Recycling of Flexible Packaging using a sink-float method

Separation and Economic Analysis

BSc. Thesis

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Abstract

The European Commission proposed to increase recycling of packaging to 80% by 2030. This undermines the goal of a resource efficient Europe, because this may lead to the substitution of flexible packaging with the relatively easy to recycle rigid packaging. Developing a feasible method to separate materials in flexible packaging can contribute to the substitution of rigid packaging with flexible packaging, and can result in saving millions of tonnes of packaging material from being used and disposed, as well as reducing greenhouse gas emissions, water usage, and transport costs.
The goal of this project was to test a sink-float method for the separation of materials from a type of flexible packaging that consists of 77% LDPE, 12% aluminium and 11% PET. A bench-scale set-up was constructed and multiple experiments were performed. A product of 98.6% pure LDPE was produced from the float fraction of the set-up and has value and a destination in injection moulding. The aluminium product had a grade ranging from 58% to 82% depending on the recovery. This could possibly be upgraded to 90% by a simple sieving step in the process. The aluminium product needs to be processed further before it can go to its next destination. It needs to be briquetted to be useful for a smelter. An economic analysis was performed including an estimation of investment costs, earnings and Net Present Values of different scenarios. All were considered feasible. Even if an aluminium product of around 50% purity is made, the process would still be feasible due to the LDPE product. However, much value is given away like this, and adding a step to the process to concentrate the aluminium further could be well worth the effort.

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1. Introduction

1.1 Background

The Resource-Efficient Europe Flagship Initiative is part of the Europe 2020 Strategy, the EU's growth strategy for a smart and sustainable economy.
The Communication "Towards a Circular Economy" further promotes a fundamental transition in the EU, away from a linear economy where resources are not simply extracted, used and disposed, but are recycled so they can stay in use for longer.
As part of the circular economy package, the European Commission adopted a legislative proposal to review recycling and other waste-related target in the EU.

The proposal aims to:

- Increase recycling/re-use of municipal waste to 70% in 2030;
- Increase packaging waste recycling/re-use to 80% in 2030 with material-specific targets set to gradually increase between 2020 and 2030. [1]

Flexible Packaging Europe (FPE) stated in the presentation: "Towards a Resource Efficient Europe"

> *"A concern of the FPE is that focusing solely on high material recycling targets may lead to substitution of flexible packaging due to the relative ease of recycling rigid packaging, hereby undermining the overall objective for a more resource efficient Europe*."

To understand why this would undermine the objective for a resource efficient Europe, one needs to know what flexible packaging is. Flexible packaging is packaging material made of flexible or easily yielding materials that, when filled or closed, can be readily changed in shape.
Flexible packaging has been one of the fastest growing segments in packaging for the last decade and still new products are being developed. It has developed from simple monolayer bags and wrappings to multilayer structures incorporating different material properties from plastics, paper and metal foils, to provide high barrier properties and an increased shelf life. Besides the significant performance advantages, flexible packaging also has reduced material and transportation costs compared to rigid packaging. It also allows packaging to be assembled from roll materials at the filling location, removing the need to transport ready-formed but empty packaging. A well-known example of flexible packaging replacing rigid packaging is the pouched soup products replacing canned soup. [2]

Today 40% of the food packaging material in Europe is flexible packaging. [3]
The FPE has asked the IFEU (Institut für Energie und Umweltforschung) to do a hypothetical Life Cycle Analysis study of the following scenarios:

1. All flexible food packaging was substituted by non-flexible packaging.
2. All non-flexible packaging was substituted by flexible packaging.

Results of scenario 1, with 100% recycling:

- Increases packaging by 23.3 million tonnes of material per year. (67% by weight)
- Increases the carbon footprint by 6 million tonnes CO2-equivalent. (5.6%)
- Increases the water footprint by 32.8 million m3 of water. (5.3%)

Results of scenario 2, with no recycling:

- Decreases packaging by 26 million tonnes of material per year. (77%)
- Decreases the carbon footprint by 42 million tonnes of CO_2 equivalent. (39%)
- Decreases the water footprint by 276 million m^3 of water. (44%)

Replacing more rigid packaging with flexible packaging will contribute to the resource efficiency, but will lower the amount of packaging being recycled, which will result in the targets not being met. Today, no flexible packaging is being recycled industrially, while about 64% of rigid packaging is being recycled. [3]

1.2 Purpose of Research

Even if flexible packaging is a more sustainable form of packaging with zero recycling, finding a feasible recycling method for flexible packaging can contribute to meeting the EU's recycling targets as well as replacing more rigid packaging with flexible packaging. The purpose of this research is to find a suitable method for recycling the given type of flexible packaging. Not only does the method need to work technically, it is also desirable for the method to eventually be profitable in a full scale operation. Only then will the method be actively picked up by the industry. For this purpose a calculation into full scale will be done, and an economic analysis of the material will be given.

Developing a feasible method to separate materials in flexible packaging can contribute to the substitution of rigid packaging with flexible packaging, and can result in saving millions of tonnes of packaging material from being used and disposed, as well as reducing greenhouse gas emissions, water usage, and transport costs.

1.3 Project Description

1.3.1 Material

The project will focus on a type of flexible packaging that consists of three materials, namely Low Density Polyethylene (LDPE), Polyethylene terephthalate (PET) and aluminium. This material is production waste from the production process of flexible packaging containers. The material consists of circular and heart-shaped flakes that were punched out of sheets, and have been peeled chemically.

Figure 1.1 Sample of the material

1.3.2 Separation Method

The separation method that will be tested is a sink-float method which aims to separate the material based on their densities and settling velocities. The material will be fed into a water tank which will have a steady laminar flow running through it. It is expected that the LDPE will float on the water, and the aluminium and PET will sink. However, because it is expected that aluminium will sink faster than PET, the two materials can be separated by splitters on the bottom of the tank.

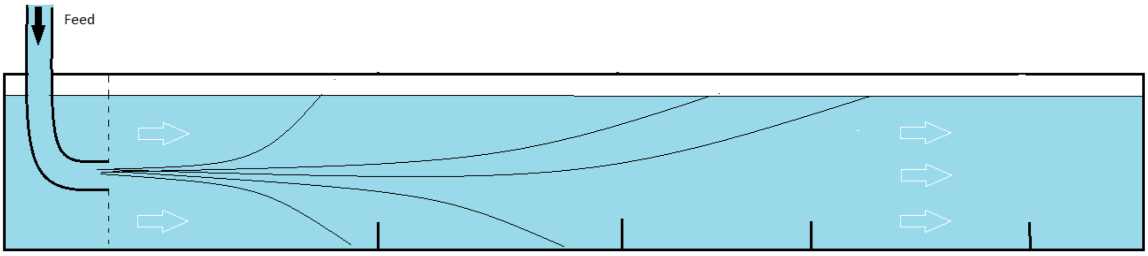


Figure 1.2 Sketch of the separation principle

1.3.3 Wetting

To separate the material using this method, the material needs to be well wetted. If the material is not wetted the behaviour is influenced by air in the material. This is especially the case for the aluminium particles, since they contain folds where air can be trapped inside. The aluminium particles will actually float if they are not wetted. There are also clusters of particles which have air trapped inside; an example is shown in figure 1.3.

Figure 1.3 Left: Air trapped inside a cluster of PET particles. Right: Floating aluminium

The method for wetting has been chosen based on previous research. The material will be boiled in tap water, which will deposit a thin layer of calcium carbonate on the material.[4] Afterwards the material will be put into a vacuum, which removes the air from the material and allows water to enter folds and 'pores'.

1.3.4 Research questions

- Is the sink-float method a feasible method to recycle the flexible packaging material?

Sub-questions

- What is the most economical material to focus the separation process on?
- How can we address the challenges for recycling flexible packaging using this method?
- What does the current European market and recycling situation look like?
- Will a full scale setup be feasible for recycling?
- Does the material need to be treated further after applying this method?

2. Methods

2.1 Material Analysis

For analyses and experiments a batch of the material of ca. 1.8 kg was available. Any sample that was taken from this batch was done so representatively by splitting the material using a sample splitter.

2.1.1 Composition

Composition analysis was done through hand sorting and weighing of the material. Care was taken not to separate any combinations of particles, such as an aluminium piece rolled up in a piece of PE. These kinds of combinations of materials were classified as such at first.
Because the types of combinations are very diverse, a composition of the material was measured where combinations of materials were separated, and a pure composition of the three components was determined. An exception is the combination of one piece of PET and one piece of aluminium glued together, which is difficult to separate and is treated as its own type for now
Furthermore, after each separation experiment with the sink-float method, the output material was analysed which also resulted in a composition of the input material. Combining this with the first analysis, a total of 9 measurements give a good result of the composition of the material.

2.1.2 Particle mass

The mass of individual particles was measured by taking 10 particles of each material and measuring the weight. Dividing that weight by ten gives the average mass of an individual particle.

2.1.3 Bulk density

The bulk density of the material was calculated by measuring the weight of a sample and measuring the volume of that sample in a graduating cylinder. This measurement was performed for dry, uncompressed material as well as for wet, drained, uncompressed material.

2.1.4 Settling velocity

The settling velocities were measured by releasing wetted particles in a graduating cylinder filled with water. The settling time or rising time between two marked heights in the cylinder was measured and thus the settling velocity was calculated. For each material type 20 measurements were made.

2.2 Prediction Model

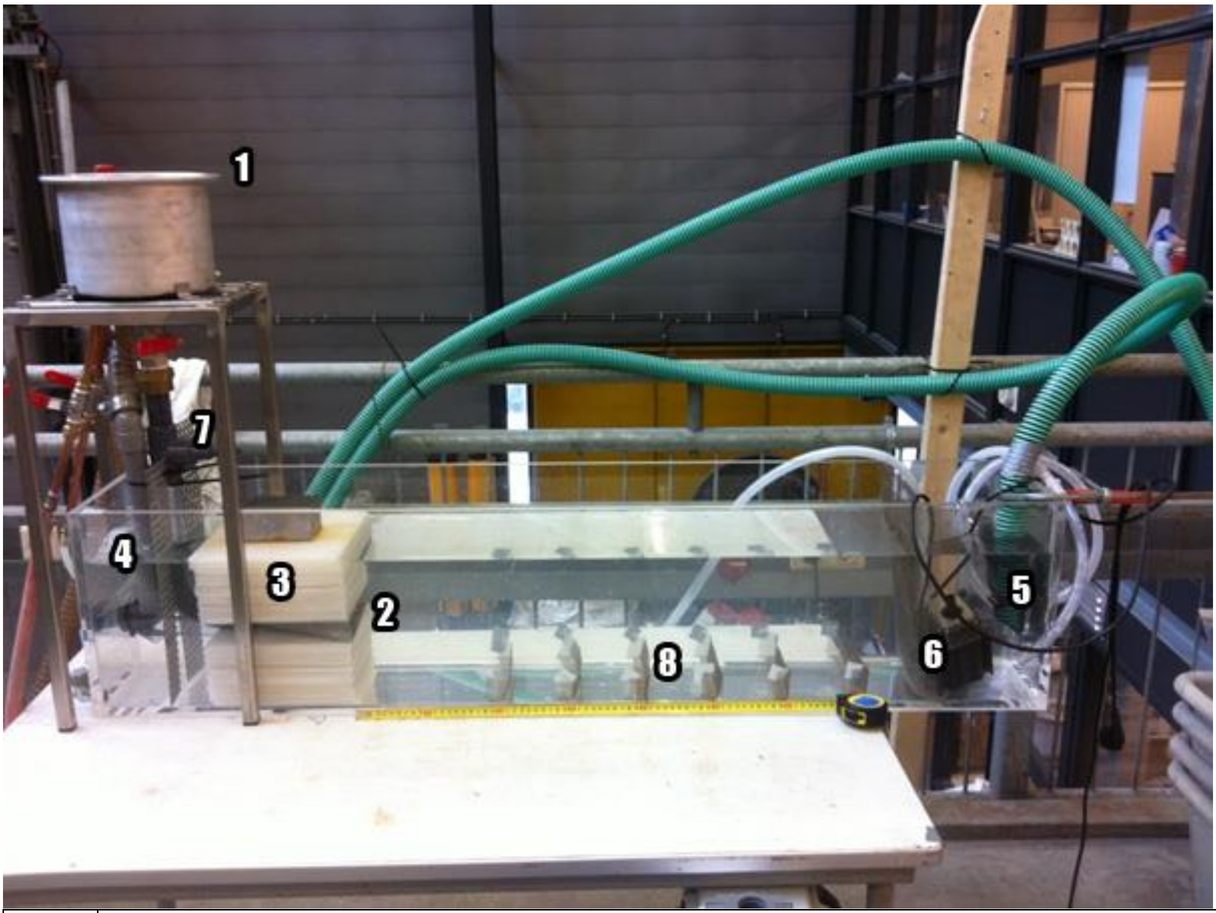
To predict what the effect of different parameter changes would be in the experiments, a Matlab code was written. The program uses the measurements of settling velocities and material composition to simulate the outcome of the experiment with different parameters such as flow velocity.
The simulation takes a number of particles from each material based on the sample input size and determined mass composition. For each of these particles a settling velocity is 'drawn' from a probability distribution, which has been made from the settling velocity measurements. The simulation puts each particle through the tank with the given flow velocity, and records its output location on either the bottom of the tank or the water surface.
The simulation uses only individual particles of the three materials. Since the real material contains all sorts of combinations of materials, this simulation cannot predict the true outcome. However, it can give some valuable insight into how the flow velocity affects the outcome.

2.3 Separation

2.3.1 Experimental Set-up

The experimental set-up consists of a Plexiglas (PMMA) water tank with measurement 0.20 x 0.30 x 1.30 m which will have a water height of 20 centimetres. Water is pumped out from the end of the tank and into the beginning of the tank by two pumps. Each pump has an adjustable flowrate of up to 7 m^3/h.

Figure 2.1 Picture of the experimental set-up. On the left the main pumps can be seen.



1	Vacuum Chamber
2	Spout
3	Laminator Sheets
4	Main pump output
5	Main pump input
6	Submergible pump
7	Acentric input for submergible pump for mixing
8	Splitters

Figure 2.2 Side view of set-up

The laminar flow is achieved by a stack of laminator sheets containing small channels inside them. The material is fed into the tank from a vacuum chamber located above the tank, in which the material is wetted. The material is fed from the bottom of the chamber through a pipe which makes a 90 degree angle into the tank and ends in a spout. The purpose of the spout is to spread the material coming into the tank along the width. Two types of spouts were used.
The first is a spout with a 67° angle and parallel running top and bottom. This is called the straight spout.

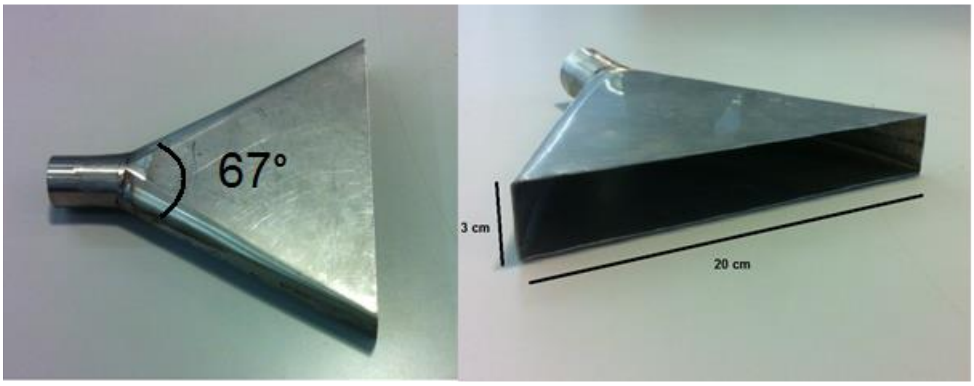


Figure 2.3 Straight Spout

Because normally material diverges with a 6° angle, the angle is too wide to properly spread the material along the width of the tank. Therefore, another spout was made. The converging spout has the top and bottom sides converging from 3 cm to 1 cm, which causes a better spread of the material along the width of the tank.

Figure 2.4. Converging spout

The material is fed through by pumping water into the chamber from the tank using a submergible pump with a flowrate of 0.12 m^3/ h. Another submergible pump pumps in water into the pipe with an acentric hole which causes a vortex to form in the pipe which mixes the material. The total water flow out the spout is 0.24 m^3/ h. For the straight spout this results in a flow velocity of about 2 cm/s from the spout.

Inside the chamber a tube is placed which directs the incoming water flow to above the outlet opening, which allows for some mixing of the material and prevents clogging of the pipe.

1	Air inlet
2	Water inlet
3	Main valve
4	Acentric water input
5	Tube shape inside vacuum chamber

Figure 2.5. Vacuum chamber

2.3.2 Experimental Procedure

The material was wetted by boiling it and putting it in a vacuum. The first step is boiling the material in tap water for 2-3 minutes. After boiling the material is drained and transferred to the vacuum chamber. The chamber is closed and the material is kept in a high vacuum (about 760 mmHg or 1 bar pressure difference) for 2 minutes. The valve under the chamber is opened slightly to raise the water level in the tube to the bottom of the chamber. The valves are closed again. The vacuum is released by opening the air inlet and the material is now considered wetted.

The main pumps are started to create a laminar flow through the tank. The two submergible pumps are turned on. The chamber is filled with water by opening the water inlet valve. The main valve underneath the chamber is opened. The water and material now flows out of the chamber into the tank with the volumetric flow of the two submergible pumps. Every now and then the air inlet is opened slightly which drains the water from the chamber and allows for the floating material to be fed into the tank. After this the main valve is closed temporarily to allow the chamber to fill again. This process is repeated until all the material has been fed into the tank.

The parameters for each test that was performed is given in table 2.1

Parameters for each test				
	Flow velocity (cm/s)	Output type	Output height (cm)	Remarks
T0	2.8	Straight	10	No splitters
T1	2.8	Straight	8	
T2	3.5	Straight	8	
T3	3.5	Converging	8	
T4	3.0	Converging	18	
T5	2.1	Straight	8	
F1	Unknown	Straight	8	Invalid: Turbulent flow
F2	4.9	Straight	8	Invalid: Turbulent burst and overflowing

Table 2.1

2.4 Economic Analysis

The economic analysis was done with a literature review and interviews with some knowledgeable people from the recycling industry. Norbert Fraunholcz, owner of Recycling Avenue B.V., was asked about the value of the LDPE product and possible destinations. Jelle Sernee from Synvase was asked about the value and options for the aluminium product.

3. Results

3.1 Material Analysis

3.1.1 Description

The researched material is a mix of foils of LDPE, PET and aluminium. The material consists of thin circle and heart shaped flakes with a diameter of 12 mm. The material was at some point glued together and has been peeled chemically, but still some particles remain glued to each other.

3.1.2 Composition

A representative sample of 23.6 g was analysed. The materials were separated by hand through determination by sight. The following mass composition was measured.

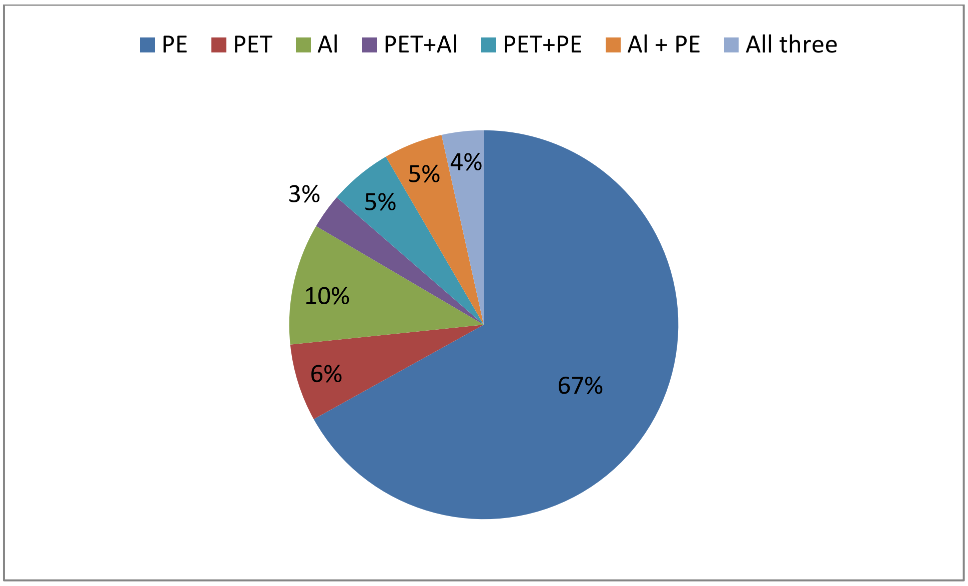


Figure 3.1. Composition of the material, including combinations

In the hand sorting process care was taken not to separate the materials that were in any way connected to each other. This explains the combinations of materials.

Examples of combinations:

- LDPE and aluminium: this only occurs when an aluminium particle is wrapped inside a LDPE particle. See figure 3.2
- LDPE and PET: glued together or LDPE stuck in PET cluster.
- Aluminium and PET: particles of PET and aluminium still glued together. See figure 3.4
- All 3: combination of glued and clustered.

Figure 3.2 Aluminium particle wrapped in LDPE particles.

After the first analysis, the combinations of materials were separated and again a mass composition was determined. Together with the determined mass compositions of input material from the 8 sink-float separation tests, the average composition was determined and is given in figure 3.3

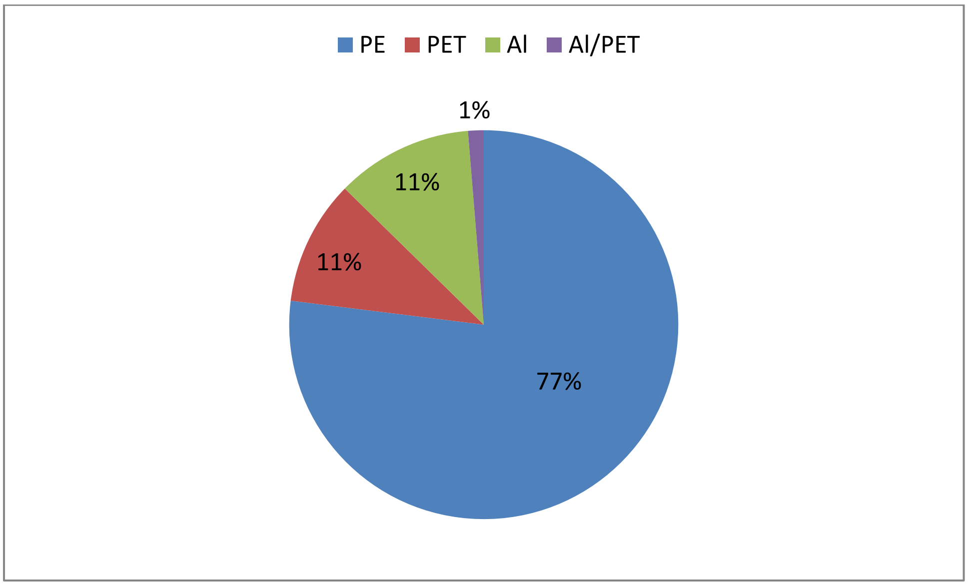


Figure 3.3 Mass composition of the material.

The Al/PET combinations are treated as a separate material because it is difficult to separate. It consists of one part aluminium foil and one part PET foil.

Figure 3.4 AL/PET combination

3.1.3 Bulk density

The dry, uncompressed bulk density of the material is 60 kg/m3. Wetted and drained the material has a bulk density of 75 kg/m^3.

3.1.4 Settling Velocities

The settling velocities were measured by releasing wetted particles in a graduating cylinder filled with water. The time how long a particle took to sink, or float, between two marked heights was measured, and thus the velocity was calculated. The results are given in table 3.1

Settling velocities		
Material	Settling velocity mean (cm/s)	Settling velocity standard deviation
LDPE	-0.96	0.23
PET	1.67	0.12
Aluminium	2.27	0.35

Table 3.1

The aluminium has the highest variation in settling velocities, which is attributed to the variation in shape of the particles, due to folding of the material.

3.2 Prediction Model

First the settling velocity and mass distribution data is imported into Matlab. For demonstration purpose, the sample size is chosen at 1 gram. To visualize what the effects of flow speed are, plots are made for 4 cm/s, 8 cm/s and 12 cm/s and are shown in figure 3.5. The y = 10 line should be considered the water surface in the tank, and the y = -10 line is the bottom of the tank, so the spout is located at y = 0.

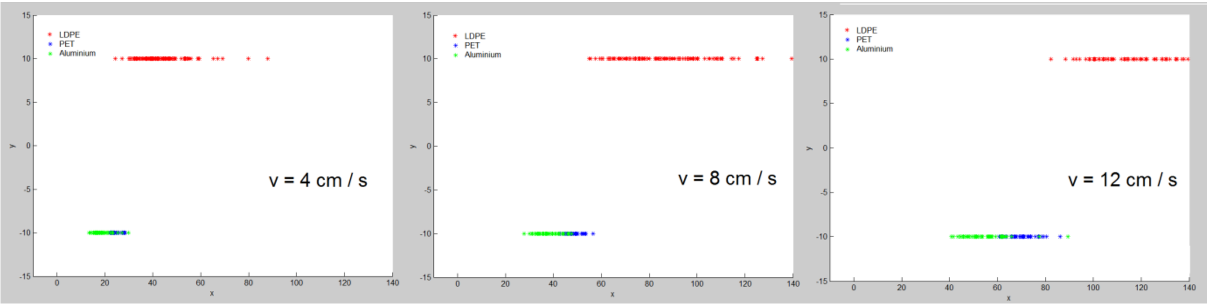


Figure 3.5. Plots of simulation outcome with different velocities

The script is extended by increasing the velocity with each step and plotting the grade-recovery curve for aluminium for each flow velocity. Figure 3.6 shows the plots for a sample of 80 grams and velocities ranging from 2 to 8 cm/s. It can be seen that the separation performance increases with velocity; this can also be predicted from the plots in figure 3.5.

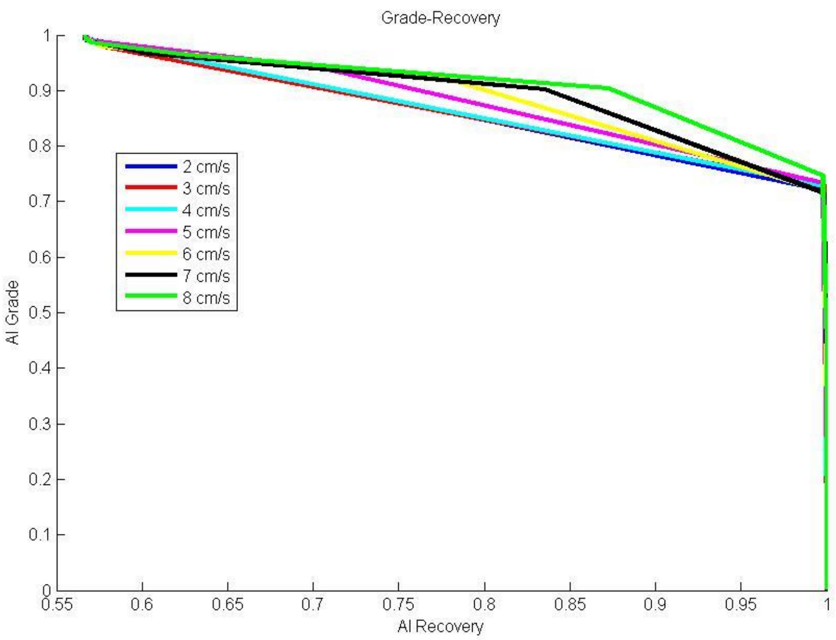


Figure 3.6 Grade recoveries at different velocities

3.3 Separation

In total six experiments were determined valid and their results were analysed. Two more experiments were invalid due to turbulent input of the material but were still purposefully analysed on float fraction and total sink fraction.
Each fraction was dried and then hand sorted and analysed. All the results can be found in appendix A1.

Figure 3.7. Result in tank after experiment T5

3.3.1 Float Fraction

The composition of the float fraction for each test is given in table 3.2. The highest LDPE grade of the valid tests is achieved with T1. An invalid test, F1, gave even a higher LDPE grade.
There were two ways PET was ending up in the floating fraction. The first is PET clusters which could still have had air trapped inside them. The second is PET which was glued to LDPE particles. The PET clusters in the float fraction could be eliminated by better wetting. Analysis on the float fraction of other tests showed that 35% to 49% of the PET in the floating fraction consisted of clustered PET. So in theory, the PET contamination in the float fraction could be reduced to 0.6% by better wetting. This would results in a LDPE grade of 99.2 %
The aluminium in the float fraction was entirely caused by aluminium particles which were rolled or otherwise trapped inside LDPE particles. The AL/PET combinations were either rolled inside LDPE or glued to it.

Float Fraction Composition				
	PE	Al	PET	Al+PET
T0	95,9%	0,2%	3,8%	0,1%
T1	98,6%	0,1%	1,2%	0,1%
T2	97,2%	0,2%	2,5%	0,2%
T3	98,3%	0,1%	1,6%	0,0%
T4	97,8%	0,1%	2,0%	0,1%
T5	97,2%	0,1%	2,6%	0,1%
F1	98,8%	0,2%	1,0%	0,1%
F2	97,2%	0,2%	2,5%	0,2%

Table 3.2

3.3.2 Sink Fraction

For each test a grade-recovery curve of the aluminium was made to compare the tests. In this way the effect of velocity, output type and output height in the tank could be examined. In figure 3.8 the grade-recovery curves of all valid tests are shown.

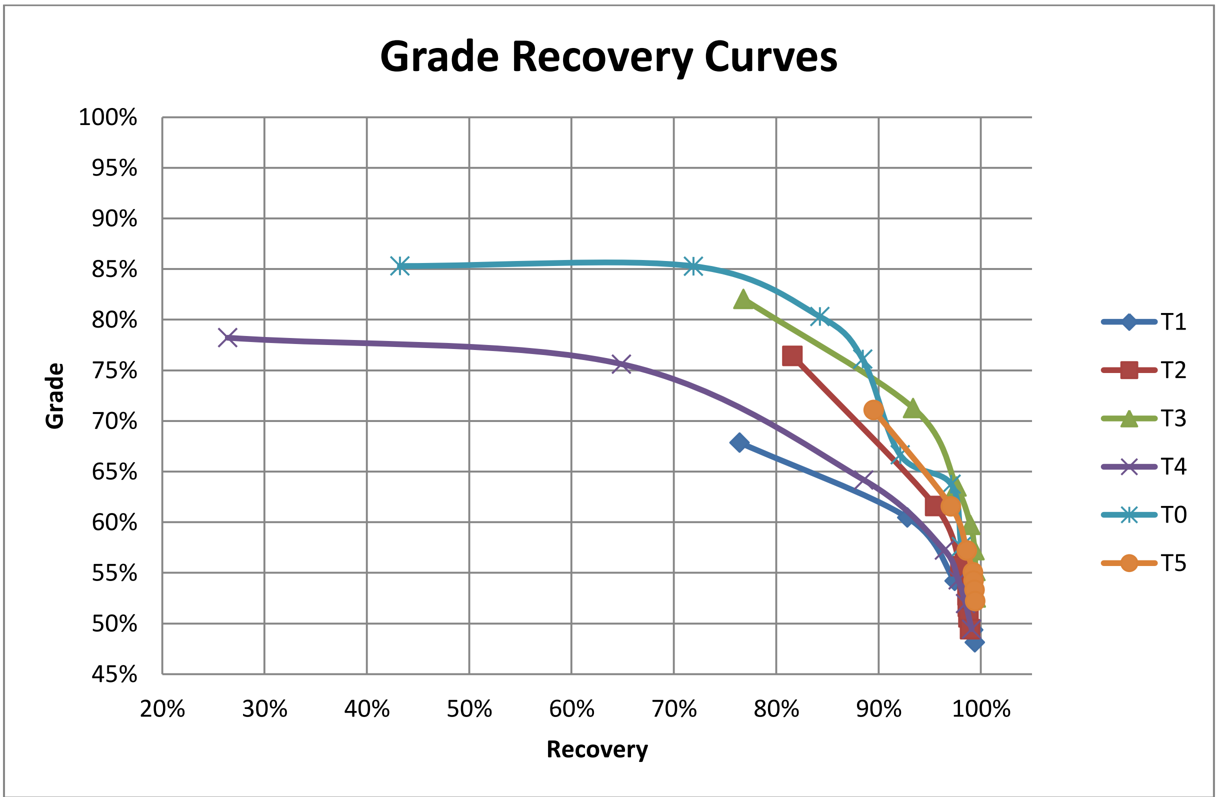


Figure 3.8 Grade recovery curves

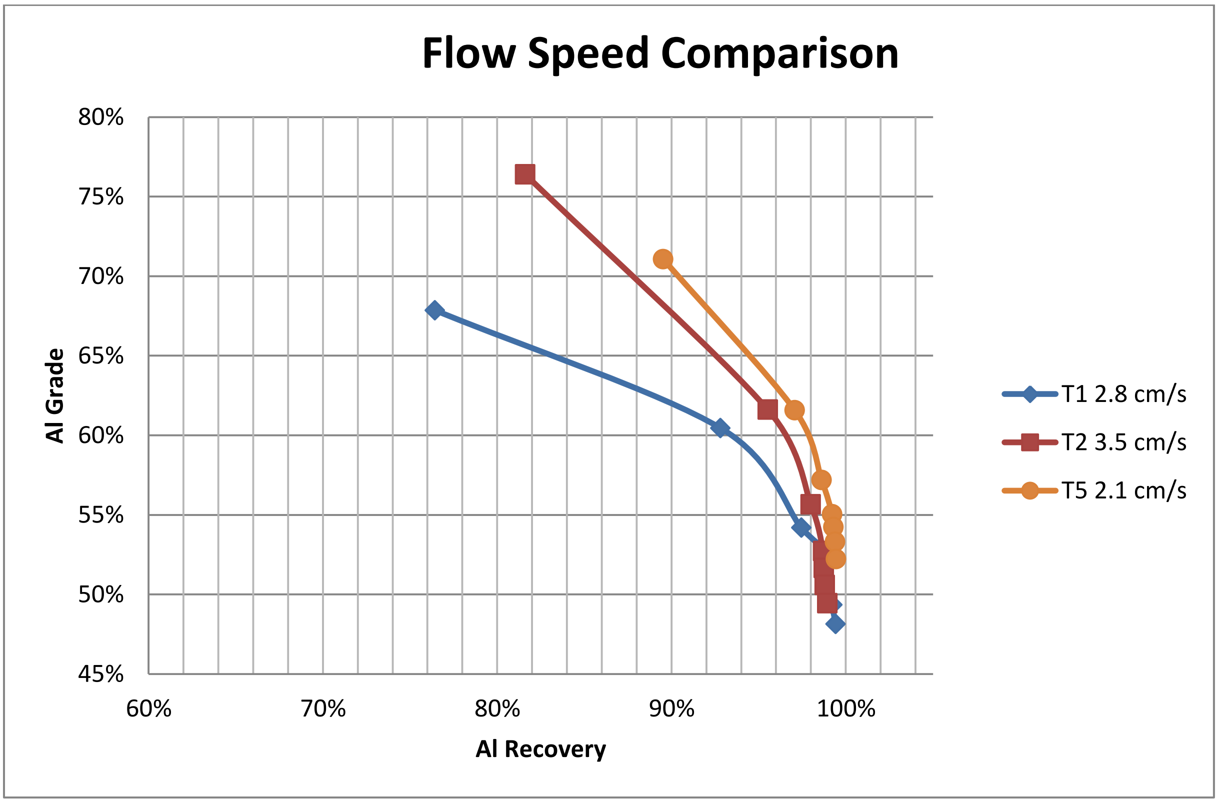


Figure 3.9 Flow speed comparison

In figure 3.9, the grade-recovery curves have been plotted for tests T1, T2 and T5. For these tests the flow speed differs while all other parameters are the same. It was expected that a higher flow speed would give a better separation. However, from the graph it can be seen that while a 3.5 cm/s velocity gave a better results that a 2.8 cm/s velocity, the test with a 2.1 cm/s velocity gave an even better result. By analysing the video material this could be explained by the observation that material has a higher chance of flowing over the splitter ridges when the velocity is increased. This is especially visible in the test F1, which had a flow speed of 4.9 cm/s and was determined invalid because of too much material flowing over the splitters.

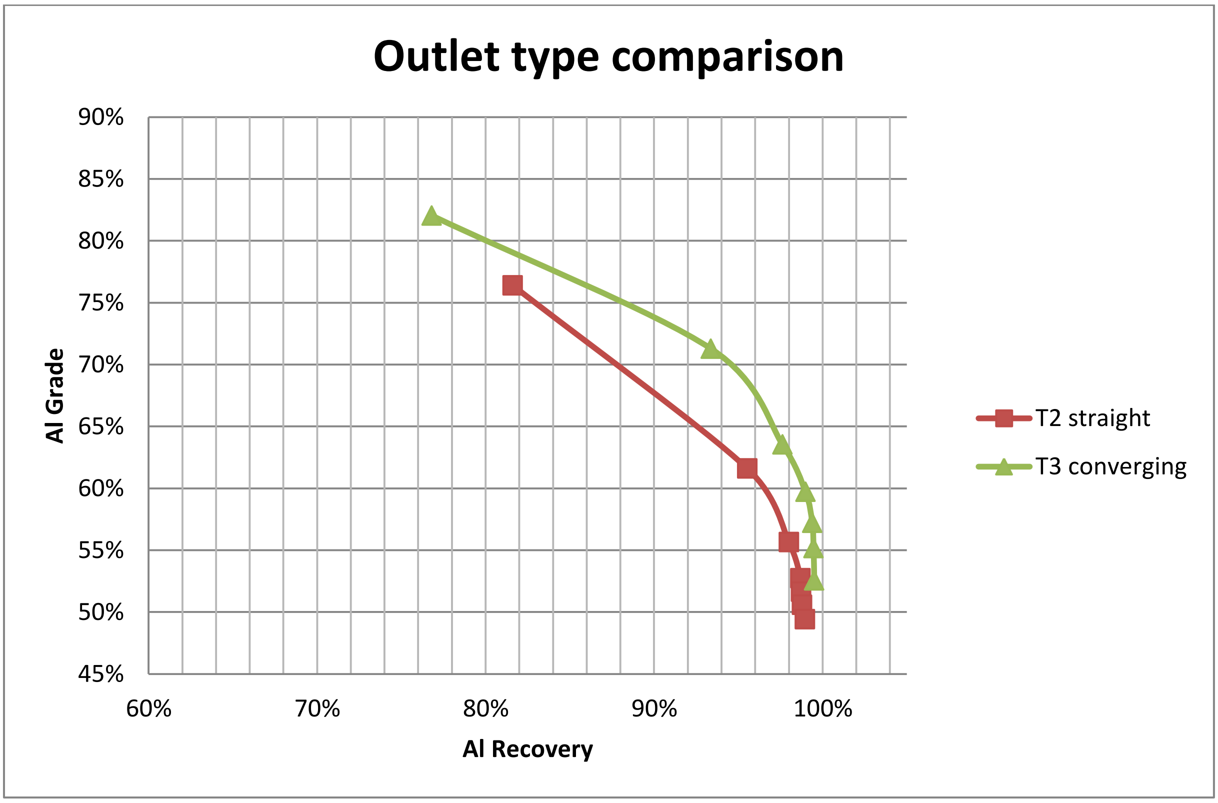


Figure 3.10 Outlet type comparison

In figure 3.10, the results of tests T2 and T3 have been plotted. Here the outlet type was different, while the remaining parameters were kept the same. It can be seen clearly that the converging outlet type improves the separation performance.

Screening test

On basis of the observation that a significant part of the plastic in the sink fractions was clustered, an experiment with sieving was performed.
The dry 0-20 cm fraction of T1 was sieved with a screen with 8 mm round openings and a screen with 12.5 mm square openings. The total sink fraction was sieved with the 8 mm screen.

0-20 cm fraction with 12.5 mm sieve					
	Al	PET	PE	AL/PET	Amount (g)
Before sieving	67,9%	24,0%	0,9%	7,3%	10,1368
After sieving	83,4%	7,4%	0,2%	9,0%	8,2347

0-20 fraction with 8.0 mm sieve					
	Al	PET	PE	AL/PET	Amount (g)
Before sieving	67,9%	24,0%	0,9%	7,3%	10,1368
After sieving	89,5%	2,0%	0,6%	7,9%	7,2385

Total sink fraction with 8.0 mm sieve					
	Al	PET	PE	AL/PET	Amount (g)
Before sieving	48,1%	39,4%	6,8%	5,6%	18,5912
After sieving	85,5%	4,7%	1,9%	7,9%	10,4335

Considering that the AL/PET consists of one part Al and one part PET, the mass of the AL/PET should be distributed as follows, based on particle mass measurements:

Mass composition of Al/PET combination	
Material	**Mass percentage**
Aluminium	45,5 %
PET	54,6 %

Table 3.4

Separating the Al/PET mathematically and putting the mass in the respective materials, the following mass composition is calculated for the sieved sink fraction:

Mass composition of total sink fraction after sieving.		
Al	**PET**	**LDPE**
89,1%	9,0%	1,9%

Table 3.5

A sieving experiment was also performed with wet material. Hand sieving wet material did not work; the material stuck together.

3.4 Economic Analysis

3.4.1 Product value and destination

The best LDPE product produced with a valid test had the following composition:

- 98.6 % LDPE
- 1.2 % PET
- 0.1 % Aluminium
- 0.1 % Al/PET combination

Norbert Fraunholcz, owner of Recycling Avenue B.V. was asked about the value of this material and a possible destination. The following was his response:

> "It's difficult to estimate, but I expect the value of this material to be around 350-400 euro/tonne and could have an application together with post-consumer foil for injection moulding of construction buckets and the like.
> A problem is the mainly the PET contamination. Aluminium can be relatively easily removed with melt filtration. If the PET can be brought to < 0.1 % the value will shoot up to 500-600 euro/tonne"

Jellse Sernee of Synvase, a business development company in recycling and mineral processing, was shown the aluminium product from the sink-float separations as described in chapter 3.3.2. A summary of the conversation with him:

The material is really light and cannot be put into a smelter oven as such. It will mostly burn and end up with the fly-ashes. So, the material needs to be briquetted. This way the material will be heavy enough to penetrate the oxide layer in a smelting oven and be smelted.
The material needs to be tested for briquetting. It might not be possible to briquette because of the plastic content.

For a smelter the maximum allowable plastic is around 5%. Maybe 10% in an extreme situation but the price will drop fast in this case.
The value of briquetted aluminium foil with <5% plastics would be 1000-1200 euro/tonne.
50% plastics would only be about 300 euro/tonne or even less.
My own estimation for 10% plastics: 500-600 euro/tonne.

Another option for a destination for the aluminium is as aluminium powder, since the aluminium in this material is wrought aluminium and is very pure.
It needs to be researched if the material is millable into powder and if perhaps the plastics would be less millable and as such easy to separate from the aluminium.

An estimation for investment costs, revenues, earnings and net present value have been made for two different scenarios.

3.4.2 Scenario A

In this scenario the separation is done with a standard sink-float separator. This means that the output of this machine will be a floating fraction and a sink fraction, but the sink fraction will not be split during the process. After separation, the float fraction will be dried and sold to the injection moulding factory. The sink fraction will be wet sieved and the concentrated aluminium product will be briquetted and sold to the smelter. The rest product (85% PET) will be moved to a waste incinerator where a gate fee of 100 euro per ton has to be paid. The flowchart of the process is given in figure 3.11. A full page version is given in appendix A2

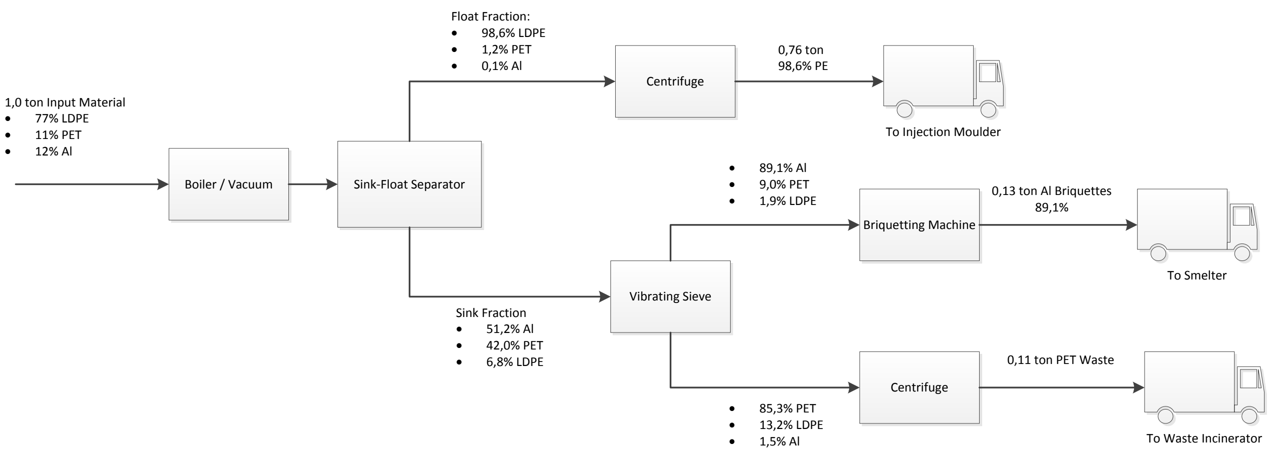


Figure 3.11 Flowchart of Scenario A

Estimation of Investment Costs					
	Capacity per unit	Amount	Price determination	Cost per unit (x1000 €)	Cost(x1000 €)
Process line					
Sink-float separator	4 t / h	1	Inquired	60	60
Boiler	2 t /h	1	Estimated	30	
Vacuum system	2 t /h	1	Estimated	40	
Centrifuges	4 t / h	2	Inquired	16	32
Vibrating Sieve	5 t / h	1	Inquired	16	16
Water Treatment	20 m^3 / h	2	Estimated	40	80
Conveyers/Pipes			Estimated	-	30
Hoppers		2	Estimated	10	20
Briquetting machine	0.7 t / h	1	Estimated	40	40
Design / Engineering			Estimated		30
Electrical System			Estimated		30
Equipment					
Loader		1	Estimated	30	30
Forklift		2	Estimated	20	40
Other				20	20
Permits/License					10
Total					438
Unforeseen			Estimated 50% of Total		
Total					**657**

Operational cost

Fixed OPEX			Cost(x1000 €)
Capital Cost	2 year duration, r = 10%		360
Rent	200 m2	150 € per m2	30
Personnel	5 x 1 operator 1700 hours per year per operator 1 Manager	5 * 50.000 + 1 * 70.000	320
Maintenance	10% of investment cost		65
Electricity/Gas			10
Charges/Taxes/Insurance	5% of investment cost		33
Total			**818**

Variable OPEX		Euro per ton input	
Electricity	80 KW * 0,10 per KWh	8,0	
Waste gate fee	0,11 * 100 per ton input	11,0	
Transport		4,0	
Water		1,0	
Total		**24,0**	

Revenue per ton of processed input material	
Gate fee	€ 100
LDPE product	0.76* € 350
Aluminium product	0.13* € 500
Total	**€ 431**

Scenario A1 **1 ton/h processed with 10% downtime:**		
Tonnage	365 * 24 * 0,90 * 1	7884 tons
Revenue	431 * 7884	€ 3,398,000 per year
Costs	818,000 + 24 * 7884	€ 1,007,000 per year
EBT	3,398,000 – 1,007,000	**€ 2,391,000 per year**
NPV (discount rate 10%)	-600,000 + (2,391,000 / 1.10) + (2,391,000 / 1.10^2)	**€ 3,549,000**

Scenario A2 **1 ton/h processed with 20% downtime**		
Tonnage	365 * 24 * 0,80 * 1	7008 tons per year
Revenue	431 * 7008	€ 3,020,000 per year
Costs	818,000 + 24,0 * 7008	€ 986,000 per year
EBT	3,020,000 - 948,000	**€ 2,034,000 per year**
NPV	-600,000 + (2,034,000 / 1.10) + (2,034 / 1.10^2)	**€ 2,930,000**

Scenario A3: **1 ton /h processed with 50% downtime**		
Tonnage	$365 * 24 * 0{,}50 * 1$	4380 tons per year
Revenue	$431 * 4380$	€ 1,888,000 per year
Costs	818,000 + 24,0*4380	€ 923,000 per year
EBT	1,888,000 – 885,000	**€ 965,000 per year**
NPV	-600,000 + (965,000 / 1.10) + (965,000 / 1.10^2)	**€ 1,074,000**

3.4.3 Scenario B

For Scenario B the researched sink-float method is applied, where the material is split at the bottom of the sink-float tank. The results of T3 are used. A recovery of 98% is chosen, which gives the aluminium product a grade of ca. 58% aluminium with 45% plastics. The value of this material is estimated at 200 euro per ton.
To use this method, the sink-float separator needs a big working area.

Estimation of needed area and separators.
In the performed tests a sample of 80 g was put through the bench-scale separator in about 8 minutes. It is assumed that an industrial separator would have a much better performance and applying this performance to the bench-scale separator a sample of 100 gram would take 2 minutes to put through, at the same area of 0.2 m^2. That would be 15 kg of material per hour per m^2.

If one industrial machine would have a working area of 20 m^2, that would mean that it could process 300 kg per hour. So 3 of these machines would be needed to achieve the 1 ton per hour goal.
A flowchart for scenario B is given in figure 3.12 A full page version is given in appendix A2

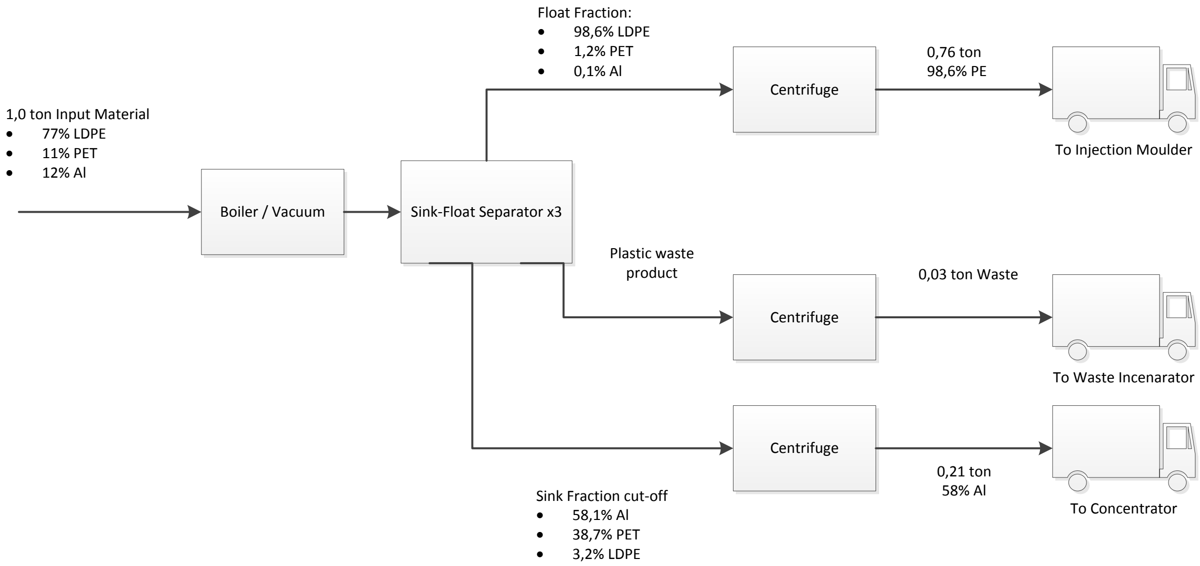


Figure 3.12 Flowchart of scenario B

Estimation of investment costs

	Capacity per unit	Amount	Price Determination	Cost per unit (x1000 €)	Cost(x1000 €)
Process line					
Sink-float separator	0.3 t / h	4	Estimated: 50	50	200
Boiler	2 t / h	1	Estimated	30	
Vacuum system	2 t /h	1	Estimated	40	
Centrifuges	4 t / h	2	Inquired: 16	16	32
Water Treatment	20 m^3 / h	2	Estimated	40	80
Conveyers/Pipes			Estimated	-	30
Hoppers		2	Estimated	10	20
Design / Engineering			Estimated		30
Electrical System			Estimated		30
Equipment					
Loader		1	Estimated	30	30
Forklift		2	Estimated	20	40
Other				20	20
Permits/License					10
Subtotal					532
Unforeseen			Estimated 50% of subtotal		
Total					**783**

Operational cost

Fixed OPEX			Cost(x1000 €)
Capital Cost	2 year duration, r = 10%		430
Rent	200 m2	150 € per m2	30
Personnel	5 x 1 operator 1700 hours per year per operator 1 Manager	5 * 50.000 + 1 * 70.000	320
Maintenance	10% of investment cost		78
Electricity/Gas			10
Charges/Taxes/Insurance	5% of investment cost		39
Total			**907**

Variable OPEX		Euro per ton input	
Electricity	80 KW * 0,10 per KWh	8,0	
Waste gate fee	0,03 * 100 per ton input	3,0	
Transport		4,0	
Water		1,0	
Total		**16,0**	

Revenue per ton of processed input material	
Gate fee	€ 100
LDPE product	0.76* € 350 = € 266
Aluminium product	0.21* € 200 = € 42
Total	**€ 408**

Scenario B1 1 ton/h processed with 20% downtime:		
Tonnage	365 * 24 * 0,80 * 1	7008 tons
Revenue	429 * 7008	€ 2,859,000 per year
Costs	907,000 + 16,0 * 7008	€ 1,019,000 per year
EBT	2,859,000 – 1,019,000	**€ 1,840,000 per year**
NPV (discount rate 10%)	-708,000 + (1,840,000 / 1.10) + (1,840,000 / 1.10^2)	**€ 2,485,000**

4. Conclusions

4.1 Separation

The sink-float separation resulted in a LDPE product with a purity ranging from 95.9% to 98.8%. With better wetting this grade might be increases to 99.2% because 35%-49% of the PET contaminations in the float fraction were clusters containing air.

The best result for the aluminium product came from T3. The grade and recovery depends on which splitter the material is cut off. The highest grade was 82% aluminium with a recovery of 76.8%. The highest recovery for this test would be 99.5% with an aluminium grade of 52.6%. From the MATLAB simulation it was predicted that a higher flow velocity in the tank would result in better separation. This was not always the case in practice. Due to higher velocities there were errors occurring like the overflowing of material over the splitters.

During the analyses of the sink fractions it was observed that a significant part of the PET in the sink fraction consists of big clusters. A quick test with a sieve showed that the aluminium product could fairly easily be concentrated from ca. 50% to ca. 90% by sieving. However, more research needs to be done to see if this also holds for wet sieving.

4.2 Economic Analysis

The economic analysis of chapter 3.4 shows that this sink-float method is very feasible to recycle flexible packaging.

The most economical material to focus the separation on is LDPE. 77% of the flexible packaging material consists of good quality LDPE. With the researched method, this can be concentrated to a 98.6% pure LDPE product. The value of this material lies around 350-400 euro per ton.
Even with the low achieved grade of 58% Aluminium in Scenario B of chapter 4.3, the method would be feasible. However, a lot of value which is in the aluminium product is given away like this. It would be better to include another step in the process to concentrate the aluminium product. Sieving the aluminium product as in scenario A, or milling the aluminium as discussed in chapter 3.4.1 could be well worth the effort.

If further research proofs that sieving the sink fraction can indeed improve the aluminium grade from 50% to 90 - 95%, then adding a sieving step after the sink-float separation in the process would be the easiest and most cost-effective method to concentrate the aluminium. The advantage is that a regular sink-float separator design could be used instead of a separator where a big bottom surface area with splitters and a laminar flow are needed.

5. Limitations and Recommendations

Vacuum chamber
In the set-up used for this project, the vacuum chamber was used to feed the material into the tank. This did not work very well. The pipe through which the material would pass would often get clogged and manual intervention was needed to get the material through each test. The chamber is also not suited to feed floating material into the tank, since this material will keep floating on the surface of the water in the vacuum chamber and would net get fed into the tank. Different attempts were made to create a mixing current through the chamber with tubing, but none proofed to be up to the task.

It is therefore recommended to wet the material by boiling and vacuum in one step, and then transport the material to a proper feeding system for feeding the material into the tank. The material does not necessarily need to be fed into the middle of the tank.
Because there was almost always manual help needed to feed the material, not much can be said about the capacity of the set-up. In the economic analysis an estimation is made for the capacity of a industrial scale set-up, but this estimation is uncertain.

Recommended research questions for further research
Can the 90% aluminium, 10% plastics mixture be briquetted?
Can the 90% aluminium, 10% plastics mixture be milled to obtain aluminium powder?
Can the sink fraction be concentrated by wet sieving?
Can the wetting be improved by adding a surfactant?
Can the particles that are glued together be separated further by adding a dissolvent for the glue to the water? What are the consequences for the process?

6. References

1] European Commission, *“Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directives 2008/98/EC on waste, 94/62/EC on packaging and packaging waste, 1999/31/EC on the landfill of waste, 2000/53/EC on end-of-life vehicles, 2006/66/EC on batteries and accumulators and waste batteries and accumulators, and 2012/19/EU on waste electrical and electronic equipment”,* 2014

[2] T.A. Cooper, “*Developments in plastic materials and recycling systems for packaging food, beverages and other fast-moving consumer goods.*”, Argo Group International, USA

[3] Flexible Packaging Europe, “*Towards a Resource Efficient Europe*”, Presentation

[4] B. Hu, N. Fraunholz and P. Rem, *Wetting Technologies for High-Accuracy Sink-Float Separations in Water Based Media,* Delft University of Technology, Delft, The Netherlands

A. Appendices

A1. Separation Test Results

Test name	T0
Date	8-5
Test duration	
Water height	0,2 m
Height of spout	0,1 m
Spout type	Straight
Pumps	1
Flow speed	2,8 cm/s
Comments	No splitters at bottom Pump output - Tube

Weights					
Fractie	**Al**	**PET**	**PE**	**Al+PET**	**Total**
Float	0,0355	0,587	14,9418	0,0183	15,5826
0-20 cm	0,801			0,138	0,9389
20-30 cm	0,532	0,077		0,016	0,6237
30-40 cm	0,228	0,120		0,033	0,381
40-50 cm	0,078	0,092		0,040	0,2099
50-60 cm	0,068	0,236	0,056	0,047	0,4068
60-70 cm	0,092	0,159		0,010	0,2618
>70 cm	0,018	0,280	0,035		0,3337
Total	1,8527	1,5511	15,0328	0,3018	18,7384

Composition per fraction					
Fractie	**Al**	**PET**	**PE**	**Al+PET**	**Total**
Float	0,2%	3,8%	95,9%	0,1%	100,0%
0-20 cm	85,3%	0,0%	0,0%	14,7%	100,0%
20-30 cm	85,2%	12,3%	0,0%	2,5%	100,0%
30-40 cm	59,9%	31,4%	0,0%	8,6%	100,0%
40-50 cm	37,0%	43,9%	0,0%	19,1%	100,0%
50-60 cm	16,7%	58,1%	13,8%	11,5%	100,0%
60-70 cm	35,3%	60,8%	0,0%	3,9%	100,0%
>70 cm	5,5%	84,0%	10,5%	0,0%	100,0%
Total	9,9%	8,3%	80,2%	1,6%	100,0%

Recovery (percentage of total input)				
Fractie	**Al**	**PET**	**PE**	**Al+PET**
Float	1,9%	37,8%	99,4%	6,1%
0-20 cm	43,2%	0,0%	0,0%	45,7%
20-30 cm	28,7%	4,9%	0,0%	5,1%
30-40 cm	12,3%	7,7%	0,0%	10,9%
40-50 cm	4,2%	5,9%	0,0%	13,3%
50-60 cm	3,7%	15,2%	0,4%	15,5%
60-70 cm	5,0%	10,3%	0,0%	3,4%
>70 cm	1,0%	18,1%	0,2%	0,0%
Total	100,0%	100,0%	100,0%	100,0%

Test name	T1
Date	20-5
Test duration	
Water height	0,2 m
Height of spout	0,1 m
Spout type	Straight
Pumps	1
Flow speed	2,8 cm/s
Comments	

Weights					
Fractie	**Al**	**PET**	**PE**	**Al+PET**	**Total**
Float	0,0526	0,716	58,0757	0,0431	58,8874
0-20 cm	6,8792	2,4299	0,0904	0,7373	10,1368
20-30 cm	1,4746	1,8664	0,1352	0,2042	3,6804
30-40 cm	0,4178	1,7237	0,1682	0,0576	2,3673
40-50 cm	0,1322	0,4699	0,0813	0,022	0,7054
50-60 cm	0,0147	0,1945	0,0451	0	0,2543
60-70 cm	0,0143	0,3273	0,61	0,0029	0,9545
>70 cm	0,016	0,3188	0,1431	0,0146	0,4925
Total	9,0014	8,0465	59,349	1,0817	77,4786

Composition per fraction					
Fractie	**Al**	**PET**	**PE**	**Al+PET**	**Total**
Float	0,1%	1,2%	98,6%	0,1%	100,0%
0-20 cm	67,9%	24,0%	0,9%	7,3%	100,0%
20-30 cm	40,1%	50,7%	3,7%	5,5%	100,0%
30-40 cm	17,6%	72,8%	7,1%	2,4%	100,0%
40-50 cm	18,7%	66,6%	11,5%	3,1%	100,0%
50-60 cm	5,8%	76,5%	17,7%	0,0%	100,0%
60-70 cm	1,5%	34,3%	63,9%	0,3%	100,0%
>70 cm	3,2%	64,7%	29,1%	3,0%	100,0%
Total	11,6%	10,4%	76,6%	1,4%	100,0%

Recovery (percentage of total input)				
Fractie	**Al**	**PET**	**PE**	**Al+PET**
Float	0,6%	8,9%	97,9%	4,0%
0-20 cm	76,4%	30,2%	0,2%	68,2%
20-30 cm	16,4%	23,2%	0,2%	18,9%
30-40 cm	4,6%	21,4%	0,3%	5,3%
40-50 cm	1,5%	5,8%	0,1%	2,0%
50-60 cm	0,2%	2,4%	0,1%	0,0%
60-70 cm	0,2%	4,1%	1,0%	0,3%
>70 cm	0,2%	4,0%	0,2%	1,3%
Total	100,0%	100,0%	100,0%	100,0%

Test name	T2
Date	22-5
Test duration	
Water height	0,2 m
Height of spout	0,1 m
Spout type	Straight
Pumps	2
Flow speed	3,5 cm/s
Comments	

Weights (g)					
Fractie	**Al**	**PET**	**PE**	**Al+PET**	**Total**
Float	0,05	0,73	28,26	0,05	29,09
0-20 cm	3,63	0,80	0,01	0,31	4,75
20-30 cm	0,62	1,28	0,15	0,09	2,14
30-40 cm	0,11	0,71	0,09	0,02	0,93
40-50 cm	0,03	0,33	0,11	0,02	0,49
50-60 cm	0,00	0,14	0,03	0,01	0,18
60-70 cm	0,00	0,16	0,02	0,00	0,18
>70 cm	0,01	0,13	0,08	0,00	0,22
Total	4,44	4,28	28,77	0,49	37,98

Composition per fraction					
Fraction	**Al**	**PET**	**PE**	**Al+PET**	**Total**
Float	0,2%	2,5%	97,2%	0,2%	100,0%
0-20 cm	76,4%	16,8%	0,3%	6,5%	100,0%
20-30 cm	28,9%	59,9%	7,2%	4,0%	100,0%
30-40 cm	11,7%	76,4%	9,7%	2,1%	100,0%
40-50 cm	6,3%	66,2%	23,1%	4,4%	100,0%
50-60 cm	0,9%	79,3%	16,9%	2,9%	100,0%
60-70 cm	1,4%	86,6%	12,0%	0,0%	100,0%
>70 cm	3,2%	59,1%	37,7%	0,0%	100,0%
Total	11,7%	11,3%	75,7%	1,3%	100,0%

Recovery (percentage of total input)				
Fractie	**Al**	**PET**	**PE**	**Al+PET**
Float	1,1%	17,0%	98,2%	10,6%
0-20 cm	81,6%	18,7%	0,0%	62,4%
20-30 cm	13,9%	30,0%	0,5%	17,5%
30-40 cm	2,5%	16,7%	0,3%	4,0%
40-50 cm	0,7%	7,6%	0,4%	4,4%
50-60 cm	0,0%	3,3%	0,1%	1,1%
60-70 cm	0,1%	3,7%	0,1%	0,0%
>70 cm	0,2%	3,0%	0,3%	0,0%
Total	100,0%	100,0%	100,0%	100,0%

Test name	T3
Date	22-5
Test duration	
Water height	0,2 m
Height of spout	0,1 m
Spout type	Converging
Pumps	2
Flow speed	3,5 cm/s
Comments	

Weights (g)					
Fractie	**Al**	**PET**	**PE**	**Al+PET**	**Total**
Float	0,0197	0,402	25,4039	0,0083	25,8339
0-20 cm	3,0642	0,3524	0,015	0,3032	3,7348
20-30 cm	0,6612	0,6735	0,0443	0,1121	1,4911
30-40 cm	0,1695	0,6532	0,0399	0,0412	0,9038
40-50 cm	0,0545	0,3835	0,0152	0,0301	0,4833
50-60 cm	0,0159	0,2651	0,0352	0	0,3162
60-70 cm	0,0032	0,2228	0,0366	0	0,2626
>70 cm	0,0017	0,3251	0,0349	0	0,3617
Total	3,9899	3,2776	25,625	0,4949	33,3874

Composition per fraction					
Fractie	**Al**	**PET**	**PE**	**Al+PET**	**Total**
Float	0,1%	1,6%	98,3%	0,0%	100,0%
0-20 cm	82,0%	9,4%	0,4%	8,1%	100,0%
20-30 cm	44,3%	45,2%	3,0%	7,5%	100,0%
30-40 cm	18,8%	72,3%	4,4%	4,6%	100,0%
40-50 cm	11,3%	79,4%	3,1%	6,2%	100,0%
50-60 cm	5,0%	83,8%	11,1%	0,0%	100,0%
60-70 cm	1,2%	84,8%	13,9%	0,0%	100,0%
>70 cm	0,5%	89,9%	9,6%	0,0%	100,0%
Total	12,0%	9,8%	76,8%	1,5%	100,0%

Recovery (percentage of total input)				
Fractie	**Al**	**PET**	**PE**	**Al+PET**
Float	0,5%	12,3%	99,1%	1,7%
0-20 cm	76,8%	10,8%	0,1%	61,3%
20-30 cm	16,6%	20,5%	0,2%	22,7%
30-40 cm	4,2%	19,9%	0,2%	8,3%
40-50 cm	1,4%	11,7%	0,1%	6,1%
50-60 cm	0,4%	8,1%	0,1%	0,0%
60-70 cm	0,1%	6,8%	0,1%	0,0%
>70 cm	0,0%	9,9%	0,1%	0,0%
Total	100,0%	100,0%	100,0%	100,0%

Test name	T4
Date	26-5
Test duration	
Water height	0,23 m
Height of spout	0,2 m
Spout type	Converging
Pumps	2
Flow speed	3,0 cm/s
Comments	

Weights					
Fractie	**Al**	**PET**	**PE**	**Al+PET**	**Total**
Float	0,04	0,54	26,74	0,02	27,3473
0-20 cm	1,06	0,17	0,03	0,09	1,3574
20-30 cm	1,55	0,34	0,06	0,15	2,0924
30-40 cm	0,95	0,97	0,09	0,08	2,0977
40-50 cm	0,32	0,78	0,09	0,03	1,2251
50-60 cm	0,05	0,34	0,06	0,01	0,4679
60-70 cm	0,03	0,31	0,04	0,00	0,3817
>70 cm	0,02	0,30	0,11	0,00	0,4344
Total	4,02	3,7618	27,2253	0,3968	35,4039

Composition per fraction					
Fractie	**Al**	**PET**	**PE**	**Al+PET**	**Total**
Float	0,1%	2,0%	97,8%	0,1%	100,0%
0-20 cm	78,2%	12,9%	2,1%	6,8%	100,0%
20-30 cm	73,9%	16,1%	2,8%	7,1%	100,0%
30-40 cm	45,4%	46,3%	4,4%	3,9%	100,0%
40-50 cm	25,9%	64,1%	7,6%	2,5%	100,0%
50-60 cm	11,5%	72,5%	13,0%	3,0%	100,0%
60-70 cm	7,6%	81,3%	9,9%	1,2%	100,0%
>70 cm	5,4%	69,2%	25,3%	0,0%	100,0%
Total	11,4%	10,6%	76,9%	1,1%	100,0%

Recovery (percentage of total input)				
Fractie	**Al**	**PET**	**PE**	**Al+PET**
Float	0,9%	14,4%	98,2%	6,1%
0-20 cm	26,4%	4,6%	0,1%	23,4%
20-30 cm	38,5%	9,0%	0,2%	37,6%
30-40 cm	23,7%	25,8%	0,3%	20,6%
40-50 cm	7,9%	20,9%	0,3%	7,7%
50-60 cm	1,3%	9,0%	0,2%	3,5%
60-70 cm	0,7%	8,3%	0,1%	1,1%
>70 cm	0,6%	8,0%	0,4%	0,0%
Total	100,0%	100,0%	100,0%	100,0%

Test name	T5
Date	19-5
Test duration	
Water height	0,20 m
Height of spout	0,1 m
Spout type	Straight
Pumps	2
Flow speed	2,1 cm/s
Comments	

Weights					
Fractie	**Al**	**PET**	**PE**	**Al+PET**	**Total**
Float	0,05	1,50	57,00	0,07	58,63
0-20 cm	8,16	2,53	0,04	0,75	11,48
20-30 cm	0,69	1,96	0,12	0,12	2,89
30-40 cm	0,14	1,12	0,04	0,06	1,35
40-50 cm	0,06	0,61	0,03	0,02	0,72
50-60 cm	0,01	0,25	0,00	0,00	0,26
60-70 cm	0,01	0,28	0,01	0,00	0,30
>70 cm	0,00	0,34	0,02	0,00	0,36
Total	9,12	8,58	57,26	1,02	75,98

Composition per fraction					
Fractie	**Al**	**PET**	**PE**	**Al+PET**	**Total**
Float	0,1%	2,6%	97,2%	0,1%	100,0%
0-20 cm	71,1%	22,1%	0,3%	6,5%	100,0%
20-30 cm	23,8%	67,8%	4,1%	4,3%	100,0%
30-40 cm	10,5%	82,8%	2,6%	4,1%	100,0%
40-50 cm	7,7%	84,7%	4,9%	2,7%	100,0%
50-60 cm	2,7%	97,3%	0,0%	0,0%	100,0%
60-70 cm	2,4%	93,0%	4,6%	0,0%	100,0%
>70 cm	1,3%	92,1%	6,6%	0,0%	100,0%
Total	12,0%	11,3%	75,4%	1,3%	100,0%

Recovery (percentage of total input)				
Fractie	**Al**	**PET**	**PE**	**Al+PET**
Float	0,6%	17,5%	99,5%	6,7%
0-20 cm	89,5%	29,5%	0,1%	73,8%
20-30 cm	7,5%	22,8%	0,2%	12,1%
30-40 cm	1,5%	13,0%	0,1%	5,5%
40-50 cm	0,6%	7,1%	0,1%	1,9%
50-60 cm	0,1%	2,9%	0,0%	0,0%
60-70 cm	0,1%	3,3%	0,0%	0,0%
>70 cm	0,1%	3,9%	0,0%	0,0%
Total	100,0%	100,0%	100,0%	100,0%

Test name	F1
Date	18-5
Test duration	
Water height	0,20 m
Height of spout	0,1 m
Spout type	Straight
Pumps	2
Flow speed	
Comments	Test invalid for separation purpose Material was flushed uncontrolled through tank

Weights					
Fractie	**Al**	**PET**	**PE**	**Al+PET**	**Total**
Float	0,0886	0,54687	55,4903	0,0488	56,17457
0-20 cm	3,0815	0,9018	0,0574	0,2941	4,3348
20-30 cm	1,5303	0,9534	0,0332	0,1179	2,6348
30-40 cm	1,2205	1,332	0,1103	0,0818	2,7446
40-50 cm	1,0785	1,3679	0,0549	0,0751	2,5764
50-60 cm	0,474	0,7155	0,0752	0,0682	1,3329
60-70 cm	0,3203	0,9036	0,0727	0,0202	1,3168
>70 cm	0,138	1,1289	0,0952	0,021	1,3831
Total	7,9317	7,84997	55,9892	0,7271	72,49797

Composition per fraction					
Fractie	**Al**	**PET**	**PE**	**Al+PET**	**Total**
Float	0,2%	1,0%	98,8%	0,1%	100,0%
0-20 cm	71,1%	20,8%	1,3%	6,8%	100,0%
20-30 cm	58,1%	36,2%	1,3%	4,5%	100,0%
30-40 cm	44,5%	48,5%	4,0%	3,0%	100,0%
40-50 cm	41,9%	53,1%	2,1%	2,9%	100,0%
50-60 cm	35,6%	53,7%	5,6%	5,1%	100,0%
60-70 cm	24,3%	68,6%	5,5%	1,5%	100,0%
>70 cm	10,0%	81,6%	6,9%	1,5%	100,0%
Total	10,9%	10,8%	77,2%	1,0%	100,0%

Recovery (percentage of total input)				
Fractie	**Al**	**PET**	**PE**	**Al+PET**
Float	1,1%	7,0%	99,1%	6,7%
0-20 cm	38,9%	11,5%	0,1%	40,4%
20-30 cm	19,3%	12,1%	0,1%	16,2%
30-40 cm	15,4%	17,0%	0,2%	11,3%
40-50 cm	13,6%	17,4%	0,1%	10,3%
50-60 cm	6,0%	9,1%	0,1%	9,4%
60-70 cm	4,0%	11,5%	0,1%	2,8%
>70 cm	1,7%	14,4%	0,2%	2,9%
Total	100,0%	100,0%	100,0%	100,0%

Test name	F2
Date	21-5
Test duration	
Water height	0,20 m
Height of spout	0,1 m
Spout type	Straight
Pumps	2
Flow speed	4,1 cm/s
Comments	Test invalid for separation purpose Burst of turbulent flow and material flowing over splitters

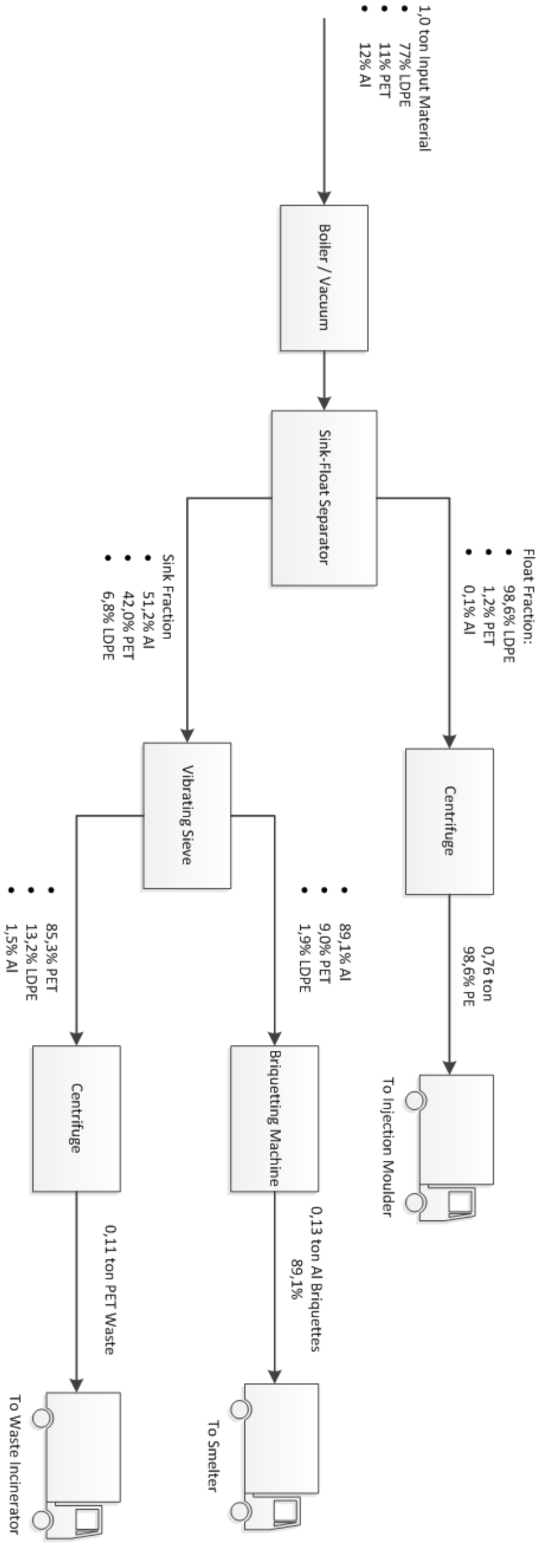
Weights (g)					
Fractie	**Al**	**PET**	**PE**	**Al+PET**	**Total**
Float	0,0334	0,2898	56,3886	0,0042	56,716
0-20 cm	2,7565	0,4085	0,0589	0,1614	3,3853
20-30 cm	2,8071	1,2119	0,0505	0,309	4,3785
30-40 cm	1,3876	1,326	0,1071	0,1658	2,9865
40-50 cm	0,6692	1,2948	0,0492	0,1191	2,1323
50-60 cm	0,45	0,8713	0,0673	0,0444	1,433
60-70 cm	0,24	0,8568	0,0857	0,0137	1,1962
>70 cm	0,166	1,5029	0,2575	0,0347	1,9611
Total	8,5098	7,762	57,0648	0,8523	74,1889

Composition per fraction					
Fractie	**Al**	**PET**	**PE**	**Al+PET**	**Total**
Float	0,1%	0,5%	99,4%	0,0%	100,0%
0-20 cm	81,4%	12,1%	1,7%	4,8%	100,0%
20-30 cm	64,1%	27,7%	1,2%	7,1%	100,0%
30-40 cm	46,5%	44,4%	3,6%	5,6%	100,0%
40-50 cm	31,4%	60,7%	2,3%	5,6%	100,0%
50-60 cm	31,4%	60,8%	4,7%	3,1%	100,0%
60-70 cm	20,1%	71,6%	7,2%	1,1%	100,0%
>70 cm	8,5%	76,6%	13,1%	1,8%	100,0%
Total	11,5%	10,5%	76,9%	1,1%	100,0%

Recovery (percentage of total input)				
Fractie	**Al**	**PET**	**PE**	**Al+PET**
Float	0,4%	3,7%	98,8%	0,5%
0-20 cm	32,4%	5,3%	0,1%	18,9%
20-30 cm	33,0%	15,6%	0,1%	36,3%
30-40 cm	16,3%	17,1%	0,2%	19,5%
40-50 cm	7,9%	16,7%	0,1%	14,0%
50-60 cm	5,3%	11,2%	0,1%	5,2%
60-70 cm	2,8%	11,0%	0,2%	1,6%
>70 cm	2,0%	19,4%	0,5%	4,1%
Total	100,0%	100,0%	100,0%	100,0%

A2. Flowcharts

Flowchart of Scenario A:



Flowchart of Scenario B: