to high temperature. This to test if the bottles have a barrier. All bottles which discolour at high temperature have a barrier but not all barriers discolour at high temperature. The percentage of coloured bottles is 8% of 102 bottles. At least of 98 bottles the product residue is measured. The average product residue is 3.58 gram.



Assumptions:

Average weight
- n=102

Composition, discolouration, ink on body
- n=102

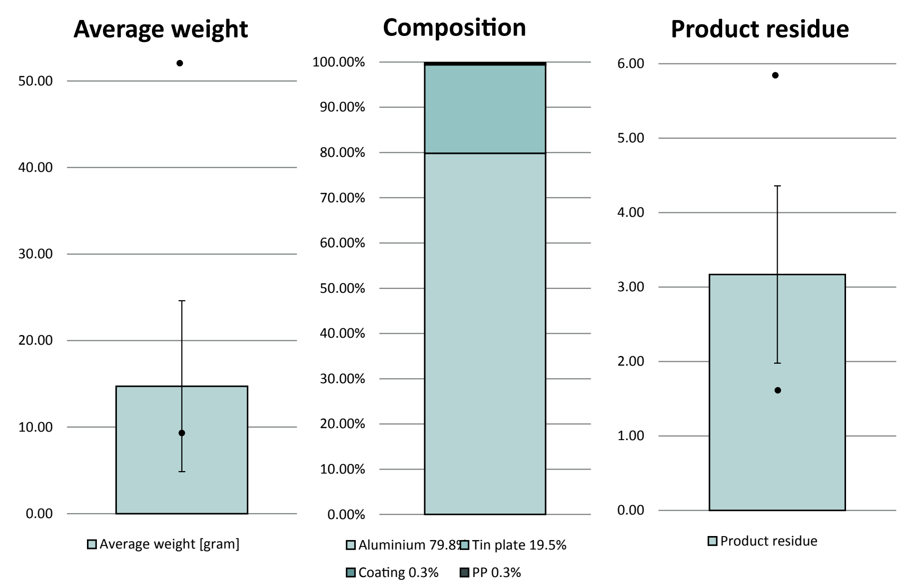
Product residue
- n=98
- Density content ρ=1.00 gram/ml {water}

Product type
- n=102
- Juices/sports drink/water/coffee/ice tea/milk

Figure 30 - Overview of the results non-carbonated beverages ≤0.5 litre PET bottle

Non-carbonated beverages PET bottle	Total weight [gram]	PET [gram]	PP [gram]	PE [gram]	PS [gram]	PA [gram]	Paper [gram]	Metal [gram]
Average	24.84	20.87	0.93	2.68	0.19	0.02	0.14	0.00
Standard deviation	6.84	6.66	1.61	1.33	0.57	0.18	0.38	0.03
Minimum	11.14	9.55	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	39.56	35.05	5.21	5.39	2.59	2.17	1.76	0.21

Table 13 - Average, standard deviation, minimum and maximum of the non-carbonated beverages ≤0.5 litre PET bottle composition



Assumptions:

Average weight
- n=18

Composition
- n=18
- Ratio coating and tin plate 0.3% and 99.7%

Product residue
- n=18
- Density content ρ=1.06 gram/ml {n=2}

Product type
- n=18
- Juices/sports drink/water/coffee/ice tea/milk

Figure 31 - Overview of the results non-carbonated beverages ≤0.5 litre metal can

Non-carbonated beverages metal can	Total weight [gram]	Aluminium[gram]	Tinplate [gram]	Coating [gram]	PP [gram]
Average	14.73	11.76	2.88	0.04	0.05
Standard deviation	9.88	4.33	12.22	0.03	0.20
Minimum	9.33	0.00	0.00	0.03	0.00
Maximum	51.98	22.81	51.82	0.16	0.84

Table 14 - Average, standard deviation, minimum and maximum of the non-carbonated beverages ≤0.5 litre metal can composition

Non-carbonated beverage - metal cans

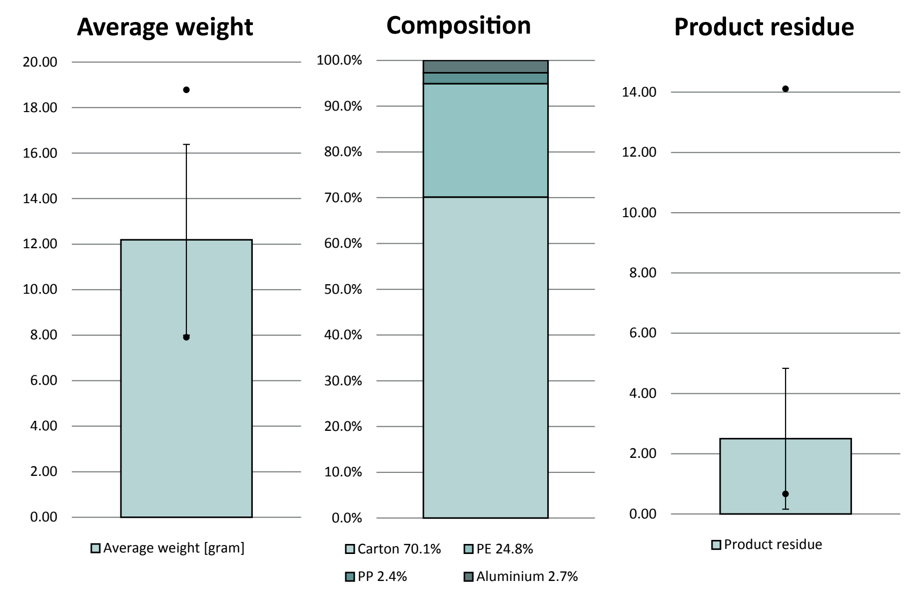
A total of eighteen metal cans are measured. An overview of the results can be seen in figure 31. The average weight is 14.7 gram. The ratio of materials in metal cans is 79.8% aluminium, 19.5% tin plate, 0.3% coating and 0.3% PP. It is assumed that the ratio coating and body is 0.3% and 99.7% The standard deviation, minimum and maximum of the composition can be seen in table 14. One metal can was made of tin plate which influences the weights because the tin plate is heavier than aluminium. Besides, this influences the composition percentages too. One metal can had a cap with an inside cap made of PP. The product residue is 3.17 gram. This is measured at eighteen packages.

Non-carbonated beverage - beverage carton

A total of 127 packages is measured of which 69 doubles. An overview of the results can be seen in figure 32. The average weight is 12.2 gram. he composition of liquid carton is based on a previous research of the Wageningen UR (Thoden van Velzen et al., 2013). The average composition of a liquid carton is 70.1% carton, 24.8% PE, 2.4% PP and 2.7% aluminium. The standard deviation, minimum and maximum composition are shown in table 15. The beverage cartons can be subdivided into a straw sipped beverage carton (Tetrapak Tetrabrik and SIG Combibloc) and a beverage which can be poured out when the consumer wants to drink (Elopak Diamond and Elopak PurePak). The average composition of the Tetrabrik and Combibloc packages is 66.4% carton, 23.0% PE, 5.0% PP and 5.7% aluminium. The average composition of the Diamond and PurePak packages is 73.6% carton and 26.4% PE see figure 33. The average product residue, based on 75 packages, is 2.50 gram. Besides, at nine packages the natural moisture is calculated. 2.4 gram of the dry package weight is natural moisture.

Product residue

Of all packaging options the product residue is measured. The relation between volume of the product content and the weight of the product residue can be seen in appendix 8. The trend lines of the graphs show how the residue increase or decrease when the volume gets bigger. In three of nine cases the trend line shows a decreasing relation. These are the packaging options soups liquid carton, shower gel PET bottle and non-carbonated beverages metal can. The pouches do not have a trend line because the measured packages all have the same volume. The dispersion in the graph shows that some volumes are measured more than others. This influences the trend line in the graph a lot. Also it could be that the product residue does not only depends on the volume of the package but also more variables. This could be for example the size of the opening. Due to this uncertainties no conclusions are made.



Assumptions:

Average weight
- n=58

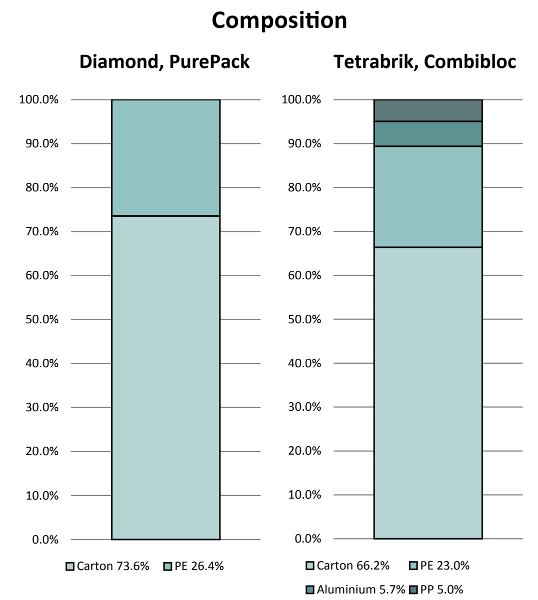
Composition
- n=58
- Ratio packages: carton, aluminium and PE. (Thoden van Velzen et al. 2013)

Product residue
- n=75
- Density content ρ=1.00 gram/ml {water}

Natural moisture
- n=9

Product type
- n=58
- Juices/sports drink/water/ coffee/ice tea/milk

Figure 32 - Overview of the results non-carbonated beverages ≤0.5 litre beverage carton



Assumptions:

Diamond, PurePack
- n=21
- Ratio packages: carton, aluminium and PE. (Thoden van Velzen et al. 2013)

Tetrabrik, combibloc
- n=37
- Ratio packages: carton, aluminium and PE. (Thoden van Velzen et al. 2013)

Figure 33 - Composition of two different types of beverage cartons

Non-carbonated beverages beverage carton	Total weight	Massa Karton [gram]	Massa PE [gram]	Massa PP [gram]	Massa aluminium [gram]	Natural moisture [gram]
Average	12.19	12.19	8.55	3.02	0.29	2.40
Standard deviation	4.19	4.19	3.36	1.40	0.27	1.75
Minimum	7.99	7.99	5.37	1.70	0.00	0.66
Maximum	18.77	18.77	13.78	5.25	1.44	7.03

Table 15 - Average, standard deviation, minimum and maximum of the non-carbonated beverages ≤0.5 litre beverage carton composition

3.4 DISCUSSION AND CONCLUSION

The aim of this research was to measure the composition and product residues of the 3x3 matrix. To achieve this test methods are formed. All packaging options' average composition, weighted average weight and the percentage of product residue are calculated. An overview of the composition per packaging type can be seen in figure 34. The average natural moisture in beverage cartons is 2.40 gram and liquid cartons is 1.00 gram. The natural moisture raises the results of the product residue. This has to be subtracted. The non-carbonated beverage cans has many different contents.

The internal validation of measuring the packages is good. The measurements are done by reliable instruments. Some materials which cannot been detected with the arranged measuring method or other methods were assumed. The composition of the metal cans was an estimation of the market. The extreme values of the ratio between coating and body is not measured. Besides, the layers of the pouches could not be determined and the ratio of the layers were not available at the market. The calculated averages of these packages are not completely reliable. In further research these ratios could be investigated per package.

The external validation is not good in all packaging options. Soups pouch, soups liquid cartons, shower gel aluminium pressurized can and shower gel PET bottle had a survey smaller or equal to 10. All these packages were representative of the market but some had big differences in the results. The calculated averages of these packages are not completely reliable. The consistency of measuring the packages was very good. All packages per packaging option were measured in the same way at the same points. Only the full weight and the product residue is not always measured. This is because of the full weight of packages could only been measured when the packages were bought. The product residue was not measured in the data of previous researches. The environment variable time was hard to control. The time between emptying the packages and measuring the packages is determined to be a maximum of one week. But in practice the time between emptying and hand in the package was not controllable. This was sometimes probable more than a week because some moulds grew and/or the product was dried in. Although this will be representative for the recycling process because in the recycling process the packages would not always be recycled within one week.

3.4 RECOMMENDATIONS

Recommendations to the composition research:

- Include glass in the research.
- In general metal cans have a ratio of aluminium and coating. This is done because there is no additional information available. In further research also the coating can be measured. For example put the metal cans in the oven. The coating burns and the aluminium remains. This way the weight of the coating can be measured. The extreme values are very interesting in this research.
- Execute more measurements about the natural moisture in beverage cartons. I only did two measurements in the category of soups liquid cartons and nine in the non-carbonated beverage ≤0.5 litre beverage cartons category. This is not completely reliable.
- Execute more measurements about the product residue. The measurements have to be done at different volumes to see a good relation between the volume of the product content and the weight of the product residue.
- Execute more measurements about the packaging . This especially in the categories with less than or equal to ten samples.
- Other researches which could be interesting to execute are a research of the influence of ink on body in the recycling process and/ or the influence of barriers in the recycling process.

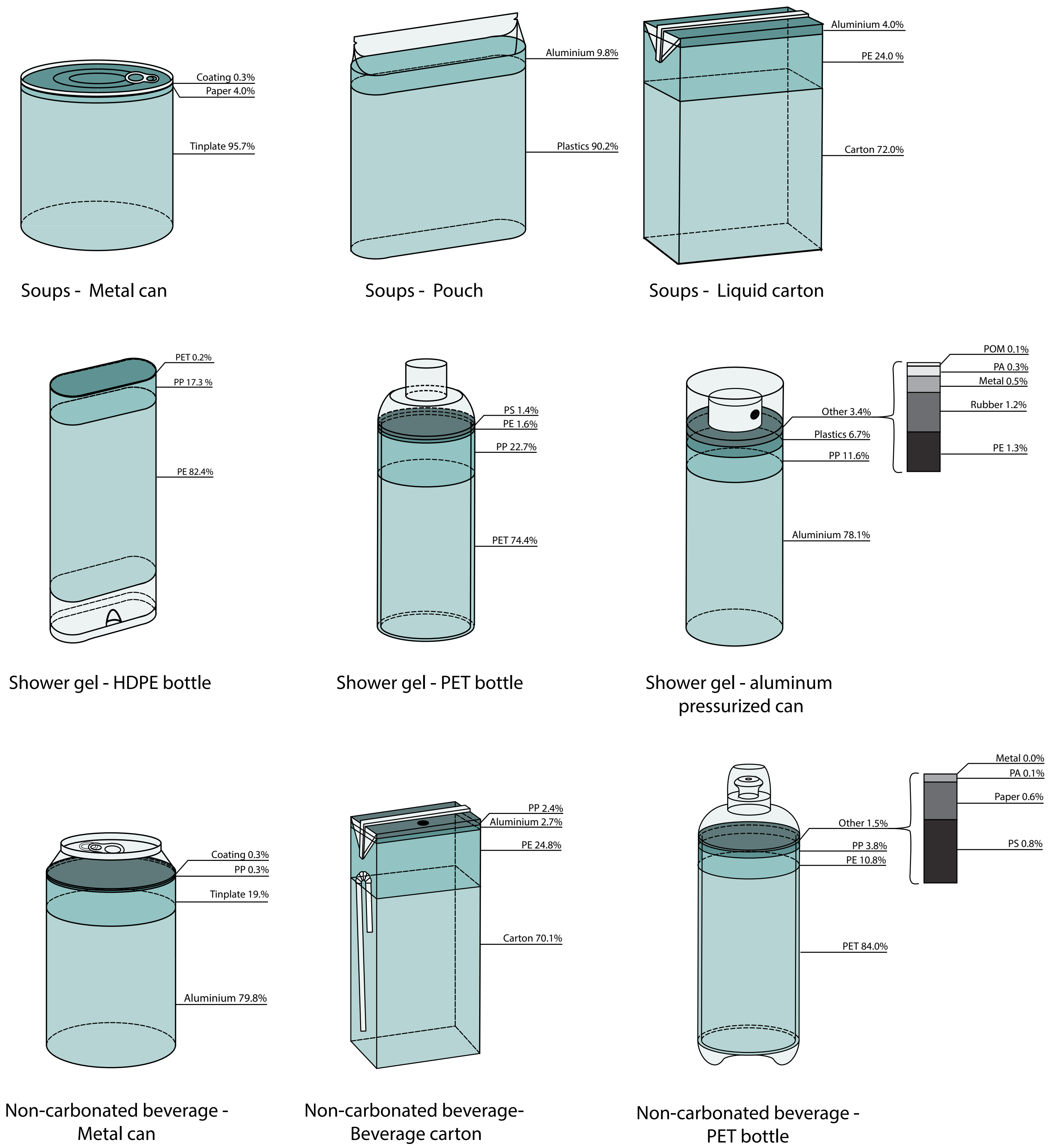


Figure 34 - Overview of the compositions per packaging option

4. RECYCLING IN PRACTICE

This chapter will explain how the individual packages of the 3x3 matrix are processed after consumers have discarded them. In the Netherlands all the municipal solid waste (MSW) is collected and incinerated, metals are recovered from the bottom ashes of the municipal solid waste incinerations. Besides, several separate collection systems have been established. This applies to glass and paper & board packages and a deposit refund system for large (>0.5 ltr) PET bottles and glass beer bottles. Since 2008 also a separate collection system for plastic packaging waste was established and simultaneously three mechanical recovery facilities started to recover plastic packaging waste from MSW. The separate collected or mechanically recovered packaging materials are recycled into packages and various other objects. The recycling system is regarded as an act of saving virgin raw materials which convey to environmental benefits. The general recycling chain can be seen in figure 35. The rigid plastic packages of the facility are going to sorting facilities and the foil are directly into mechanical recycling.

This chapter will try to resolve the question of how the packages of the 3x3 matrix will distribute over the various collection systems and what their distribution of End-of-Life fates will be. In other words, what percentage of a certain package is likely to be recycled, what percentage will be incinerated etc.

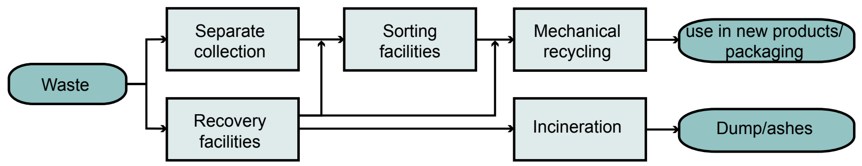


Figure 35 - General recycling chain

4.1 COLLECTION

The packages of the 3x3 matrix will divide over the separately collected packages and municipal solid waste. What is the law of collecting packages and which packages are collected separately? There are a lot of tools how to separate waste easily. A example is recyclemanger.nl. The data of municipalities and institutions which collect and process waste is merged and shown at recyclemanger.nl. The goal of these initiatives is to make waste separation as easy as possible for the consumer.

The Dutch law of environmental control (Wet Milieubeheer, 1979) states that municipalities are responsible for collecting and processing waste in their own council land. Article 10:21 to 10.29 states that the municipality must take care of the collection of domestic waste at least once a week. The way of collection is not determined by law therefore the collection varies per municipality. Collection of waste could be kerbside collection or drop-off collection. This is door-to-door collection or a central point in the street. There must be at least one waste disposal centre where bulky household waste can be delivered. Besides that municipalities must collect separately plastic, glass, paper and board and small chemical waste. All collection regulations are in the National Waste Management Plan (Landelijk afvalbeheerplan LAP, 2003).

Metal cans

Metal cans are not commonly collected separately. Metal cans cover the non-carbonated beverages metal can, soups metal can and shower gels aluminium pressurized can. These packages could be separated with metal can bins or bags. When the municipality does not separate metal cans the package can be thrown away with the residual waste. Before or after the incineration the metal cans are retrieved with magnets out of the waste. This differs per recovery facility.

Plastic packages

Plastic packages include PET bottle, shower gels PET and HDPE bottle. There are multiple ways of separating plastics which depends on the municipality. The collection system of plastic waste is Plastic Heroes (see figure 36). This is an initiative of packaging manufacturers in the Netherlands to make the waste separation as easy as possible for the consumer. Plastics can be deposited in special Plastic Heroes bins. Other municipalities do kerbside collection. There are also municipalities which choose to recover the plastic packages from MSW.

Figure 36 - Logo Plastic Heroes

Beverage cartons

Since 2015 liquid cartons can increasingly be separated for recycling. When the municipality is not collecting liquid cartons separately the packages go with the residual waste and not with the paper and board stream. Some municipalities are collecting liquid cartons together with paper and board. In the recovery facility the paper and liquid cartons are sorted out.

Combination

A part of the municipalities are combining the collection of plastic waste with liquid cartons, liquid cartons with metal cans or plastics metal cans and liquid cartons (PMD). In the sorting facilities these waste streams are separated.

Glass

An additional packaging option of the 3x3 matrix is glass. This includes soups and non-carbonated beverages. These packages can be deposited in the glass recycling bin or at the waste deposit centre. The covers and the body can be thrown away together. Only packaging glass is allowed to be thrown away in the glass recycling bin others must be deposited at the waste deposit centre.

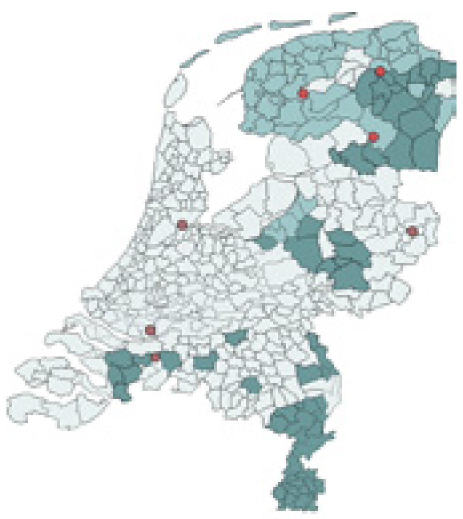
Residual waste

The residual waste is waste which is not recycled yet. This waste is (sometimes) going to recovery facilities where the recyclable materials are sorted out. The waste which cannot be separated will be burnt in incinerators to generate energy. This way even residual waste is recovered.

The products of the 3x3 matrix can be collected separately into glass, liquid cartons, plastic packages, metal cans and residual waste. The plastic packages will be input for plastic sorting facilities and facilities where the waste is purified. The residual waste is going to recovery facilities.

4.3 RECYCLING PROCESSES

In the recycling processes the glass packaging materials is excluded. The CE Delft did, in commission of the Vereniging Afvalbedrijven, a comparative research to plastic recycling. The result is that both source separation and recovery are better for the environment than incineration. A combination of source separation and recovery has the best environmental returns (Attero, n.d). Besides, Attero states that this also applies to all waste streams. In figure 37 can be seen which municipalities are source separating, doing recovery or combine both (Corijn et al., 2015). This is a general overview of the separation method per municipality and does not directly tell something about the recycling results per municipality. At the moment there are not many municipalities which are separating in both manners. The red dots are the current operational recovery facilities. The brown dots are the planned or expected recovery facilities in the future. The percentage of plastic recycling in 2014 and the estimated percentage in the future can be seen in figure 39 (Corijn et al., 2015).



- *Source separation*
- *Recovery*
- *Combination of source separation and recovery*
- *Current operational recovery facilities*
- *Expected/planned recovery facilities*

Figure 37 - Source separating, recovery or combination of both.

The estimation is that the amount of plastic recycling will increase from 120000 ton in 2014 to 175000 ton when all the planned recovery facilities are realised. The amount in tons is inclusive clinging organics and product rest. The “Afvalfonds Verpakkingen” illustrates in figure 38 the growth of plastic recycling over seven years (van der Meulen, n.d.). Also the multiple collection options can be seen. The amount in tons are clear plastic packages.

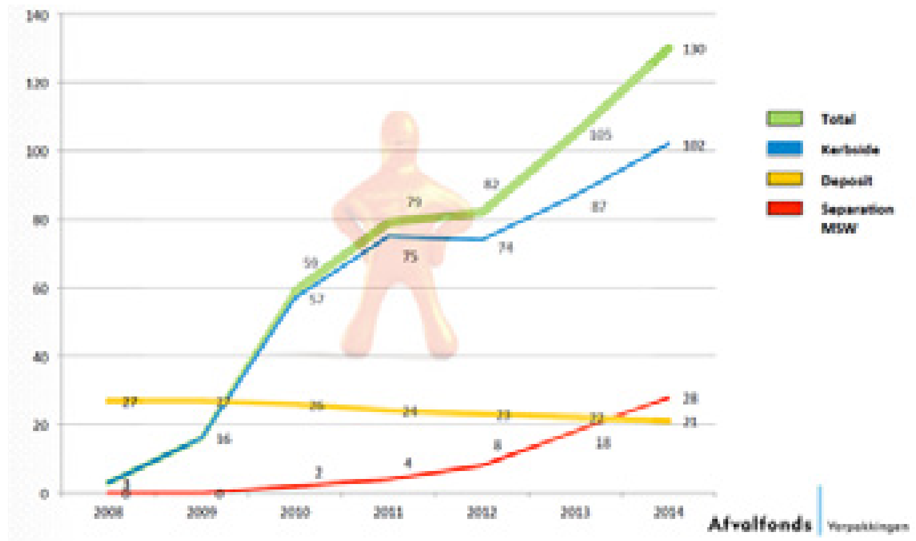


Figure 38 - Growth of plastic recycling from 2008 to 2014. Amount of plastic waste is in kton

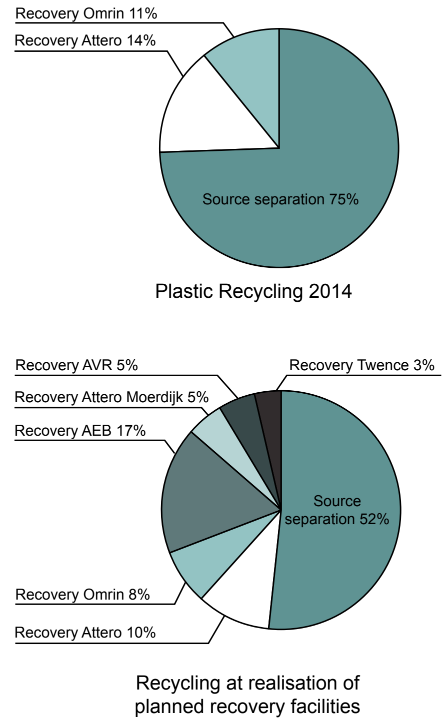


Figure 39 - Percentage of plastic recycling in 2014 and in the future

Recovery

The residual waste is going to recovery facilities. As said earlier, all facilities have their own process and configuration of separation machines. The simplified process of Omrin in Oudehaske and Attero Noord in Groningen are described in appendix 8.1 (Thoden van Velzen et al., 2013). A general process of recovery facilities, which can be seen in figure 40, is made on basis of these two facilities. The simplified processes only describe the longest process through a facilities and which waste is separated. The branches of the simplified process are mostly going through more machines which are not described here. Recovery facilities mostly separate coarse materials, fine materials, films, metals, non-ferrous materials, beverage cartons and plastic. The remaining waste is in refuse derived fuel (RDF) where the waste is burned and energy is generated.

The separation process is done by multiple separation machines. Firstly, the waste is deposited into a large storage point. The waste is moved onto a conveyor belt that transports the waste into a debaling process. Rotating metal pins open the bags and keeping the material inside intact. When the bags are opened the waste is going to a coarse and fine screen.

Screens are separating the waste on basis of geometry, the smaller parts fall through the screen and the bigger parts does not. The coarse screens are 200 - 250 mm and the fine screens differ from 50 to 70 (Thoden van Velzen, 2015). The coarse materials can be separated in three categories; Fe coarse, films and the remaining materials are going to RDF. The fine materials also can be separated in three categories; organics, Fe fine and non-ferrous material.

The materials with an dimension between 50/70 mm and 200/250 mm will go further to the air classifiers. Air classifiers are separating the waste on basis of size, shape and density. The waste stream is going underneath the air classifier

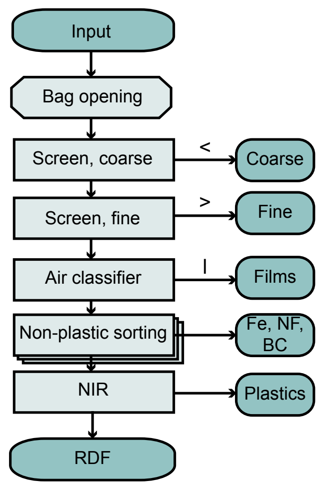


Figure 40 - General process of recovery facilities.

which is containing a column of rising air. Due to the dependence of air drag on object size and shape, the films will be lifted up into the air so the films will be sorted.

The heavy materials will go to the non-plastic sorting machines. In this part of the recovery process the beverage cartons, ferrous- and non-ferrous materials are separated. Ferrous materials are existing of more than 50% of iron. The non-ferrous materials consist of none or less than 50% of iron. The ferrous materials are filtered out with a magnet. This can also be done after the incineration process. The non-ferrous materials can be sorted out with an ‘Eddy current separator’ which can be seen in figure 41. The separating technique of this machine is based on the use of a magnetic rotor with alternating polarity, spinning rapidly inside a non-metallic drum. When non-ferrous materials pass over the drum the magnetic fields creates eddy currents in the non-ferrous metal repelling the material away from the conveyor. The non-ferrous materials are propelled forward over a splitter for separation. The other materials are dropped off at the end of the conveyor belt (Walker magnetics, 2015).

The beverage cartons and plastics are separated by using Near Infra Red spectroscopy technology. NIR scanners utilize the Near Infrared part of the electromagnetic spectrum (see figure 42). Electromagnetic waves are another term for light. All waves have different frequencies which shows what kind of radiation it is. The radiation varies from gamma rays to radio waves. The wave length range of the NIR scanner’s light is between 700 and 2500 nanometre. The NIR scanner register electromagnetic absorption. Electromagnetic radiation can cause vibration between the atoms of a molecule. When this happens the radiation is absorbed and not reflected. The NIR sorting machine sends out a spectrum of electromagnetic radiation to a plastic object. The machine detects which radiation is absorbed by the product and which is reflected. All polymer types have their own absorption and reflection spectra. In figure 43 the spectra of PET, PP and nylon can be seen. In the recovery facility the NIR sorter’s settings is based on all plastics. The scanner measures the shape, place and material of the waste on the conveyor belt. When the plastic is detected it gets blown by high-precision jets of pressurized air to another separate conveyor belt. This process can be seen in figure 44.

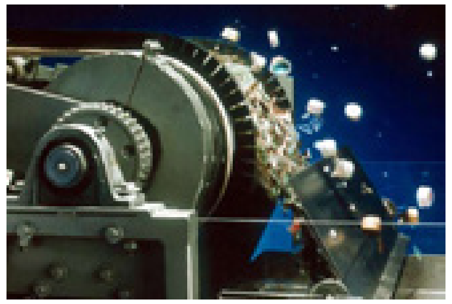


Figure 41 - Eddy current separator, remover non-ferrous materials

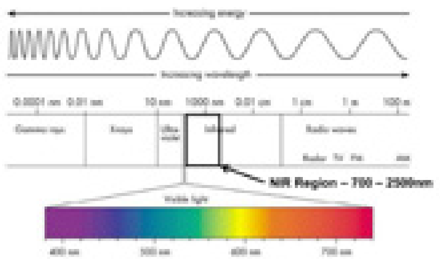


Figure 42 - Electro magnetic spectrum

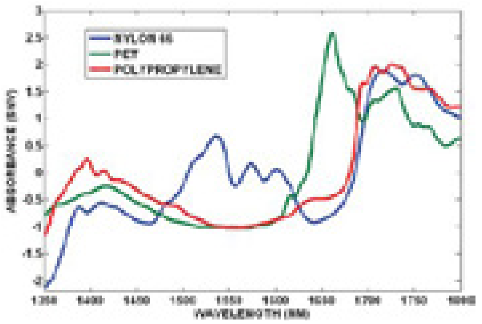


Figure 43 - Absorption and reflection spectrum

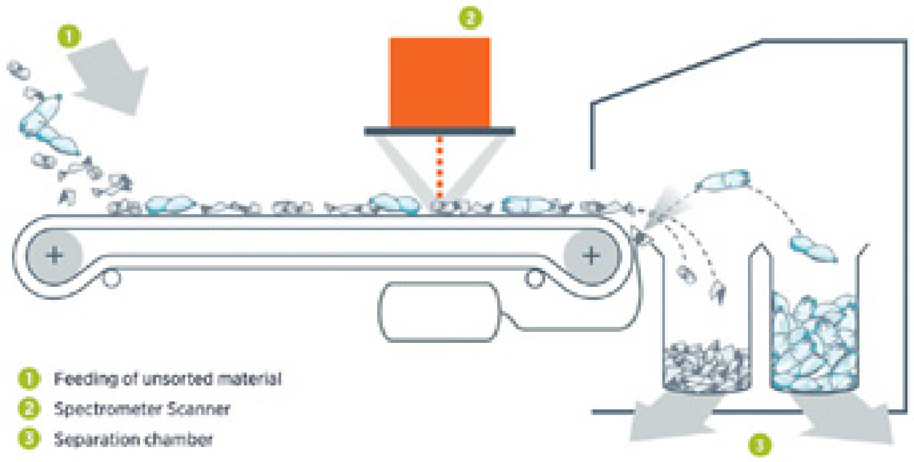


Figure 44 - Process of a NIR sorter

Sorting facilities

The plastics of the recovery facilities and the collection system of plastic Hero’s are the input in the sorting facilities. The general plastic sorting process, which can be seen in figure 45, is based a simplified sorting process made by the Sustainable Packaging project (Go, 2015). Also is looked at four facilities. The simplified process of Schönmackers in Kempen, Augustin Entsorgung in Meppen and SITA in Rotterdam are described in appendix 8.2. The machines in the recycling process of sorting plants is almost the same as in recovery facilities. The settings of some machines are different. The coarse screens differ from 200 mm to 300 mm and the fine screens from 40 to 65 mm. Besides, there are multiple NIR scanners which are sorting PE, PET, PE and the remaining; mixed plastics. Each NIR scanner sorts one polymer type. There are also sorting plants which sort for example paper and board and beverage cartons or other co-collection streams.

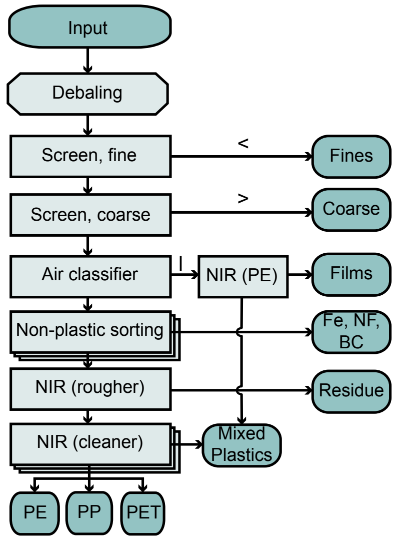


Figure 45 - General process of recovery facilities.

Mechanical Recycling

The output of the plastic sorting facilities and recovery facilities are recycled into washed milled goods. In the sorting and recovery facilities the waste is only separated on whole package but mostly the packages consist of also other materials from for example labels and caps. The plastics, metals and beverage cartons of the 3x3 matrix are needed to be purified. The general mechanical recycling processes are taken.

Metals

The ferrous and non-ferrous materials are going into a metal recycling process see figure 46. Firstly, the bales are shredded into small pieces. The non-ferrous materials are passing magnetic separator which removes any steel that may have been mixed in the bale. The ferrous materials are passing a eddy current separator which separates the non-ferrous materials. The laquer, labels and paint are removed by blowing hot air of around 550°C through the shreds on a slowly moving insulated conveyor (Novelis, n.d.). The exhaust gasses are first passed through an afterburner and then used to heat incoming air via a heat exchanger. This way the facility is minimizing the energy requirements of the system. Next, the aluminium is being melted and casting into aluminium plates.

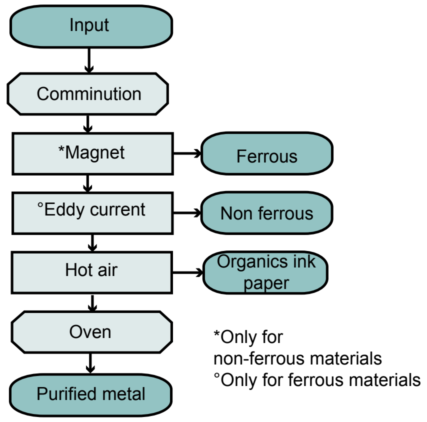


Figure 46 - General mechanical recycling process of metals

Plastics

The PP, PE and PET output of plastic sorting facilities are going to mechanical recycling plants. A general mechanical recycling process of plastics can be seen in figure 47 (Luijsterburg, 2015). All plastic waste streams passes the same mechanical recycling process but separate of each other. In the plastic mechanical recycling facility the PO-mix and PET is separated. Firstly, the plastic waste is optionally manual screened. The non-plastics can be sorted out here. Then the metals are sorted with magnets and eddy current separators. Next, the packages are shredded into small flakes. Next, the flakes are washed with detergents. The glue, organics and dirt dissolves in the detergents. After the plastic flakes are going to the density separation. In water the PP and PE floats and the PET material sinks. This because of the density is lower/higher than water. Depending on which polymer type is sorting the other material is separated. This is going to that material recycling process. The PE and PP cannot be separated with density separation. This could be processed together into PO-mix material. Then the water is removed from the flakes by using a centrifugation machine. In the oven the final water evaporates and the material is dried. The plastic material is put in a extruder to make new granulates.

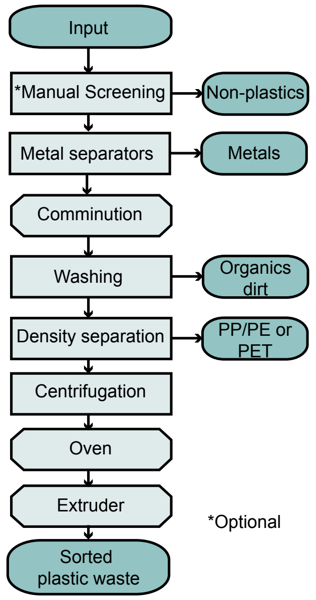


Figure 47 - General mechanical recycling process of plastics

Beverage cartons

The beverage cartons of recovery and sorting facilities and are going into beverage carton mechanical recycling. Beverage cartons consist of multiple layers; plastics, aluminium and carton. In this mechanical recycling process the aluminium, PO mix (PP an PE materials) and carton fibres are separated. Some facilities does only separate the carton fibre (HEDRA, 2015). The general sorting process of beverage cartons can be seen in figure 48 (Thoden van Velzen et al. 2013). Firstly, the beverage cartons are going into a pulper. The beverage cartons are dissolved in water. The light by-products like PO-mix (PE and PP), SRF (plastic film pieces and fibre residue) and fibre residue are floating on the pulp. The heavy by-products sink this is the aluminium layer with attached PE layer. The pulp itself is going into a screen which separates the water and dissolved product residue from the pulp. The pulp is going to the paper and board mechanical recycling and the aluminium is also recycled in the metal mechanical recycling facility as well as the PO mix.

4.4 3x3 MATRIX AND RECYCLING

To recycle all packages of the 3x3 matrix as good as possible the different materials needs to follow their own specific path through the sorting, recovery and mechanical recycling facilities. Besides, the efficiency of facilities are described if known. With the composition of packages research results and the market share of the products packaging option the input of mechanical recycling can be estimated and the efficiency of mechanical recycling facilities can be calculated.

Recovery

The products of the 3x3 matrix are connected to one (or more) intended recovery products of a recovery facility. The non-carbonated beverage PET bottle, shower gel HDPE and PET bottle are taken together in the category plastics. The soups and non-carbonated beverages liquid- and beverage cartons will be in the beverage carton stream. The aluminium pressurized can and most of the non-carbonated beverage metals cans are in the non-ferrous materials category. The tin plate metal cans of soups and non-carbonated beverages can be in multiple recovery products; Fe coarse, Fe fine or Fe. These products are good for tin plate recycling. All favoured recovery products can be seen in figure 49. Not all packages will end up in the favoured recovery product because the separation machines have efficiency lost. The efficiency of recovery facilities is not known.

Plastic sorting

A research is done to the recycling efficiency of the 3x3 matrix plastic bottles by the project of Sustainable Packaging (Go, 2015). The results of this research can be seen in appendix 9. The percentages are the average amount of packages per sorting products. The favoured sorting product for plastic sorting can be seen in figure 50. The problems extend in plastic recycling is pretty high. In PET shower gels only 54.82% of the packages are into PET recycling. In PET non-carbonated beverages the percentage is 64.13% and HDPE shower gels bottles have 75.25% of the bottles in PE recycling. The biggest loss mostly is in the heavy mixed plastics. Heavy mixed plastics are the packages which are not sorted into the right polymer type at the NIR scanner. This will be recycled into low-grade material products for example roadside bollards or sewer pipes. Also the beverage cartons can be sorted in this process. The amount of sorted beverage cartons is about 50% (Thoden van Velzen et al.,2013). The greatest loss is 27% in the mixed plastics. In an ideal sorting process 80% of beverage cartons can be separated.

Mechanical recycling

The End-of-Life fate of pouches is incineration in recovery facilities. The other packages of the 3x3 matrix are into the mechanical recycling of metals, plastics or beverage cartons. Firstly, a estimation of the input of the mechanical recycling facilities is made. The weight of retailed packages is calculated by multiplying the amount of retailed packages (Euromonitor,2015) explained in paragraph 2.1 by the average weight with residue of the packages which is measured in the composition

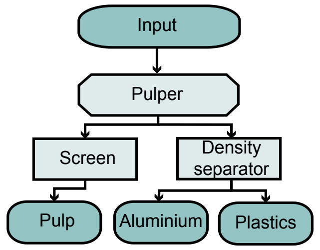


Figure 48 - General mechanical recycling process of beverage cartons

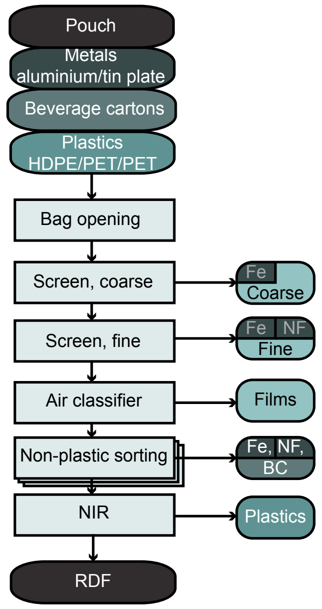


Figure 49 - General process of recovery facilities.

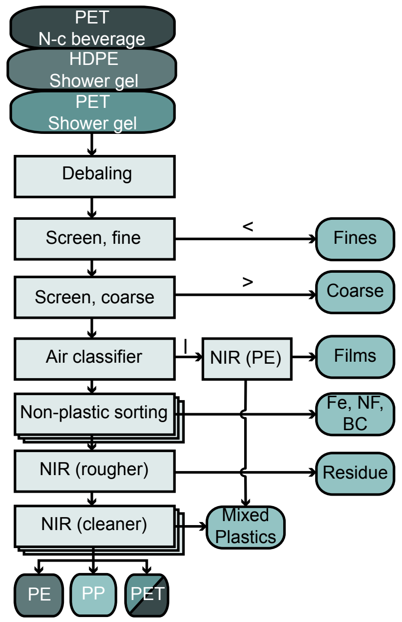


Figure 50 - General process of recovery facilities.

research. The amount of retailed packages of non-carbonated beverages are not specified at ≤0.5 litre. Not all packages are recycled. Nedvang monitors the weight of recycled packages in recovery and sorting facilities. The determine the total percentage of recycled packages Nedvang devides the recycled packages by the total weight of retailed packages (Nedvang,2013). This way the input weight of mechanical recycling is calculated. This calculation does take into account that all the parts of the packages stick together. Secondly, with the product compositions and the product residue multiplied by the amount of recycled packages the output per part of the mechanical recycling system can be calculated. It is assumed that the efficiency of the mechanical recycling machines and processes is 100%. The calculations can be seen in appendices 10.1 to 10.9. These percentages and numbers are the theoretical amount and are not tested in practice.

Metal cans

The percentage recycled metal packages is in general 93%. The estimated input in the metal mechanical recycling facilities is for soups metal can around 8.3 kton, shower gels aluminium pressurized can 0.1 kton and non-carbonated beverages metal can 6.7 kton packages (see appendices 10.4, 10.5 and 10.6). This calculation assumes that the packages are separated before incineration and does not take into account the wrong separated packages. Besides, it assumes that all recovery recycled packages are going to mechanical recycling facilities but sometimes trade intermediaries buy the metal from the recovery facilities. This because the metals bring in lots of money. The efficiency of the mechanical recycling can be seen in figure 51. The original data of the non-carbonated beverages metal cans is including one tin plate can this is excluded in this calculation because this will be separated in the recovery facility. In this case the composition of non-carbonated beverages is 99.3% aluminium, 0.3% coating and 0.39% PP. The percentages of mechanical recycled packages are soups metal can 81.5%, shower gels aluminium pressurized cans 63.1% and non-carbonated beverages metal cans 65.7%.

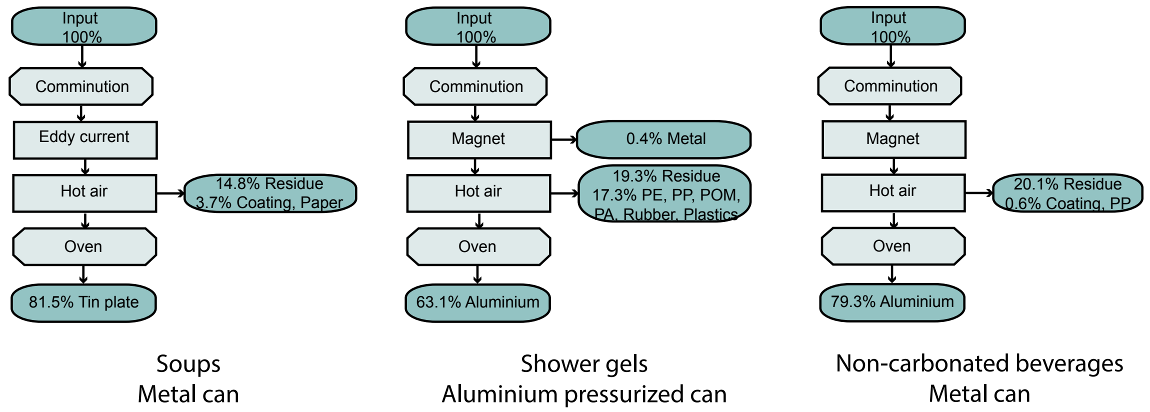


Figure 51- Efficiency of metal mechanical recycling facilities.

Plastics

The percentage of recycled plastic are 46% monitored by Nedvang. The estimated input in the plastic mechanical recycling facilities is for shower gels PET bottle 0.04 kton, shower gel HDPE bottle 1.2 kton and non-carbonated beverages PET bottles 10.8 kton (see appendices 10.1, 10.2 and 10.3). This calculation takes into account the wrong separated packages (WS). The DKR-specification of plastics is that 10% of the total weight may be polluted.10% of the calculated input is added to get the total input. The polluted packages will be separated for 80% in

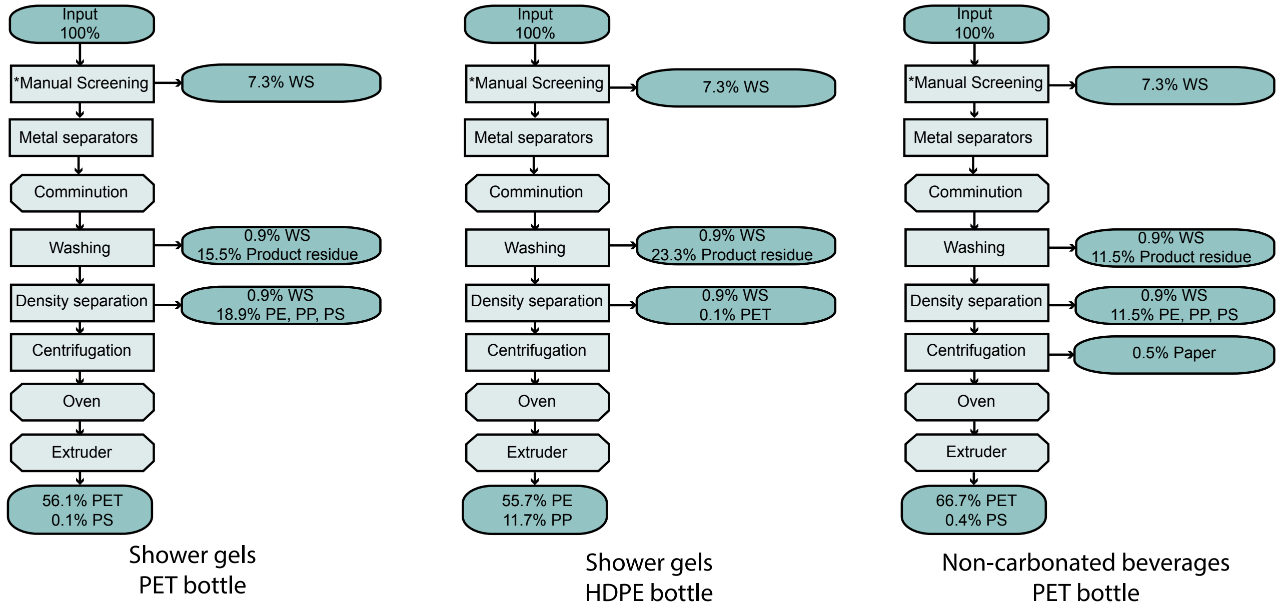


Figure 52 - Efficiency of plastic mechanical recycling facilities.

manual screening, 10% in washing and 10% in density separation (Thoden van Velzen, 2015). The efficiency of the mechanical recycling is shown in figure 52. The PS material is described in various mechanical recycling products because this has a density of 1.00 gram/cm^3 and the half will sink and the other half floats at the density separation. The percentages of mechanical recycled packages are shower gels PET bottle 56% PET polluted with 0.1% PS, shower gels HDPE bottle 56% PE polluted with 11.7% PP and non-carbonated beverages PET bottle 67% PET polluted with 0.4% PS.

Beverage cartons

The European amount of recycled beverage cartons is 42% in 2013 (Hedra, 2015). The input in the beverage cartons mechanical recycling facilities is for soups liquid carton 0.01 kton and non-carbonated beverages beverage carton 4.1 kton packages (see appendices 10.7 en 10.8). This calculation does not take into account the wrong separated packages. The efficiency of the beverage cartons mechanical recycling is soups liquid carton 41.1% carton and non-carbonated beverages beverage carton 55.7% carton which can be seen in figure 53. The pulp will be input for the mechanical recycling of paper and board. It is assumed that all the product residue will dissolve in the water which will be separated by the screens. A part of the plastic foil sticks to the aluminium part which will burn in the

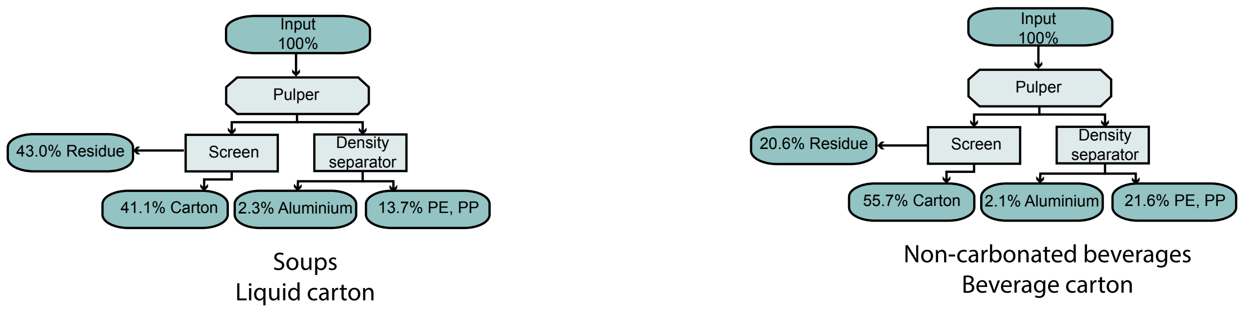


Figure 53 - Efficiency of beverage carton mechanical recycling facilities.

oven in the aluminium recycling process. The other part of the plastic foil sticks to the carton which also will float. In this research all plastic foil is taken into account in the PE material. In previous research the efficiency of the mechanical recycling of beverage cartons is determined in practice (Thoden van Velzen et al. 2013). In this research the beverage cartons sorted in SITA rotterdam and mechanical recycled in REPA. Afterwards the composition of the outputs are measured. The mechanical recycling of non-carbonated beverages beverage carton and soups liquid carton calculations are combined to compare with the practical measurements (see appendix 10.9). The results of the theoretical approach and the practical approach are shown in table 16. The measured amount of packages corresponds approximately to the theoretical calculation.

	Carton	By-products (aluminium and plastics)	Moisture (Product residue)
Practical approach (Thoden van velzen et al., 2013)	57.2%	18.3%	24.5%
Theorethical approach	55.6%	22.8%	21.6%

Table 16 - Results of the practical and theoretical approach

The End-of-Life fates of the 3x3 matrix packages are determined by firstly describing the overall recycling system. The packages are collected, sorted in recovery or sorting facilities and then mechanical recycled or incinerated. The 3x3 packages have to follow their ideal path through the facilities. The data of Nedvang includes the amount of recycled packages in recovery and sorting facilities (Nedvang, 2013). The amount of recycled material in mechanical recycling facilities are not made. An estimation is made of the efficiency of mechanical recycling based on the composition of packages. The efficiency of machines or processes are not taken into account. In mechanical recycling 100% input does not mean 100% output. The packages consists of other materials which needs to be separated. The product residue is already around 15% of the total weight. The problems of the packages loss in the recycling system will be described in the following chapter. As well as the solutions of these problems.

5. GUIDELINES FOR DESIGNING PACKAGES

All packages are designed to protect the product of decay, to present the packages in the stores, to transport the packages safely, etc. In the design of packages also the recyclability have to be taken into account. As told in earlier chapters the recycling system is not 100% efficient. What are the problems in the recycling process and how could these problems been solved in the design of packages. The results are guidelines for designing packages. The guidelines are made to design a product-packaging combination whereby the function is realized with a maximum of recyclabiltiy.

5.1 PROBLEMS OF RECYCLING

There are multiple problems why the sorting system has efficiency loss in recycling. Recycling facilities can be set up to have the highest efficiency for the company. So the highest gain instead of the highest amount of recycling. Besides, even when the highest amount of recycling is realised this is not 100%. The machines will have efficiency loss. The limitations of machines are explained in this below. The efficiency of the 3x3 matrix packages' recycling is explained in paragraph 4.4 which shows the problems extend. Also the approximation of packages' problems in recycling will be described. The efficiency of mechanical recycling and the composition research' results will be used to see which product will have problems with recycling and the solutions of these problems are given.

The screens are sorting between 70 and 200 mm. The packages which are smaller or bigger than these sizes fall through in the recycling process. Only the small ferrous materials and ferrous metals are sorted out afterwards. The rest is going into RDF. The plastics and beverage cartons will not be recycled when separated in this step of the recycling process. To prevent that smaller parts will fall out in the recycling process it is better to keep the package complete instead of throwing away the parts separately. In the design of packages can be taken into account the dimensions of the screens.

The air classifiers are sorting the light products on basis of size, shape and density. None of the 3x3 matrix packages are needed to sorted out. But some packages are separated here. This could be because of the small wall thickness of the bottles for example. In this case it is maybe better if some product residue stays in the bottle when throwing it away. The wall thickness can be made thicker to be sure the packages will not be separated here.

The non-plastic sorting machines can be divided into beverage cartons, ferrous- and non-ferrous materials. The ferrous materials are separated by magnets. A problem could be if the magnetic material is inside other materials so that material is also separated. The non-ferrous materials are sorted out with an 'Eddy current separator'. The same problem of ferrous materials can occur.

In the NIR sorters process the packages are sorted because of the infrared light absorption and reflection of bottles. The plastics and beverage cartons are separated in this part of the recycling process. There are limitations of the NIR scanner which can cause problems with the separation. The surface ratio of materials can cause problems. When the label or cap take more space than 50% of the body's surface the bottle will be separated into the material of the label or cap. This problem can occur when the bottle is distorted. Also some body's cannot be identified because of the appearance of the material. Very dark colours, transparent or materials which reflect the infrared light cannot be detected by the NIR sorter. These products will be in the RDF of recovery and in mixed plastics of plastic sorting facility. In the designing process of packages these problems can be taken into account.

In the metal mechanical recycling process all parts will burn in the incineration. The paper of soups metal cans and the plastic parts of non-carbonated beverages and aluminium pressurized cans could be recycled but are not. These parts could be designed to easily taken off so the consumer can separate this at home.

In the plastic mechanical recycling process the PET is sometimes polluted with PS. The PS parts are a decorative lid of PET shower gel and labels in non-carbonated PET bottles. These parts can be made of another material for example PE, PP or PET.

In the beverage cartons mechanical recycling process the PO-mix, aluminium and carton fibres are recycled. Problems of this recycling process is that some of PE layer will stick to the carton and/or aluminium layer. This will pollute the different materials. The interface between the multiple layers could be made less strong so the separation is easier. This is only possible when the function of the package still will be realized.

These problems will be input for the guidelines for design. How can packages be designed that these problems do not appear. With what kind of packaging restrictions has the designer to deal with.

5.2 GUIDELINES FOR DESIGN

The aim of guidelines for designing packages of the 3x3 matrix is to encourage packaging designers to consider recycling possibilities, provide guidelines for those wishing to make their packaging (more) recyclable and provide information to prevent packaging designs inadvertently interfering with existing plastic recycling streams. The goal of improving the recyclability of packages should not compromise product safety, functionality or general consumer acceptance and should positively contribute to an overall reduction in the environmental impact of the total product offering. The guidelines are divided into general packaging guidelines and specific guidelines for plastic packages. The guidelines are made of the results of previous research and also existing guidelines for plastics (RECOUP,2015). The general guidelines applies to all packages of the 3x3 matrix. The specific guidelines for plastic packages are made because the chance to get a polluted plastic higher the other packages. The guidelines are not ordered on importance. The guidelines are not ordered on importance. The guidelines are not arranged on importance.

General recyclable packaging guidelines

- The goal of improving the recyclability cannot compromise product safety.
- Minimize the use of different materials.
- The different materials should be separated easily.
- Minimize the product residue
    - Design the package with a wide neck
    - Consider using a package that can be stood inverted to ease empting
    - Consider or investigate in use of non-stick additives to reduce the product residue stick to the package. This should not affect the recyclability of the package.
- Preferable dimensions of all parts between 70 and 200 mm. Otherwise it will be separated at the screens.
- Use a wall thickness of more than 0.1 mm so the packages cannot be sorted at the air classifiers.
- Minimize the volume of material

Plastics packaging guidelines

- Use non-pigmented polymers. This has the highest recycling value and the widest variety of end uses. Also, heavily coloured plastic cannot be identified by the NIR sorters. Otherwise, when the colour is necessary, minimize the amount of colour.
- Avoid direct printing onto not coloured plastics
- Avoid reflection in packages. The NIR scanner cannot indicate the polymer type.
- Avoid transparency in packages. It is more difficult for the NIR scanner to indicate the polymer type than indication opaque or coloured packages
- When a barrier is needed in the package prefer a barrier of which materials can be separated in the recycling stream. Otherwise consider the use of thin layers for example vapour deposition.
- Avoid the use of metal caps. This is more difficult to remove than other closure systems. Metal which is not sorted can cause great problems in the process of new material.
- Labels of paper are not ideal unless they are attached using water soluble adhesives. Otherwise the glue will cause problems such as surface defects and pinholes during the process.
- Metallised foils or labels increase the pollution and separation cost and should be avoided.
- The use of PS material parts in PET bottles will pollute the PET recycling stream.

When designing packages these guidelines have to be taken into account to ensure a better recycling of the packages. The guidelines for designing recyclable packages can be applied to the current packages of the 3x3 matrix. This to reach a better recyclablility. Nowadays the pouches are incinerated. When the interfaces between those packages is less strong the materials of the pouch could be separated. When this is done to the current pouches the package will loose it's strength. Beverage cartons have the same problem with recycling as pouches. The interfaces between the materials are strong but cannot been replaced because the strength will disappear. In the metal mechanical recycling all other parts than metal will be incinerated by the hot air. In this case it is better for recycling to minimize the use of different materials. The shower gels HDPE bottle, shower gels PET bottle and the non-carbonated beverage PET bottle all have the greatest loss in mixed plastics. Those packages do not pass the NIR scanner to the right polymer type. This could be solved by using the guidelines to avoid transparency, avoid reflection in packages, and avoid heavily coloured packages. In a further research the packages of the 3x3 matrix could be re-designed into recyclable packages.

6. CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The packages of the 3x3 matrix are described to formulate good methods for the composition research. The description consist of the difference in shape and volume, the general parts of the packages and how the packages can be used. Besides, gives the market share of the packages a good impression of the amount of packages on the market and the most commonly used packaging type per product. It can be concluded that non-carbonated beverages ≤0.5 litre is a very big and divers category. A recommendation is to specify this category. This covers probably a bigger part of the market share of that specific category than the coverage of the 93% now. This also will give more consistent results in the research.

The aim of the composition research was to measure the composition and product residues of the 3x3 matrix. To achieve this test methods are formed. All packaging options' average composition, weighted average weight and the percentage of product residue are calculated. The composition of the metal cans was an estimation of the market. The extreme values of the ratio between coating and body is not measured. Besides, the layers of the pouches could not be determined and the ratio of the layers were not available at the market. The calculated averages of these packages are not completely reliable. In further research these ratios could be investigated. The environment variable time was hard to control. The time between emptying the packages and measuring the packages is determined to be a maximum of one week. But in practice the time between emptying and hand in the package was not controllable.

The individual packages of the 3x3 matrix have to be processed after consumers have discarded them. In the Netherlands all the municipal solid waste (MSW) is collected and incinerated, metals are recovered from the bottom ashes of the municipal solid waste incinerations. Besides, several separate collection systems have been established. The separate collected or mechanically recovered packaging materials are recycled into packages and various other objects. The recycling system is regarded as an act of saving virgin raw materials which convey to environmental benefits.

The End-of-Life fates of the 3x3 matrix packages are determined by firstly describing the overall recycling system. The packages are collected, sorted in recovery or sorting facilities and then mechanical recycled or incinerated. The 3x3 packages have to follow their ideal path through the facilities. The data of Nedvang includes the amount of recycled packages in recovery and sorting facilities (Nedvang, 2013). The amount of recycled material in mechanical recycling facilities are not made. An estimation is made of the efficiency of mechanical recycling based on the composition of packages.

The guidelines for recyclable packages are made to have a better recycling of the packages. The guidelines for designing recyclable packages can be applied to the current packages of the 3x3 matrix. In a further research the packages of the 3x3 matrix could be re-designed into recyclable packages.

6.2 RECOMMENDATIONS

Composition research

- Include glass in the research.
- Redefine the non-carbonated beverages ≤0.5 litre category into a smaller group. This group is too divers for getting consistently results.
- In general metal cans have a ratio of aluminium and coating. This is done because there is no additional information available. In further research also the coating can be measured. For example put the metal cans in the oven. The coating burns and the aluminium remains. This way the weight of the coating can be measured. The extreme values are very interesting in this research.
- Control the environment variable time
- Execute more measurements about the natural moisture in beverage cartons. I only did two measurements in the category of soups liquid cartons and nine in the non-carbonated beverage ≤0.5 litre beverage cartons category. This is not completely reliable.
- Execute more measurements about the product residue. The measurements have to be done at different volumes to see a good relation between the volume of the product content and the weight of the product residue.
- Execute more measurements about the packaging . This especially in the categories with less than or equal to ten samples.
- Other researches which could be interesting to execute are a research of the influence of ink on body in the recycling process and/ or the influence of barriers in the recycling process.

Recycling research

- Research the paper and board recycling process because the beverage cartons will be input into this stream
- In the efficiency of recycling beverage cartons research also take into account the ratio of plastic foil which stick to the carton and PE foil which stick to aluminium.
- In the efficiency of mechanical recycling calculations take out the assumptions to get a more reliable outcome. Assumptions are; efficiency of the machines/ processes in mechanical recycling, calculated input for mechanical recycling etc.
- Instead of simplified recovery, sorting and mechanical recycling facilities do a research to the each facility separately.

Guidelines for recyclable packages

- Arrange the guidelines on importance
- Make specific guidelines for each package of the 3x3 matrix
- In a further research the recyclable packaging guidelines could be extended with packaging guidelines which take into account all aspects of designing packages. So consider the manufacturing processes, transport etc.
- In a further research the packages of the 3x3 matrix could be re-designed into recyclable packages.

DEFINITIONS OF TERMS

Barrier	Layer inside bottles which protects the product inside
BC	Beverage carton
End-of-Life fate	The place where packages end up in the recycling system
Ferrous material	Metals which exist of more than 50% iron. .These metals are magnetic.
Niche	Packaging option which represents a small part of the market
NIR	Near Infra-Red
Non-Ferrous materials	Materials which exist of none or less than 50% iron
Off-trade	Sales to food retailers like supermarkets etc.
MSW	Municipal Solid Waste
(HD) PE	(High Density) Polyethylene
PET	Polyethylene Terephthalate / Polyester
Retail	The companies which sell goods and services directly to the consumer
RDF	Refused derived fuel
RTD	Ready-To-Drink
UHT	Ultra high temperature processing

ACKNOWLEDGEMENTS

Many persons have contributed to this report and it is impossible to thank everybody individually. I would like to thank the following individuals for their contributions.

My supervisor from Wageningen UR Marieke Brouwer and co-supervisor Ulphard Thoden van Velzen.

My supervisors from the University of Twente Marten Toxopeus, Bjorn de Koeijer and Jörg Henseler.

The project of Sustainable Packaging SD002

Marcel Staal, Saskia Bosman and Guillermo Garrido for familiarize me in collecting data for the composition research.

Robert-Jan ter Morsche, Martin de Olde and Roland ten Klooster for the interesting interviews

The team of Attero Weijster for the guided tour through the recovery facility.

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APPENDICES

1. MARKET ANALYSIS

Appendix 1 is an external pdf file named Market Analysis. The analysis provides insight in product content, volumes and shapes of all packaging options. It also includes the packages outside the 3x3 matrix.

2. DATA EUROMONITOR

The original data of the database Euromonitor. The data is based on the retail and off-trade volume of packages.

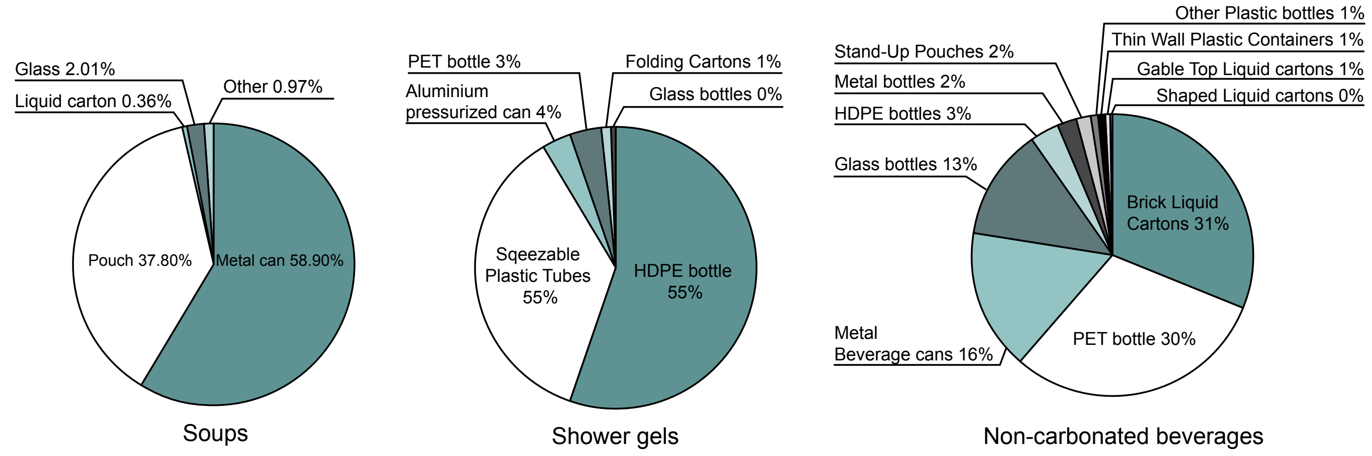


Figure 2.1 - Retail and off-trade volume of the 3x3 matrix products

Body Wash and Shower Gel Packaging NL	2014	%
HDPE Bottles	34.40	55%
Squeezable Plastic Tubes	22.50	36%
Metal Aerosol Cans	2.20	4%
PET Bottles	2.10	3%
Folding Cartons	0.80	1%
Glass Bottles	0.20	0%
Total Packaging	62.30	100%

Table 2.1 - Data shower gels

Soup Package NL	2014	%
Metal Food Cans	96.60	59%
Stand-Up Pouches	62.00	38%
Glass Jars	3.30	2%
Other Plastic Bottles	1.60	1%
Brick Liquid Cartons	0.60	0%
Total Packaging	164.10	100%

Table 2.2 - Data soups

Non-Carbonated Softdrink Packaging NL	2014	%
Brick Liquid Cartons	780.3	31%
PET Bottles	752.7	30%
Metal Beverage Cans	404	16%
Glass Bottles	317.4	13%
HDPE Bottles	85.40	3%
Metal Bottles	55.70	2%
Stand-Up Pouches	44.90	2%
Other Plastic Bottles	20.20	1%
Thin Wall Plastic Containers	18.30	1%
Gable Top Liquid Cartons	14.3	1%
Shaped Liquid Cartons	3.20	0%
Total Packaging	2496	100%

Table 2.3 - Data non-carbonated beverages

3. TEST METHODS

Appendix 2 shows the tables of the test methods per package option.

	Variable	Definition	Measuring method
General	Trade name	What is the name of the product	Description at label
	Manufacturer	Company which makes the packages	Description at label
	Type product	Product inside the package	Description at label
	Volume [ml]	Volume of package	Description at label
	Total weight (with residue) [ml]	Total weight of the package with residue	Weigh with scale
	Total weight (rinsed and dried) [ml]	Weight of the package after rinsed and dried in the oven at 60°C	Weigh with scale

Table 3.1 - General test method

	Variable	Definition	Measuring method
Soups – metal can	Total dry weight of body	Weight of the body (without label) [gram]	Weigh with scale
	Body material	Thinner steel or aluminium	Magnet
	Label material	PET, PE, PP, Paper, other	NIR scanner (and look)
	Label weight	Weight of label [gram]	Weigh with scale
	Top weight	Weight of top [gram]	Weigh with scale

Table 3.2 - Test method soups metal cans

	Variable	Definition	Measuring method
Soups – Liquid carton	Manufacturer beverage carton	SIG, Elopack, Tetrapack, etc.	Data per package
	Type beverage carton	Diamond, Tetrabrik, PurePak, Combibloc, etc.	Data per package
	Thickness bag	Measure thickness [cm]	Measure with Adamel Lhomargy MI 20
	Surface bag	Measure dimensions [cm²]	Measure with ruler

Table 3.3 - Test method soups liquid carton

	Variable	Definition	Measuring method
Shower gels – aluminium pressurized can	Total dry weight body	Weight of the body (without label) [g]	Weigh with scale
	Cap material	PET, PE, PP, Paper, other	NIR scanner
	Cap weight	Weight of the cap [g]	Weigh with scale
	Actuator material	PET, PE, PP, Paper, other	NIR scanner
	Actuator weight	Weight of actuator [g]	Weigh with scale
	Bag material	Aluminium layer? (Y/N)	Data per package
	Bag weight	Weight of bag [g]	Weigh with scale
	Bag thickness	Measure thickness [cm]	Measure with Adamel Lhomargy MI 20
	Bag surface	Measure surface [cm²	Measure with ruler

Table 3.4 - Test method shower gels aluminium pressurized can

	Variable	Definition	Measuring method
Shower gels and non-carbonated beverage – HDPE bottle and PET bottle	Total dry weight	Weight of the body (without label) [g]	Weigh with scale
	Colour body	Transparent, opaque, coloured (T/C/O)	Look at body
	Label material	PET, PE, PP, Paper, other	NIR scanner
	Label weight	Weight of label [g]	Weigh with scale
	Cap material	PET, PE, PP, Paper, other	NIR scanner
	Cap weight	Weight of cap [g]	Weigh with scale
	Neck material	PET, PE, PP, Paper, other	NIR scanner
	Neck weight	Weight of neck [g]	Weigh with scale
	Expire date	Ink, Laser	Look at bottle
	Expire date place	On body, cap, label [B/C/L]	Look at bottle
	Other parts	Metal parts, lid inlay, valve etc.	Look at bottle
	Other parts materials	PET, PE, PP, Paper, other, No	NIR scanner (and look)
	Other parts weight	Weight of other parts [g]	Weigh with scale

Table 3.5 -Test method shower gels and non-carbonated beverages HDPE bottle and PET bottle

	Variable	Definition	Measuring method
Non-carbonated beverage – beverage carton	Total dry weight	Weight of the body (without label) [g]	Weigh with scale
	Manufacturer beverage carton	SIG, Elopack, Tetrapack, etc.	Data per package
	Type beverage carton	Diamond, Tetrabrik, PurePak, Combibloc, etc.	Data per package
	Cap material	PET, PE, PP, Paper, other	NIR scanner
	Cap weight	Weight of cap [g]	Weigh with scale
	Neck material	PET, PE, PP, Paper, other	NIR scanner
	Neck weight	Weight of neck [g]	Weigh with scale
	Straw material	PET, PE, PP, Paper, other	NIR scanner
	Straw weight	Weight of straw [g]	Weigh with scale
	Flow pack material	PET, PE, PP, Paper, other	NIR scanner
	Flow pack weight	Weight of flow pack[g]	Weigh with scale
	Other parts	Metal parts, lid inlay, valve etc.	Look at bottle
	Other parts materials	PET, PE, PP, Paper, other, No	NIR scanner (and look)
	Other parts weight	Weight of other parts [g]	Weigh with scale

Table 3.6 - Test method non-carbonated beverages beverage carton

4. STANDARD EQUATIONS

Equations to calculate the weighted average weight, standard deviation, minimum and maximum.

$$\bar{x} = \frac{\sum_{i=1}^{n}(a_i)}{n}$$

Equation 4.1: Average weight

x	*Average weight [gram]*
n	*Total measured packages*
a_i	*Weight of material found in division [gram]*

$$s_x = \frac{\sum_{i=1}^{n}(x_i - \bar{x})}{n}$$

Equation 4.2: Standard deviation of weight

s_x	*Standard deviation [gram]*
x_i	*Weight of package [gram]*
x	*Average weight [gram]*
n	*Total measured packages*

Equation 4.3: Minimum and maximum

Minimum	*Minimum in division [gram or %]*
Maximum	*Maximum in division [gram or %]*

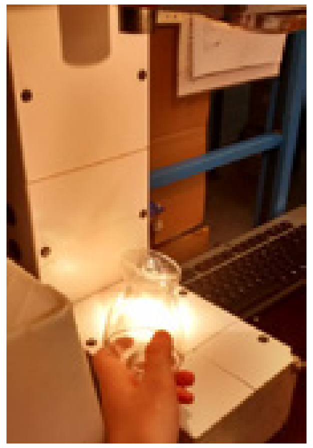
5. CONDUCTING COMPOSITION RESEARCH

Appendix 5 shows some pictures of conducting the research.

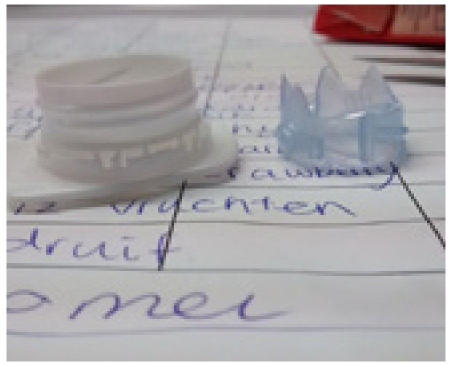
Measuring aluminium pressurized cans

Used scales

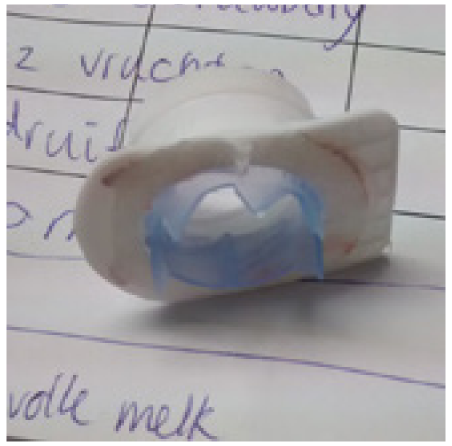
NIR-scanner to indentify the material of the bottle: PET. The machine shows the graph of the absorption and reflection. The machine indicates the material.



The light of the NIR scanner and a PET bottle



Theeth inlay and the neck of non-carbonated beverage cans ≤0.5 litre beverage carton



Assembled theeth inlay and neck. The teeth inlay cuts the aluminium when twisting the cap.

An example of a aluminium pressurized can female valve. This type of valve needs an actuator which will be in the valve.

An example of an aluminium pressurized can male valve. This type of valve needs an actuator which will be around the valve.

The aluminium pressurized can bag on valve. The valve, basis, pipe and bag can be seen.

Emptying an aluminium pressurized can. The gel does not directly turn into foam because the temperature is not high enough to boil the pentane inside the gel.

The machine, Adamel Lhomargy MI 20, to define the thickness of the bags of aluminium pressurized cans and soups pouches. In this picture a bag of aluminium pressurized cans is measured.

Non-carbonated beverages beverage cartons are collected at a primary school. The packages are collected in one week long in one class.

Rinsed beverage cartons.

Oven test of two black caps which are not detected by the NIR scanner.

Put the two caps in the oven at a temperature of 130˚C for one hour.

The oven used for the oven test to detect the material which cannot been detected by the NIR scanner

Put packages in the oven to dry the rinsed packages.

Oven used to dry the rinsed packages.

Set the oven at 60˚C to evaporate the moisture in the packages. At this temperature the material of the packages do not melt.

Total amount of packages measured by myself.

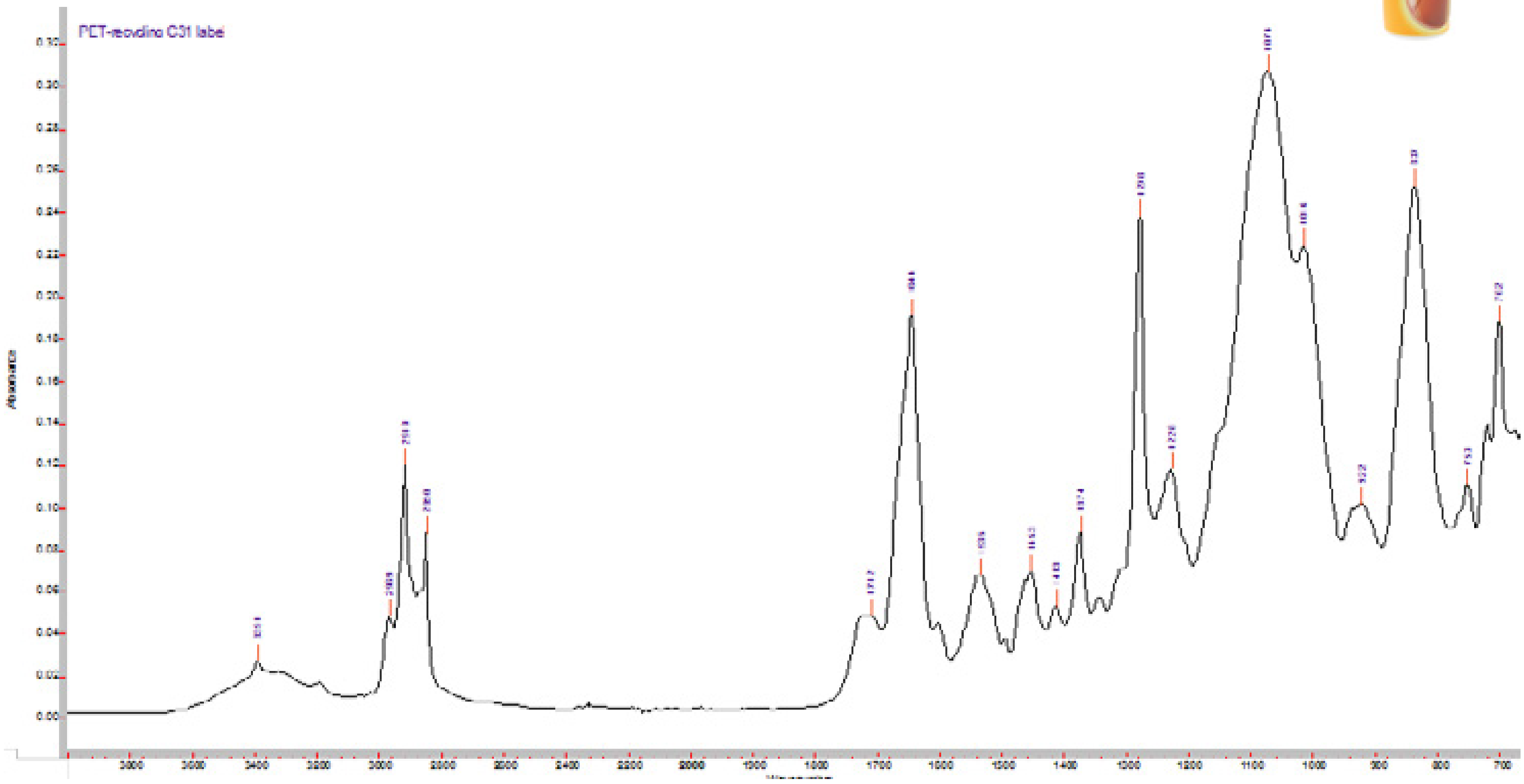
6. NIR SPECTRA

NIR-spectra of multiple parts.

Apparatus: Varian Scimitar 1000 FT-IR equipped with a Pike MIRacle™ ATR (Diamond w/ZnSe lens single reflection ATR plate)

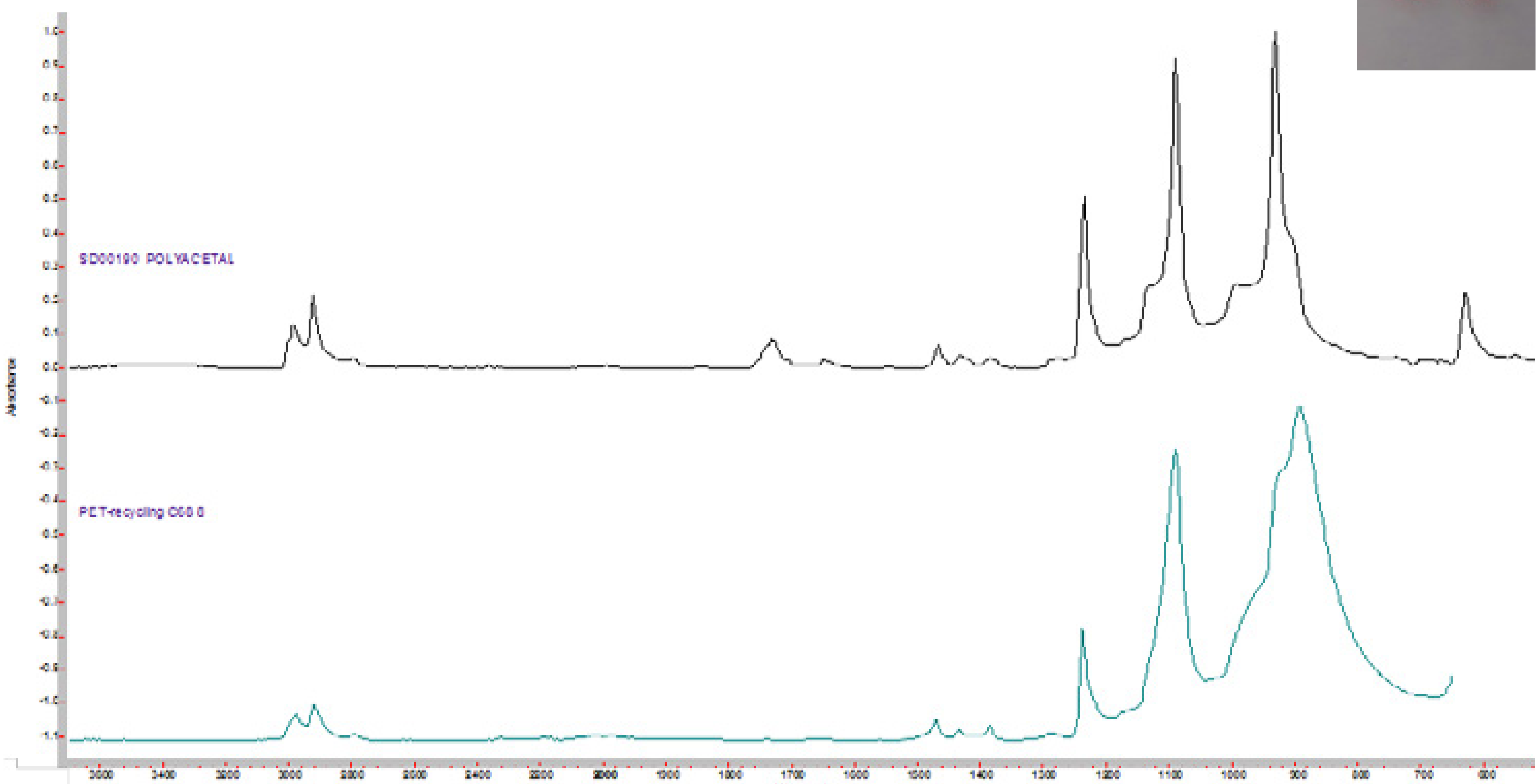
Parameters: Aperture: automatically chosen Resolution: 4 cm-1 Detector: DTGS

Scans: 64 Range: 4000 – 650 cm-1



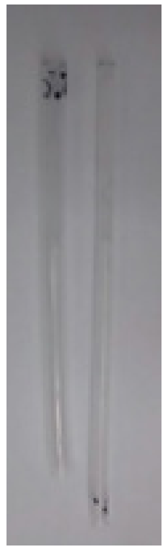
6.1 - Polyamide (PA)

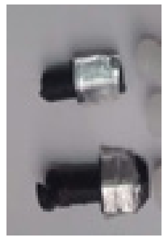
Non-carbonated beverage - PET bottle: label Chocomel

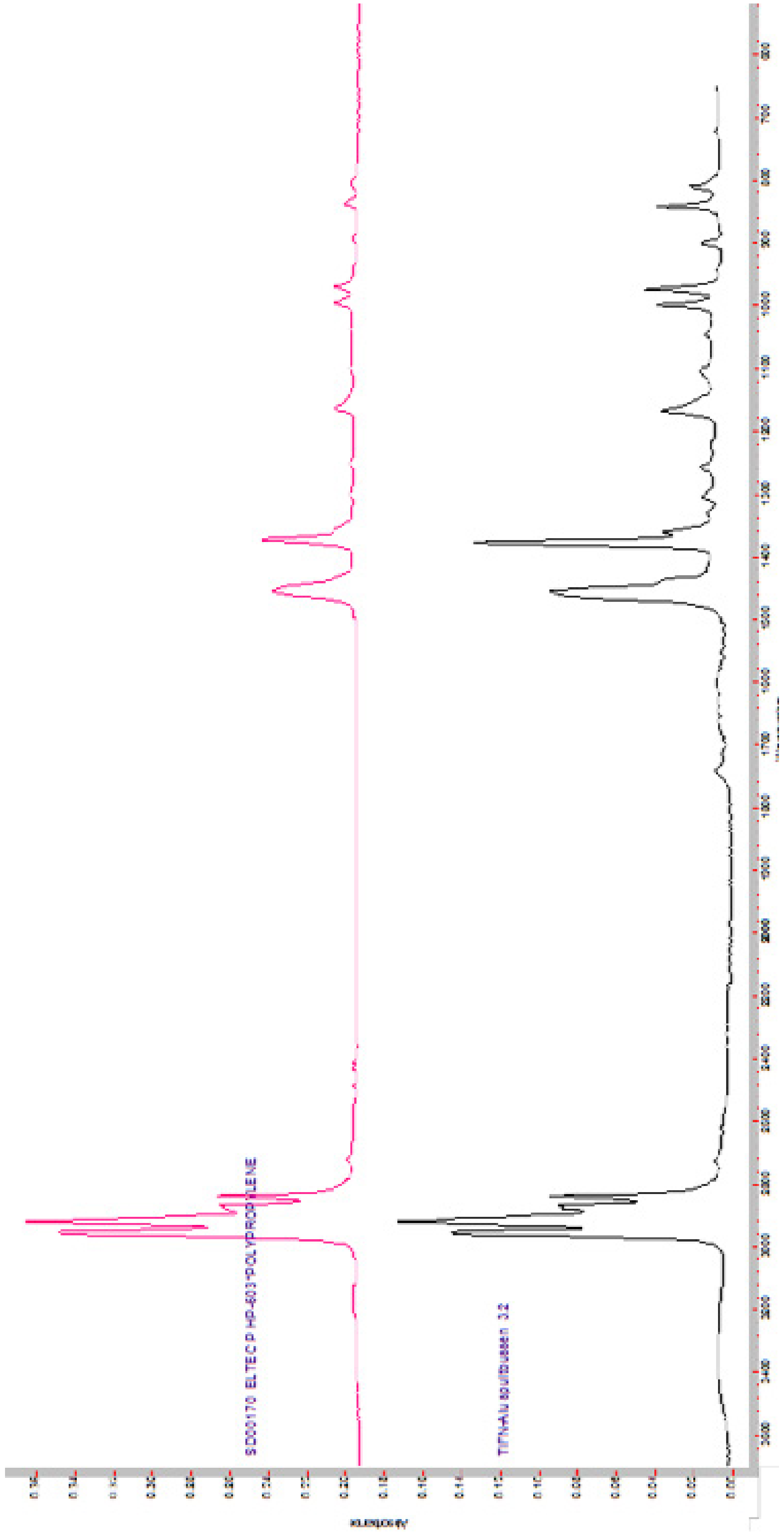


6.2 - Polyacetal (POM)

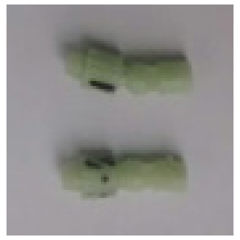
Shower gel - aluminium pressurized can: Air valve (red)

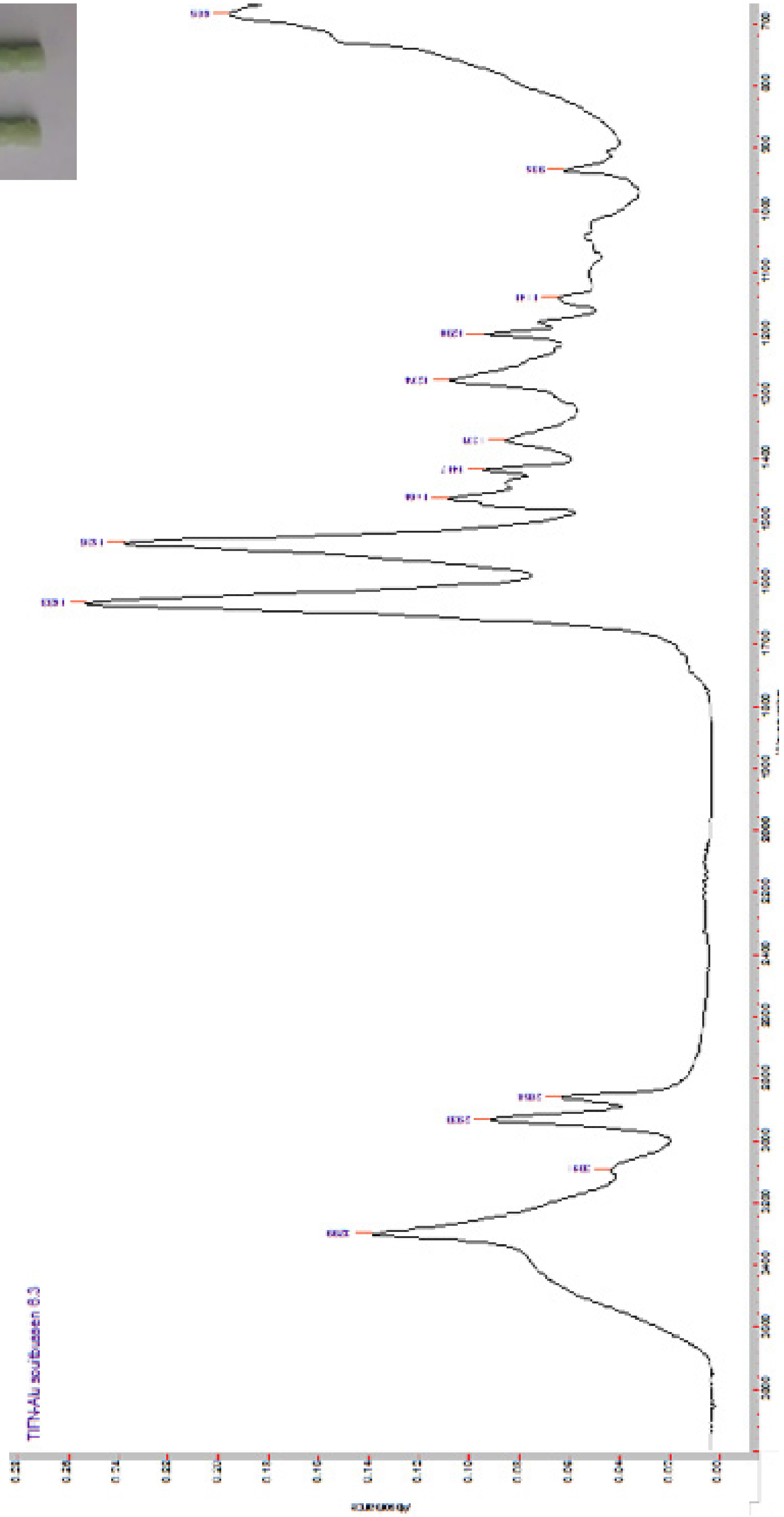






6.3 - Polypropylene (PE)
Shower gel - aluminium pressurized can: pipe and basis (black)

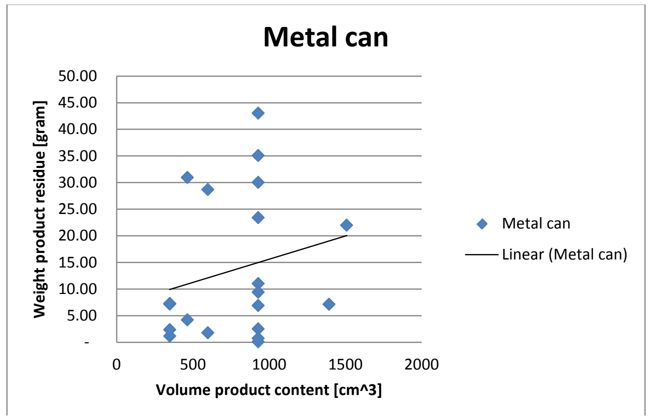




6.4 - Polyamide (PA)
PolShower gel - aluminium pressurized can: Air valve (green)

7 PRODUCT RESIDUE AND VOLUME PRODUCT CONTENT RELATIONS

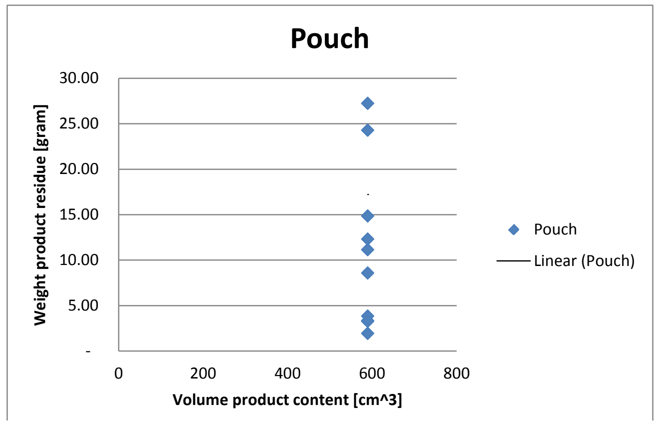
The product residue is measured. The volume of the product content is measured by multiplying the volume by the density of the product. The relations between the product residue and the volume of the product content are shown in graphs 7.1 to 7.9.The linear trend line of the relation is made in the graphs.



Assumptions:

Product residue
- n=19
- Density content ρ=1.16 gram/ml {n=19}

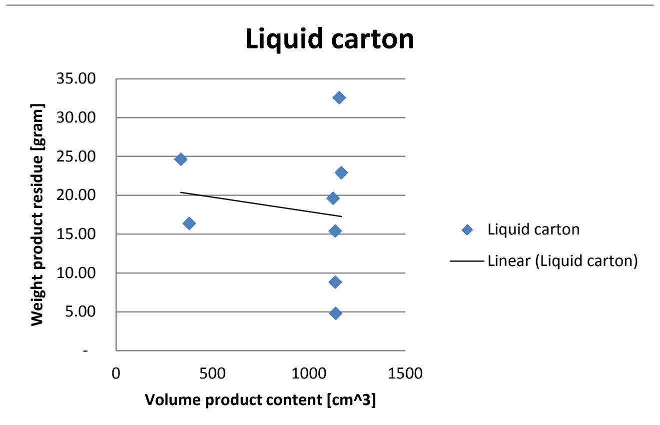
Graph 7.1 - Relation between product residue and volume product content soups metal can



Assumptions:

Product residue
- n=10
- Density content ρ=1.03 gram/ml {n=10}

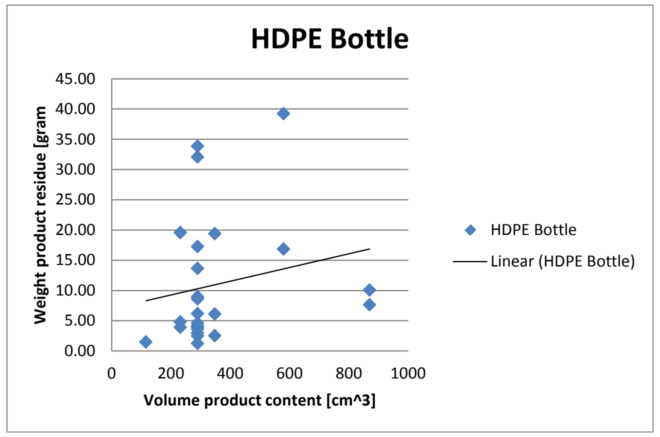
Graph 7.2 - Relation between product residue and volume product content soups pouch



Assumptions:

Product residue
- n=10
- Density content ρ=1.08 gram/ml {n=8}

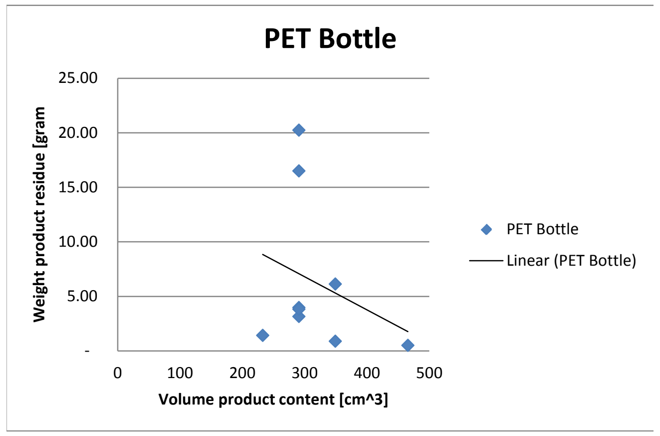
Graph 7.3 - Relation between product residue and volume product content soups liquid carton



Assumptions:

Product residue
- n=25
- Density content ρ=1.16 gram/ml {n=2 PET bottle}

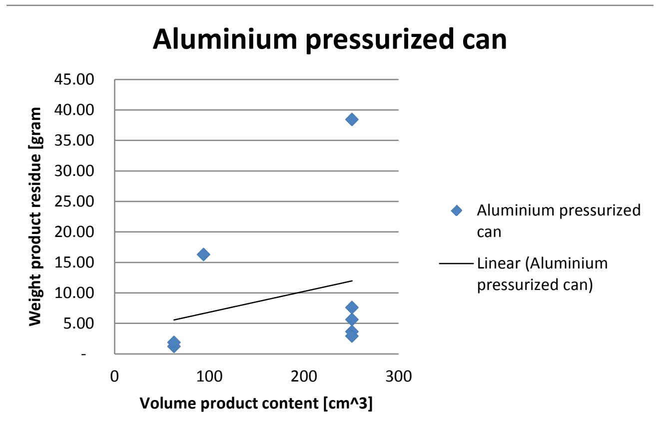
Graph 7.4 - Relation between product residue and volume product content shower gels HDPE bottle



Assumptions:

Product residue
- n=9
- Density content ρ=1.16 gram/ml {n=2}
- Emptied two bottles myself

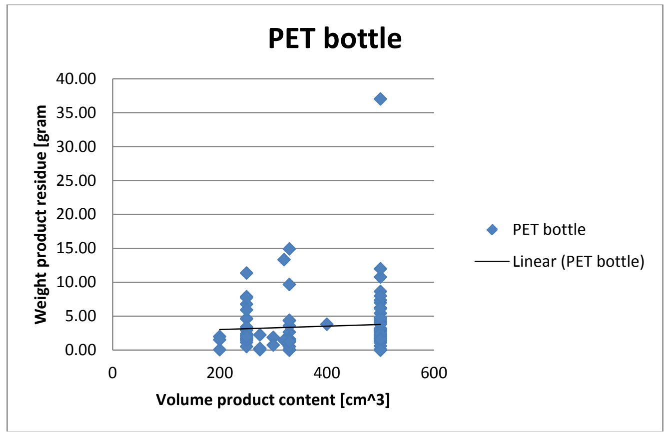
Graph 7.5 - Relation between product residue and volume product content shower gels PET bottle



Assumptions:

Product residue
- n=8
- Density content ρ=1.25 gram/ml {n=5}
- Emptied five bottles myself

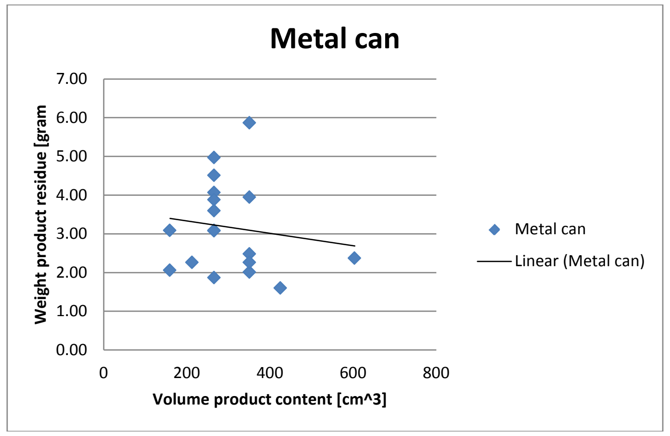
Graph 7.6 - Relation between product residue and volume product content shower gels aluminium pressurized can



Assumptions:

Product residue
- n=98
- Density content ρ=1.00 gram/ml {water}

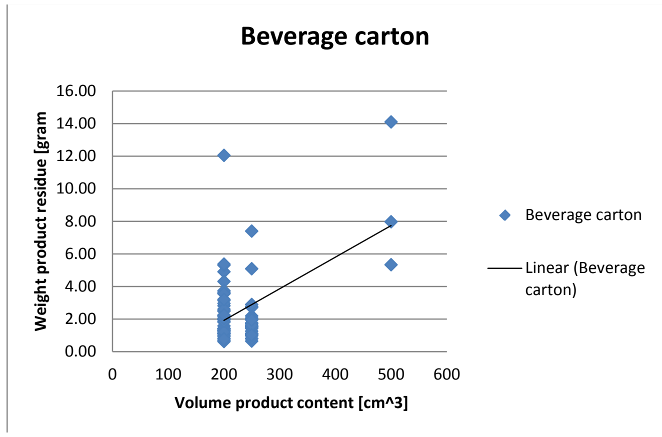
Graph 7.7 - Relation between product residue and volume product content non-carbonated beverages PET bottle



Assumptions:

Product residue
- n=18
- Density content ρ=1.06 gram/ml {n=2}

Graph 7.8 - Relation between product residue and volume product content non-carbonated beverages metal can

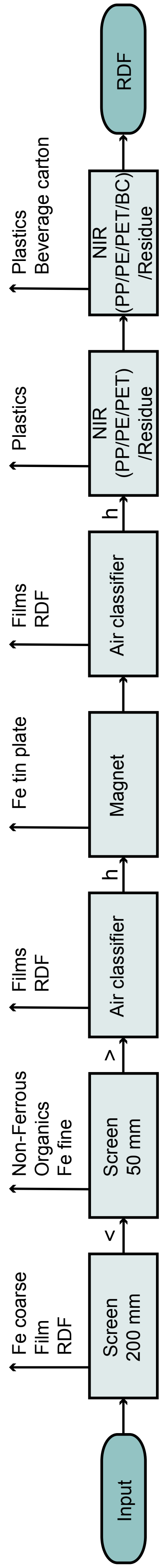


Assumptions:

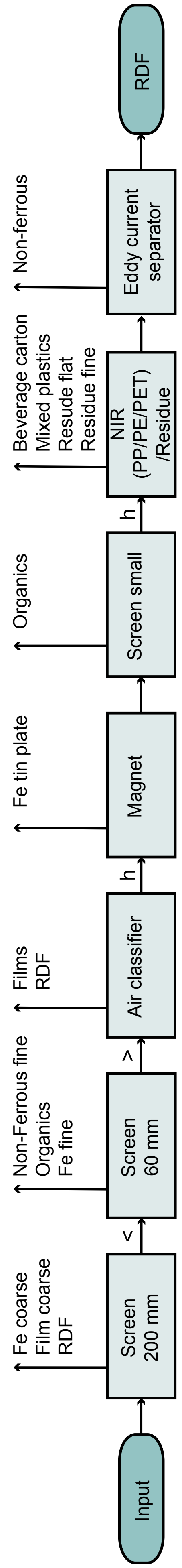
Product residue
- n=75
- Density content ρ=1.00 gram/ml {water}

Graph 7.9 - Relation between product residue and volume product content non-carbonated beverages beverage carton

8.1 Recovery facilites

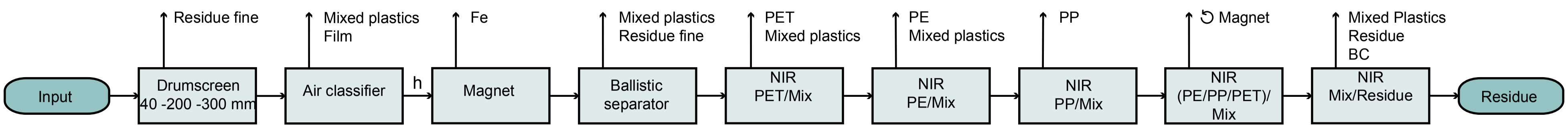


Attero Noord, Groningen

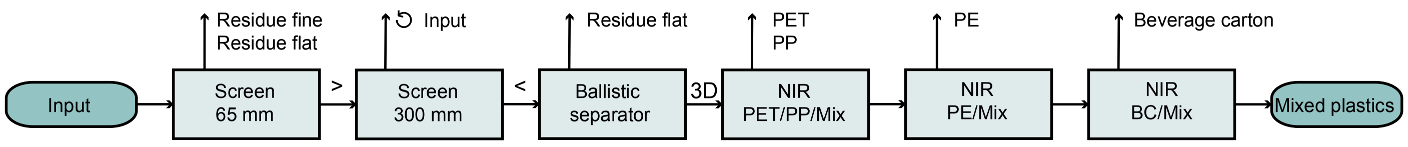


Omrin, Oudehaske

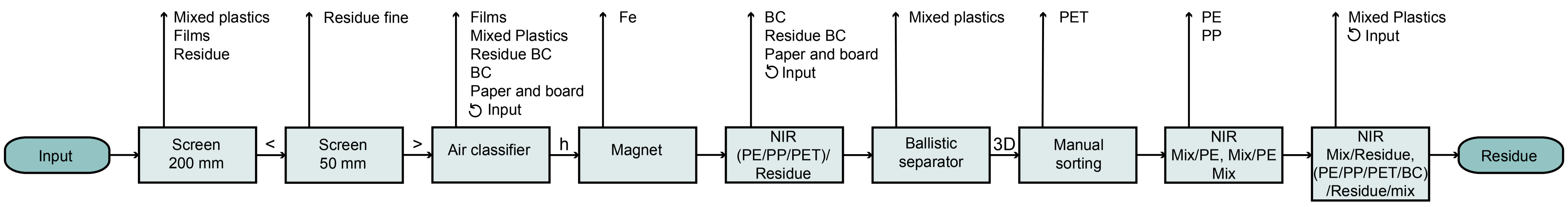
8.2 Plastic sorting facilities



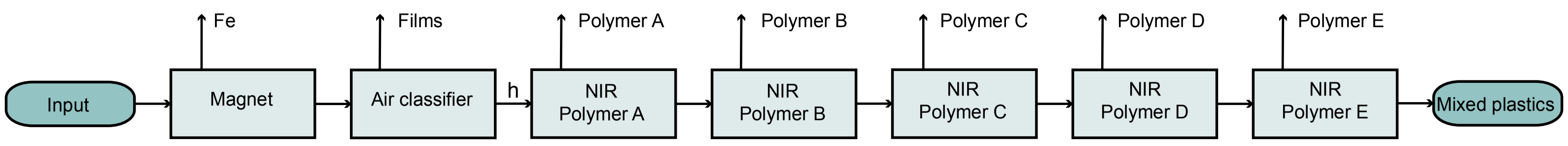
SITA, Rotterdam



Augustin, Meppen



Schönmackers, Kempen



Smaller German plastic sorting plant

9 DATA PLASTIC PACKAGING RECYCLING

		PE	PP	PET	Residue	Mixed plastics heavy	Fe, non-Fe and BC	Mixed plastic light	Films	Fines	Coarse
N-C PET bottles	Average	0.6%	0.6%	64.1%	6.9%	19.2%	1.1%	3.3%	1.0%	1.3%	2.5%
	Minimum	0.0%	0.0%	43.2%	0.7%	1.5%	0.3%	0.9%	0.0%	0.4%	0.2%
	Maximum	1.3%	1.5%	93.3%	18.2%	42.4%	3.4%	6.6%	2.7%	1.9%	5.5%
Shower gel PET bottle	Average	0.3%	0.3%	54.8%	7.0%	33.3%	0.5%	1.2%	0.0%	0.6%	2.0%
	Minimum	0.0%	0.1%	19.9%	0.5%	4.8%	0.2%	0.0%	0.0%	0.1%	0.1%
	Maximum	0.6%	0.9%	90.2%	23.6%	71.5%	1.0%	4.5%	0.3%	1.0%	4.1%
Shower gel HDPE	Average	75.3%	7.2%	0.5%	3.4%	10.5%	0.4%	0.7%	0.5%	0.3%	1.1%
	Minimum	70.4%	0.0%	0.0%	0.2%	2.8%	0.1%	0.1%	0.0%	0.1%	0.0%
	Maximum	89.8%	0.5%	1.5%	5.6%	19.0%	2.1%	1.4%	1.4%	0.6%	2.7%

10 CALCULATION OF 3X3 MATRIX PACKAGES MECHANICAL RECYCLING EFFICIENCY

10.1 Shower gel PET bottle

Marketshare [amount] (Euromonitor, 2014)	2090000	
Average weight with residue [kg]	0.037	{n=9}
Percentage recycled plastic packages [%] (Nedvang,2013)	46%	{Nedvang, all plastic packages}
Amount recycled packages	961400	
Estimated weight of recycled shower gel PET bottles [kg]	35542.958	Market share * Average weight with residue [gram] * percentage recycled packages [%]
Wrong separated packages [kg]	3554.296	{DKR-specification admission of 10% of recycled packages are wrong separated packages}
Total input mechanical recycling [kg]	39097.254	

Composition {n=9}	PET	PP	PE	PS
Percentage [%]	74.40%	22.70%	1.60%	1.40%
Density [gram/cm^3]	1.38	0.92	0.9	1.00

100.0%	Input	39097.254	kg input
0.0%	Comminution		
7.3%	Manual screening	2843.437	80% of the wrong separated packages (Thoden van Velzen, 2015)
16.4%	Washing	355.430	10% of the wrong separated packages (Thoden van Velzen, 2015)
Dry weight	29495.752	6047.206	Product residue = Amount of recycled packages * 0.00629 average residue [kg] (Euromonitor, 2014 and Composition research)
		6402.636	Total weight separated by washing
19.8%	Density separation	355.430	10% of the wrong separated packages (Thoden van Velzen, 2015)
		7373.938	1.6% PE and 22.7% PP and 0.7% PS of dry weight (Composition research)
		7729.368	Total weight separated by density separation
0.0%	Centrifugation		
0%	Oven		
0%	Extruder		
56.2%	Sorted plastic waste	21944.839	74.4% PET of dry weight (Composition research)
		20.647	0.7% PS of dry weight (Composition research)
100%		21965.487	Total weight sorted plastic waste
		56.1%	PET Sorted of total weight plus 0.4% pollution (of total weight)
		21944.839	kg PET sorted

10.2 Shower gel HDPE bottle

Marketshare [amount] (Euromonitor, 2014)	56810000	
Average weight with residue [kg]	0.043	{n=25}
Percentage recycled plastic packages [%] (Nedvang,2013)	46%	{Nedvang, all plastic packages}
Amount recycled packages	26132600	
Estimated weight of recycled shower gel HDPE bottles [kg]	1120565.888	Market share * Average weight with residue [gram] * percentage recycled packages [%]
Wrong separated packages [kg]	112056.589	{DKR-specification admission of 10% of recycled packages could be wrong separated packages}
Total input mechanical recycling	1232622.477	

Composition {n=23}	PE	PP	PET
Percentage [%]	82.43%	17.30%	0.20%
Density [gram/cm^3]	0.90	0.92	1.38

100.0%	Input	1232622.477	kg input
0.0%	Comminution		
7.3%	Manual screening	89645.271	80% of the wrong separated packages (Thoden van Velzen, 2015)
24.3%	Washing	11205.659	10% of the wrong separated packages (Thoden van Velzen, 2015)
		287719.926	Product residue = Amount of recycled packages * 0.01101 average residue [kg] (Euromonitor, 2014 and Composition research)
Dry weight	832845.962	298925.585	Total weight separated by washing
1.0%	Density separation	11205.659	10% of the wrong separated packages (Thoden van Velzen, 2015)
		1665.692	0.2% PET of dry weight
		12871.351	Total weight separated by density separation
0.0%	Centrifugation		
0%	Oven		
0%	Extruder		
67.4%	Sorted plastic waste	686514.926	82.43% PE of dry weight (Composition research)
		144082.351	17.30 % PP of dry weight(Composition research)
100%		830597.278	Total weight sorted plastic waste
		55.7%	HDPE Sorted of total weight plus 3.4% pollution (of total weight)
		686514.926	kg HDPE sorted

10.3 Non-carbonated beverages ≤0.5 litre PET bottle

Market share [amount] (Euromonitor, 2014)	752540000	{not specified on ≤0.5 litre}
Average weight with residue [kg]	0.028	{n=102}
Percentage recycled plastic packages [%] (Nedvang,2013)	46%	{Nedvang, all plastic packages}
Amount recycled packages	346168400	
Estimated weight of recycled non-carbonated beverages PET bottles [kg]	9782026.647	Market share * Average weight with residue [gram] * percentage recycled packages [%]
Wrong separated packages	978202.665	{DKR-specification admission of 10% of recycled packages are wrong separated packages}
Total input mechanical recycling	10760229.312	

Composition {n=102}	PET	PE	PP	PS	PA	Paper	Metal
Percentage [%]	84.00%	10.80%	3.80%	0.80%	0.10%	0.60%	0.02%
Density [gram/cm^3]	1.38	0.90	0.92	1.00	1.15	-	-

100.0%	Input	10760229.312	kg input
0.0%	Comminution		
7.3%	Manual screening	782562.132	80% of the wrong separated packages (Thoden van Velzen, 2015)
		1708.549	0.02% metal of dry weight (Composition research)
		784270.681	Total
12.4%	Washing	97820.266	10% of the wrong separated packages (Thoden van Velzen, 2015)
Dry weight	8542743.775	1239282.872	Product residue = Amount of recycled packages * 0.00358 average residue [kg] (Euromonitor, 2014 and Composition research)
		1337103.138	Total separated by washing
12.8%	Density separation	97820.266	10% of the wrong separated packages (Thoden van Velzen, 2015)
		1281411.566	10.8% PE and 3.8% PP and 0.4% PS of dry weight(Composistion research)
		1379231.833	Total weight separated by density separation
0.5%	Centrifugation	51256.463	0.6% Paper of dry weight (Composition research)
0%	Oven		
0%	Extruder		
67.1%	Sorted plastic waste	7175904.771	84.0% PET (Composition research)
		42713.719	0.4% PS and 0.1% PA (Composition research)
100%		7218618.490	Total weight sorted plastic weight
		67%	PET Sorted of total weight plus 0.7% pollution (of total weight)
		7175904.771	kg PET sorted

10.4 Soups metal can

Marketshare [amount] (Euromonitor, 2014)	96650000	
Average weight with residue [kg]	0.093	{n=19}
Percentage recycled metal packages [%] (Nedvang,2013)	93%	{Nedvang, all metal packages}
Amount recycled packages	89884500	
Estimated weight of recycled soups metal cans [kg]	8347573.515	Market share * Average weight with residue [gram] * percentage recycled packages [%]

Composition {n=20}	Tin plate	Coating	Paper
Percentage [%]	95.74%	0.30%	4.00%

100.0%	Input	8347573.515	kg input
0.0%	Comminution		
0.0%	Eddy current separator		
Dry weight	7112560.485		
18.5%	Hot air	1235013.03	Product residue = Amount of reycled packages * 0.01374 average residue [kg] (Euromonitor, 2014 and Composition research)
		305840.101	0.3% Coating and 4.0% Paper of dry weight (Compositon research)
		1540853.131	Total weight incinerated
0.0%	Furnance		
81.5%	Purified metal	6806720.384	95.7% Tin plate of dry weight (Composition research)
100.0%		81.5%	Tin plate sorted (of total weight)
		6806720.384	kg aluminium sorted

10.5 Shower gel aluminium pressurized can

Marketshare [amount] (Euromonitor, 2014)	2200000	
Average weight with residue [kg]	0,05027	{n=8}
Percentage recycled metal packages [%] (Nedvang,2013)	93%	{Nedvang, all metal packages}
Amount recycled packages	2046000	
Estimated weight of recycled shower gels aluminium pressurized cans [kg]	102852,42	Market share * Average weight with residue [gram] * percentage recycled packages [%]

Composition {n=8}	Aluminium	PE	PP	POM	PA	Rubber	Metal	Plastics
Percentage [%]	78.13%	1.31%	11.62%	0.13%	0.34%	1.24%	0.50%	6.74%

100,0%	Input	102852,42	kg input
0,0%	Comminution		
0,4%	Magnet	415,13	0.5% metal of dry weight weight (Composition research)
Dry weight	83026,68		
36,5%	Hot air	19825,74	Product residue = Amount of reycled packages * 0.00969 average residue [kg] (Euromonitor, 2014 and Composition research)
		17742,802	1.3% PE, 11.6% PP, 0.1% POM, 0.3% PA, 1.2% rubber, 6.7% Plastics of dry weight (Compositon research)
		37568,542	Total weight incinerated
0,0%	Furnance		
63,1%	Purified metal	64868,745	78.1% Aluminium of dry weight (Composition research)
100,0%		63,1%	Aluminium sorted (of total weight)
		64868,745	kg aluminium sorted

10.6 Non-carbonated beverages ≤0.5 litre metal can

Marketshare [amount] (Euromonitor, 2014)	459760000	
Average weight with residue [kg]	0.01574	{n=17, without tinplate beverage can}
Percentage recycled metal packages [%] (Nedvang,2013)	93%	{Nedvang, all metal packages}
Amount recycled packages	427576800	
Estimated weight of recycled non-carbonated beverages metal cans [kg]	6730058,83	Market share * Average weight with residue [gram] * percentage recycled packages [%]

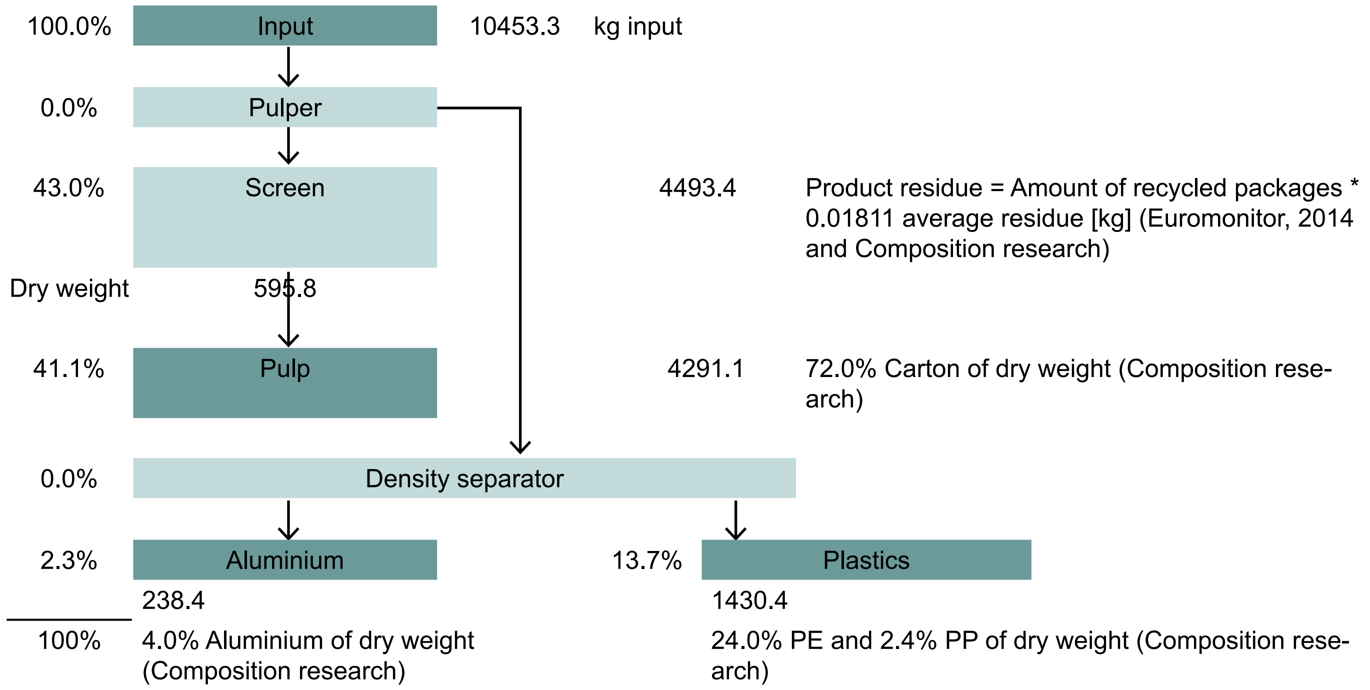
Composition {n=18}	Aluminium	Coating	PP
Percentage [%]	99.29%	0.30%	0.39%

100.0%	Input	6730058,83	kg input
0.0%	Comminution		
0.0%	Magnet		
Dry weight	6298206.264		
20.7%	Hot air	1355418.456	Product residue = Amount of recycled packages * 0.00317 average residue [kg] (Euromonitor, 2014 and Composition research)
		37085,01859	0.30% Coating and 0.39% PP of dry weight (Compositon research)
		1392503,475	Total weight incinerated
0.0%	Furnance		
79.3%	Purified metal	5336480,429	99.29% Aluminium of dry weight (Composition research)
100%		79,3%	Aluminium Sorted (of total weight)
		5336480,429	kg aluminium sorted

10.7 Soups liquid carton

Marketshare [amount] (Euromonitor, 2014)	590760	
Average weight with residue [kg]	0.04213	{n=8}
Percentage recycled liquid carton packages [%] (HEDRA, 2015)	42%	{HEDRA, European recycled liquid cartons}
Amount recycled packages	248119.2	
Estimated weight of recycled soups liquid carton [kg]	10453.3	Market share * Average weight with residue [gram] * percentage recycled packages [%]

Composition {n=10}	Carton	PE	Al
Percentage [%]	72.0%	2.40%	4.0%
Density [gram/cm^3]	-	0.90	0.27

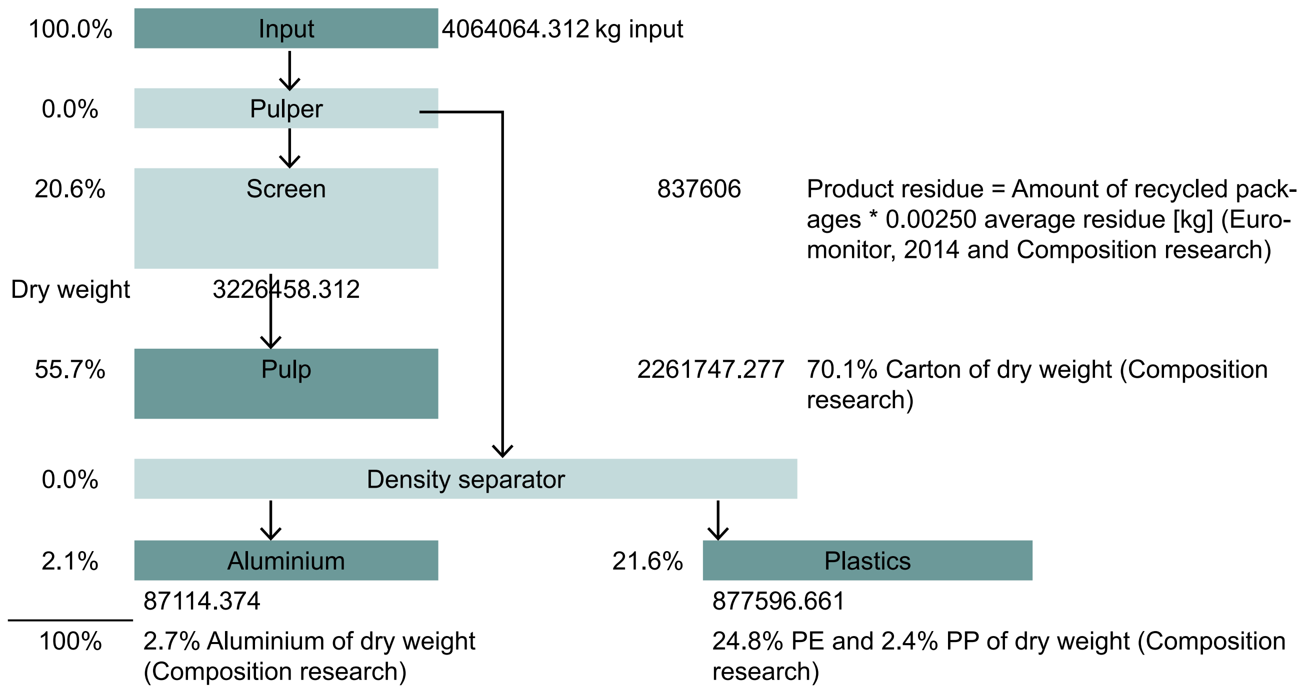


41.1%	Carton sorted plus 42.9% pollution (of total weight)
4291.1	kg carton sorted

10.8 Non-carbonated beverages ≤0.5 litre beverage carton

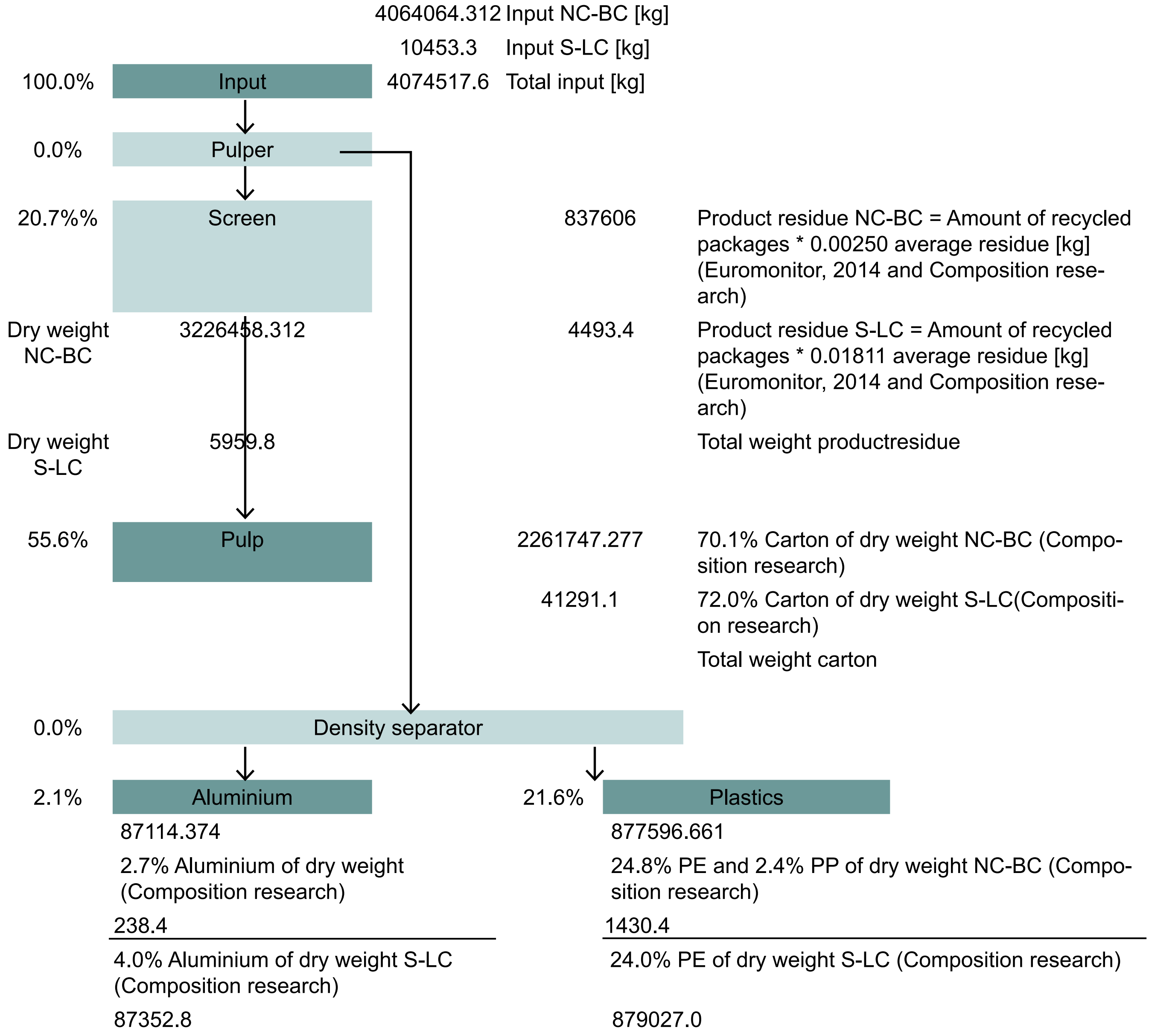
Marketshare [amount] (Euromonitor, 2014)	797720000	
Average weight with residue [kg]	0.012	{n=75}
Percentage recycled liquid carton packages [%] (HEDRA, 2015)	42%	{HEDRA, European recycled liquid cartons}
Amount recycled packages	335042400	
Estimated weight recycled non-carbonated beverages beverage carton [kg]	4064064.312	Market share * Average weight with residue [gram] * percentage recycled packages [%]

Composition {n=58}	Carton	PP	PP	Al
Percentage [%]	70.10%	24.80%	2.40%	2.70%
Density [gram/cm^3]	-	0.90	0.92	0.27



55.7%	Carton sorted plus 20.6% pollution (of total weight)
2261747.277	kg carton sorted

10.9 Combination of Soups liquid carton (S-LC) and non-carbonated beverages ≤0.5 litre beverage carton (NC-BC)



Total carton	2266038.3	55.6%
Total residue	842099.4	20.7%
Total aluminium	87352.76	2.1%
Total Plastics	879027.02	21.6%
	4074517.6	100%