Optimization of the optical sorting to recover the glass present in the mechanical and biological treatment heavy reject.

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Abstract

Recycling is an acknowledged necessity in the current overpopulated and overconsuming society. Even though this is a known fact, recyclable materials are still discarded with the mixed household waste. This type of waste is commonly processed in mechanical and biological treatment (MBT) plants that produce a heavy reject (MBTr). This heavy reject has in its composition a considerable amount of glass that could be recycled.

Optical sorting is a separation method widely used in glass recycling to separate particles of other materials from glass. This type of sorting is done using optical sorters, machines that automate the process.

The present study aims to assess if it is possible the glass in the MBTr to be sorted out and then recycled using optical sorting. MBTr samples from three different Portuguese MBT plants were provided for this purpose and analysed according to composition and particle size. Since optical sorting is a process highly sensitive to foreign materials, a procedure developed in previous studies was used to prepare the samples by removing the greater part of the contaminants.

The samples were then used to assess how the fed material, as well as some operational parameters affect the efficiency of the sorting and the sorting was optimized for the production of an output with high content in glass. The need for an additional treatment phase was also accessed.

Regardless of the origin of the sample, it was possible to produce an output of over 98% content in glass and a recovery of approximately 70% of the glass. Although, according to the regulations for already sorted glass, the final product cannot be accepted due to the presence of infusible materials in a higher amount than is permitted.

Keywords: Optimization, Optical sorting, MBT heavy reject, glass recovery

1. Introduction

The population growth rate, combined with the increase in consumption are currently putting a strain on natural resources. The rate at which raw materials are being extracted from nature to meet the increasing demand is much higher than the rate at which they are being replaced there.

Therefore, it is important that the materials that were already extracted are used to the fullest of their capacity.

Recycling is one way to do that, but even though its benefits are widely acknowledged, recyclable materials are still discarded with the mixed household waste. This type of waste is commonly treated in mechanical and biological treatment (MBT) plants. These plants remove recyclable materials from the mixed waste stream, but they still produce a heavy reject (MBTr) with a high content of glass that could potentially be recycled if properly recovered.

The present study integrates a project – RecGlass project – which main intent is precisely to recover this glass in a way that it can be recycled. An equipment (RecGlass) was developed to gravitically separate stones from glass (Dias & Carvalho, 2012) and integrate a procedure to recover the glass from the MBTr. This procedure, which will be explained in greater detail in the methodology, includes a stage of optical sorting.

Optical sorting is currently applied in a great variety of industries such as mining (TOMRA, Mining, 2014), food industry (Edwards, 2004), and waste management. In the waste management field it is used to sort almost every recyclable material including paper (TAPPI, 2001), packaging (Recycling Today, 2011), etc. Optical sorting has also been established as an efficient method to separate glass form other materials that reduce production quality and increase production costs, such as ceramic pieces for example.

Optical sorting systems (optical sorters) are composed of four subsystems that work together to do the sorting (Edwards, 2004).

- **The feed system** – the system that controls the feeding of the optical sorter. It is usually done using some sort of vibrating mechanism.
- **The optical system** – composed of the radiation source and the optical sensor(s), this system is responsible for illuminating the material to be sorted with a specific type of radiation (visible, infrared, UV light, for example) and detect the specific response of the material that either labels it as "reject" or "accept".
- **The ejection system** – The ejection system physically separates the unwanted material from the material that needs to be recovered. Usually this can be achieved when the particles are in free-fall and short bursts of compressed air are emitted through nozzles aimed directly at the rejects.
- **The image processing algorithms** – these algorithms analyse the images obtained by the optical system in fractions of a second and determine if a certain analysed particle should be rejected. If the particle does not meet the criteria to be accepted, then the ejection system is activated and the particle is rejected.

Optical sorters can be adjusted to different streams of material, provided the operational parameters of the equipment are adjusted accordingly. Though there are more parameters that could be changed, in the time span available for the execution of the present study that would not be possible. The parameters studied were the intensity of the radiation (intensity of the emitted radiation), the minimum amount of radiation that should be transmitted for a particle to be

accepted (level of radiation received) and filters (filter 1 and filter 2) – maximum opaque area that one particle can have and still be accepted.

All the processing was done at VIDROCICLO, a Portuguese materials recovery facility (MRF) plant. As a MRF plant, VIDROCICLO receives already sorted glass to remove the contaminants that are mistakenly discarded with the glass and sends the decontaminated product to a recycling plant. The company also supplied the know how to reduce the number of tested values for each operational parameter, provided they would be kept confidential due to the high competitiveness in the field.

2. Methodology

The samples used in this study were provided by three Portuguese MBT plants currently in operation – SULDOURO, RESIESTRELA and VALNOR with masses 940 kg, 520 kg and 660 kg. As mentioned before, optical sorting is a process highly sensitive to contamination, therefore, the samples needed to undergo a pre-treatment to remove most of the contaminants.

2.1 Pre-treatment

Several processes were studied to integrate this pre-treatment in a previous stage of the RecGlass project, but the ones that proved to improve the quality of the samples for optical sorting are the ones that follow (executed by the order presented):

- **Drying** – The samples were very humid, making it necessary for them to be dried in order to prevent them from sticking to the equipment. They were put on a plastic screen on the floor and exposed to the sun to dry.
- **Magnetic separation** – To extract the ferrous metals that contaminate the samples, they passed through a magnet to have them removed.
- **Mechanical Screening** – since particle size influences the optical sorting, the samples underwent two screenings to assess this influence. The two mechanical screenings were done with screens of square patterned mesh of 6 and 16 mm. The particles of size above 16 mm and between 6 and 16 mm were kept to continue the study. The particles with size under 6 mm were discarded.
- **Removal of round particles** – the particles with size between 6 and 16 mm were treated in the RecGlass equipment that separates particles with similar density but different shapes (stones are usually more round than glass).

Since the optical sorting alters the characteristics of the samples it would be inappropriate to use the same sample more than once. To still be able to execute all the tests necessary to determine how the different parameters affect the efficiency of the optical sorting and chose the best combination of them, the samples were divided into smaller samples. This division was done so that the number of subsamples was enough to do every test without having to use the same subsample twice.

The compounds present in each sample were manually separated, weighted and the percent composition was calculated.

2.2 Optical sorting

The study of the operational parameters of the optical sorting occurred using two optical sorters assembled in series. In this particular assembly (**Figure 2-1**), the second optical sorter is fed with only the material that the first sorter already accepted (OK1), which cannot be intercepted before entering the second sorter. The final product (OK2) is the result of sorting OK1. The rejected product (NOK) is a mixture of the material rejected by the first optical sorter and the second.

Even though several parameters could be tested, VIDROCICLO supplied the practical knowledge acquired from years of operation to reduce the number of parameters and the range of values for each parameter to be tested. The parameters tested were the intensity of emitted radiation (IER), the level of received radiation (LRR), filter 1 and filter 2.
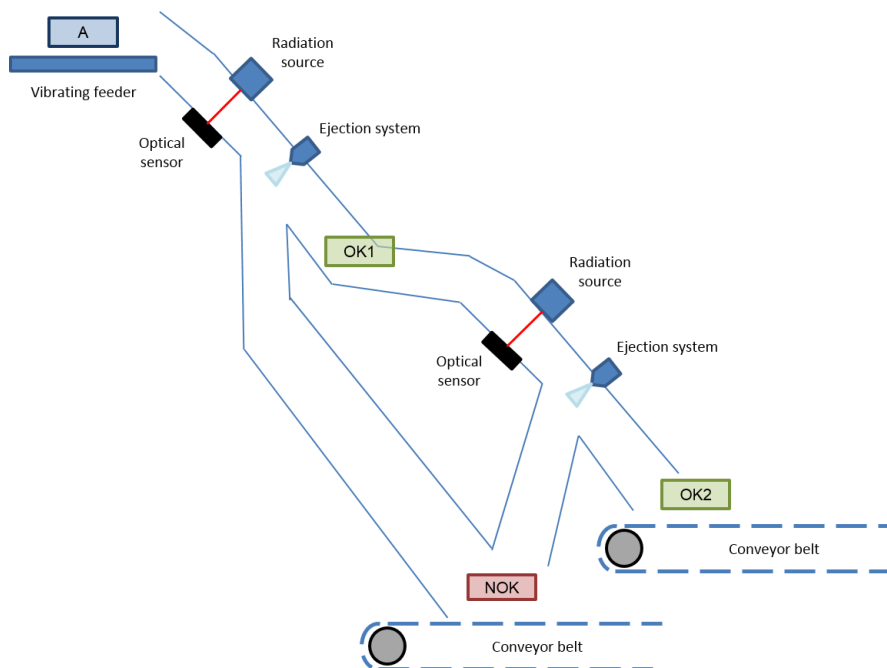

Figure 2-1 Schematic of the optical sorters used in the present study

As mentioned before, VIDROCICLO provided the knowledge necessary to the right execution of the present study, provided that their operational method remained confidential to prevent competing plants to take advantage of that information. As so, the values of the operational parameters used will not be disclosed. Instead, the values of the parameters will be represented in the results as shown in **Table 2-1**.

Table 2-1 Representation of the confidential operational parameters' values

	Higher values $\longrightarrow$ Smaller values			
Intensity of emitted radiation	IR_I	IR_{II}	IR_{III}	IR_{IV}
Level of received radiation	NR_I	NR_{II}	NR_{III}	
Filter 1	$F1_I$	$F1_{II}$	$F1_{III}$	$F1_{IV}$
Filter 2	$F2_I$	$F2_{II}$	$F2_{III}$	$F2_{IV}$

It is important to mention that the limited amount of time to execute this study, the limited amount of samples, as well as the fact that its execution inconvenienced the usual operation of VIDROCICLO made necessary to use the practical knowledge of the installation to reduce the number of tests.

To determine the values of the IER parameter that produced the better results, SULDOURO and RESIESTRELA's samples were used for the size fraction above 16 mm and VALNOR's for the 6-16 mm fraction. SULDOURO's samples were tested with the values IR_{II} and IR_{I} and RESIESTRELA's with the values IR_{II} and IR_{III}. VALNOR's samples were tested with the values IR_{II} and IR_{IV}. All the other parameters were kept constant during these tests.

Using the value of the IER that produced better results, samples from SULDOURO and VALNOR were used to test the LRR values, keeping the remaining parameters constant. The values NR_{III} and NR_{I} were tested with SULDOURO's sample of size fraction above 16 mm. The results showed that the value NR_{I} rejected a large quantity of glass, so the remaining tests for the samples of size fraction above 16 mm (SULDOURO and RESIESTRELA) were done using the value NR_{III}. VALNOR's samples were used to test the values NR_{III} and NR_{I} for the LRR that could be applied to the size fraction 6-16 mm. The following tests used the value NR_{III}.

The two filters are dependent and complementary parameters. For that reason, they were conjugated instead of being studied separately. These parameters were also the only ones that were tested with every sample possible since they're the most sensitive to small composition differences.

The first sample to be tested was SULDOURO's of size fraction above 16 mm. the values tested for filter 1 were $F1_{IV}$, $F1_{II}$ and $F1_{I}$, the values for filter 2 were $F2_{III}$, $F2_{II}$ and $F2_{I}$. **Figure 2-2** shows the values of the filters tested with the samples from SULDOURO with particle size above 16 mm to find the values that produce the better results. Each circle represents one test.
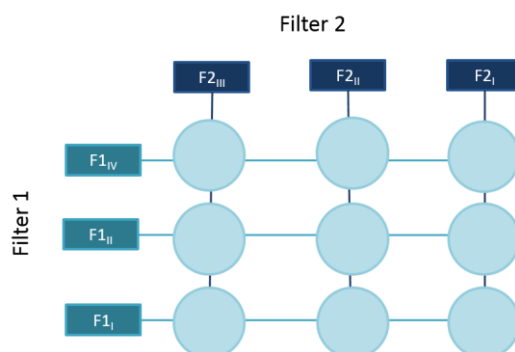

Figure 2-2 Conjugated values for filter 1 and filter 2 using the sample of particle size above 16 mm from SULDOURO

The only sample left with size fraction above 16 mm was RESIESTRELA's. In this case, it was possible to exclude the value $F1_{I}$ since it rejected a considerable amount of glass. As so, the values tested for filter 1 were $F1_{IV}$ and $F1_{II}$ and the values for filter 2 were $F2_{III}$, $F2_{II}$ and $F2_{I}$. **Figure**

2-3 shows the values of the filters tested with the samples from RESIESTRELA with particle size above 16 mm to find the values that produce the better results. Each circle represents one test.
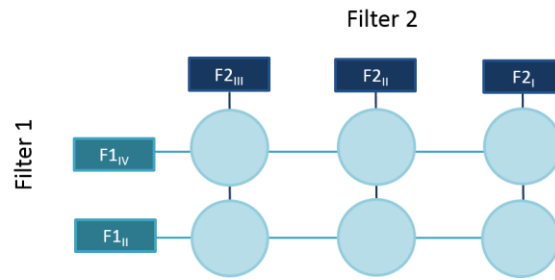

Figure 2-3 Conjugated values for filter 1 and filter 2 using the sample of particle size above 16 mm from RESIESTRELA

The tests executed using the samples of size fraction 6-16 mm were the same for every MBT plant. The values tested for filter 1 were $F1_{IV}$ and $F1_{III}$ and for filter 2 the values $F2_{IV}$, $F2_{III}$ and $F2_{II}$. **Figure 2-4** shows the values of the filters tested with the samples from SULDOURO, RESIESTRELA and VALNOR with particle size 6-16 mm to find the values that produce the better results. Each circle represents one test.
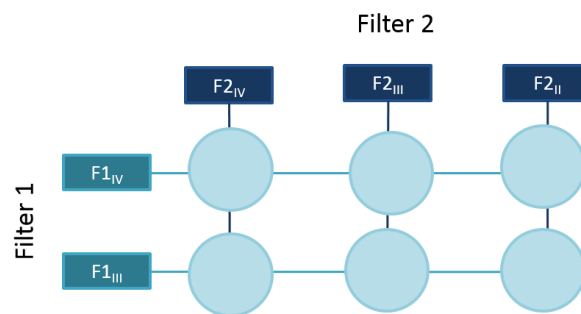

Figure 2-4 Conjugated values for filter 1 and filter 2 using the samples of particle size 6-16 mm from SULDOURO, RESIESTRELA and VALNOR

The output obtained after the optical sorting (OK2) was hand sorted into its constituent materials. These materials were weighted and the percent composition and the recovery of each material were calculated. The results were used to determine the values that produced the better results according to the criteria maximum percent composition in glass in the product OK2.

Finally, with the values that produced the better results determined previously, the sample that had been sorted with the same parameters underwent a new sorting to assess if additional treatment improved the quality of the end product.

3. Results

In this section, the results that show the influence of the operational parameters of the optical sorters on the sorting of the samples are presented. The values of the parameters that produce the better results according to each criteria mentioned before are also presented. After that, the need for additional treatment is assessed.

Across the various results presented, the graphs show the recovery of glass in the left vertical axis and the recovery of stones and ceramics in the right vertical axis since the values are so far

apart. The results for glass are represented with a square, stones are represented with a circle and the ceramics with a triangle.

Intensity of the emitted radiation

Figure 3-1 shows the results of the tests to determine the value of the intensity of the emitted radiation that produced better results.
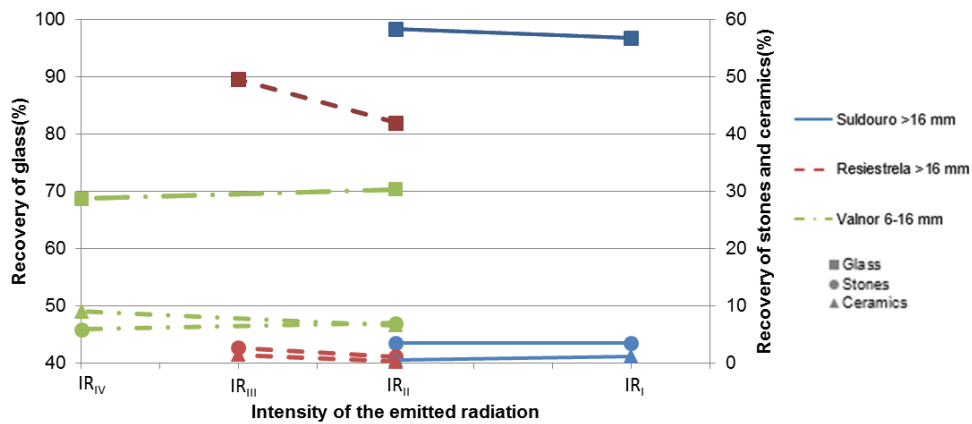

Figure 3-1 Influence of the intensity of the emitted radiation in the recovery of glass, stones and ceramics

The results show that, regardless of composition and particle size, the differences of the recovery for each material in the product OK2 were insignificant that can be attributed to small variations in the composition of the samples. The exception were the tests on RESIESTRELA's samples that presented a behaviour contrary to what was expected.

Level of received radiation

Figure 3-2 shows the results of the tests to determine the value of the level of received radiation that produced better results.
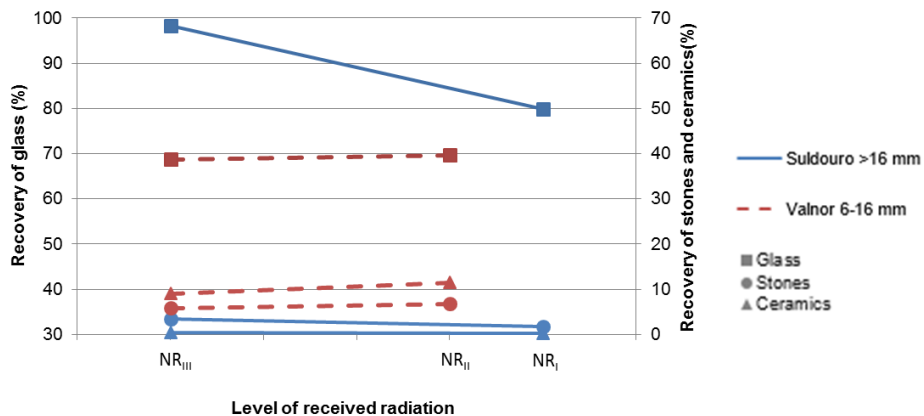

Figure 3-2 Influence of the level of emitted radiation in the recovery of glass, stones and ceramics

The recovery of glass from SULDOURO's sample decreased significantly when the level of received radiation increases, as expected. By making the system accept particle when they allow a significant amount of radiation reach the sensor (more transparent particles), the recovery of glass decreases from almost 100% to around 80%.

On the other hand, the results obtained with VALNOR's sample are constant regardless of the values of the level of received radiation tested.

Filters

Figure 3-3 shows the results of the tests to determine the values of the filters that produced better results when using samples of particle size above 16 mm.
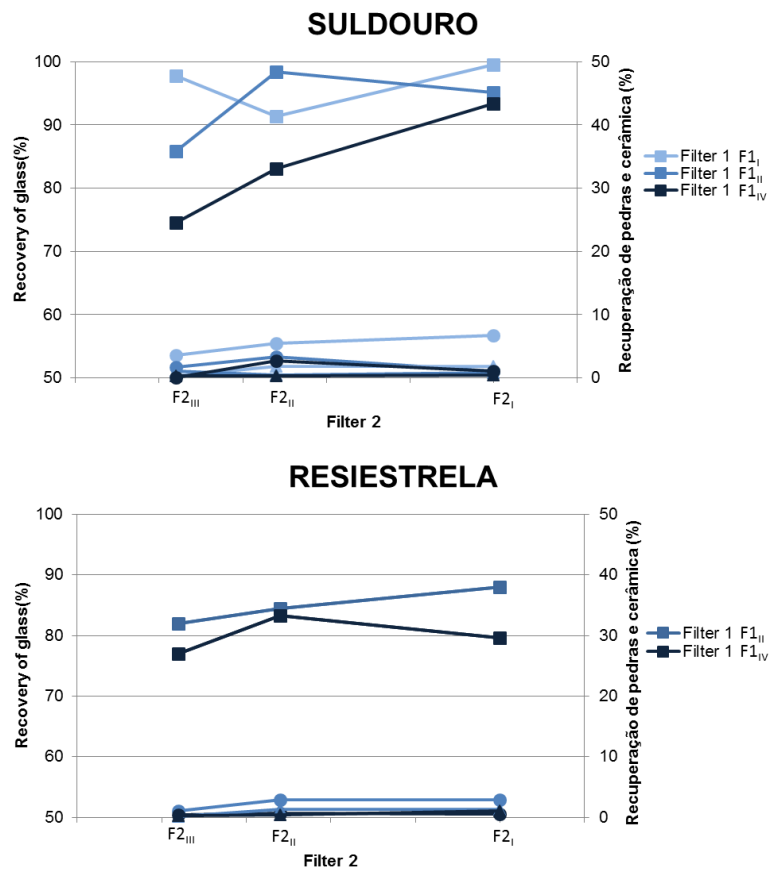

Figure 3-3 Influence of the filters in the recovery of glass, stones and ceramics using samples of particle size above 16 mm (SULDOURO and RESIESTRELA)

The results show that the lowest recoveries of contaminants are the ones produced by the lower values of both filters, although these values of filters also produce the lowest recoveries of glass. Due to the size of the particles, in some cases they would get stuck inside the equipment, which might have caused some room for error.

As the values of both filters increase, it was expected that the recoveries of both the glass and the contaminants would increase. There are cases that the recoveries decrease when the values of the filters increase, but that can be due to small differences in composition among the samples.

Figure 3-4 shows the results of the tests to determine the values of the filters that produced better results using samples of particle size 6-16 mm.
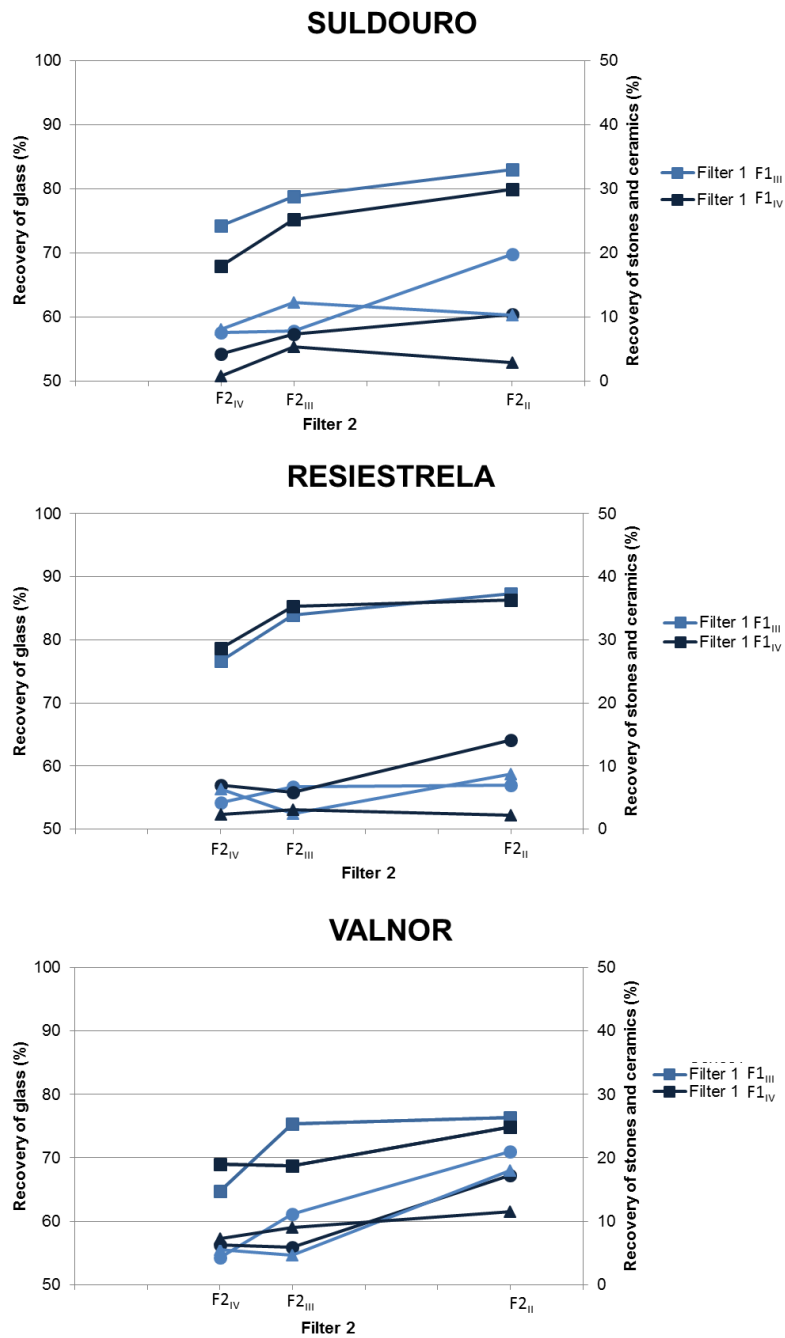

Figure 3-4 Influence of the filters in the recovery of glass, stones and ceramics using samples of particle size 6-16 mm (SULDOURO, VALNOR and RESIESTRELA)

Overlooking some exceptions, the recovery of the materials presented increase with the increase of the values of the filters.

This increase, in the particular case of the glass, seems to follow a quadratic tendency: it increases significantly for lower values of the filters and is almost constant for higher values of the filters. This might be due to the fact that the higher values of the filter are close to the particle sizes.

After testing all the parameters of the equipment, the values that produced the better results regarding the percent composition in glass were chosen and are present in **Table 3-1**.

Table 3-1 Table of values of the intensity of emitted radiation (IER), level of received radiation (LRR) and filters 1 and 2 that produced better results

Parameter	SD 6-16 mm	SD, RE >16 mm RE, VN 6-16 mm
IER	IR_{II}	IR_{II}
LRR	NR_{III}	NR_{III}
filter 1	$F1_{IV}$	$F1_{IV}$
filter 2	$F2_{IV}$	$F2_{III}$

Except for the samples of SULDOURO with particle size 6-16 mm that produced better results with a different value for filter 2, all the samples originated better results using the same values in each parameter. The percent composition in glass using these values is higher than 97% regardless of the sample's origin.

Additional treatment

Figure 3-5 shows the graphs of percent composition vs recovery of glass and contaminants to assess the need for an additional treatment phase for samples of particle size above 16 mm. The contaminants and the glass were separated for easier reading. The point with 100% of recovery is the percent composition of the fed material, the second point is the first treatment and the third point is the additional treatment.
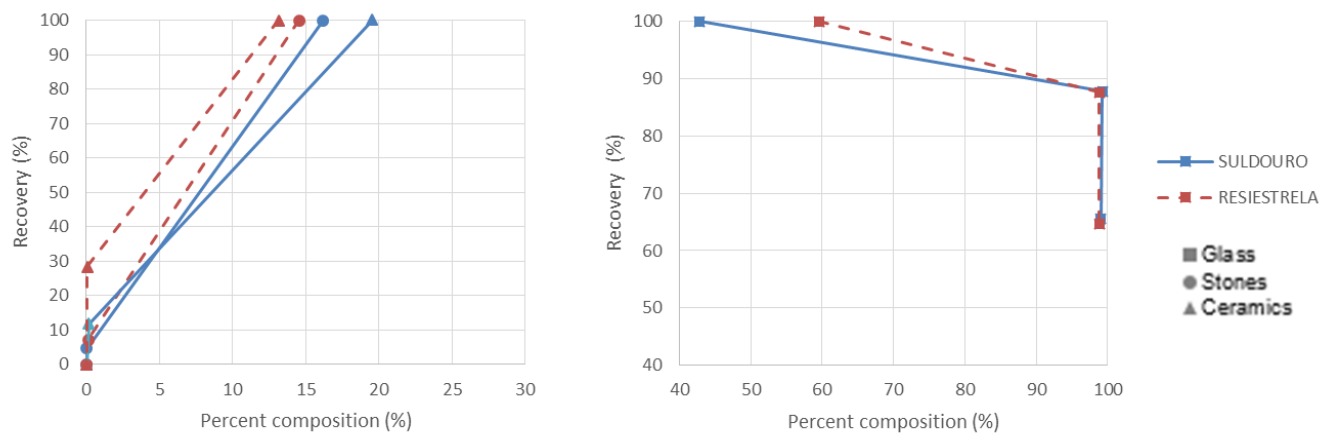

Figure 3-5 Graphs of percent composition vs recovery of glass and contaminants for samples of the feed, first treatment and additional treatment of samples of particle size above 16 mm (SULDOURO and RESIESTRELA)

It is clear that the percent content in glass increases considerably after the first treatment, but the additional step of treatment only decreases the recovery of glass, without any increase in the percent composition.

Figure 3-6 shows the graphs of percent composition vs recovery of glass and contaminants to assess the need for an additional treatment phase for samples of particle size 6-16 mm.
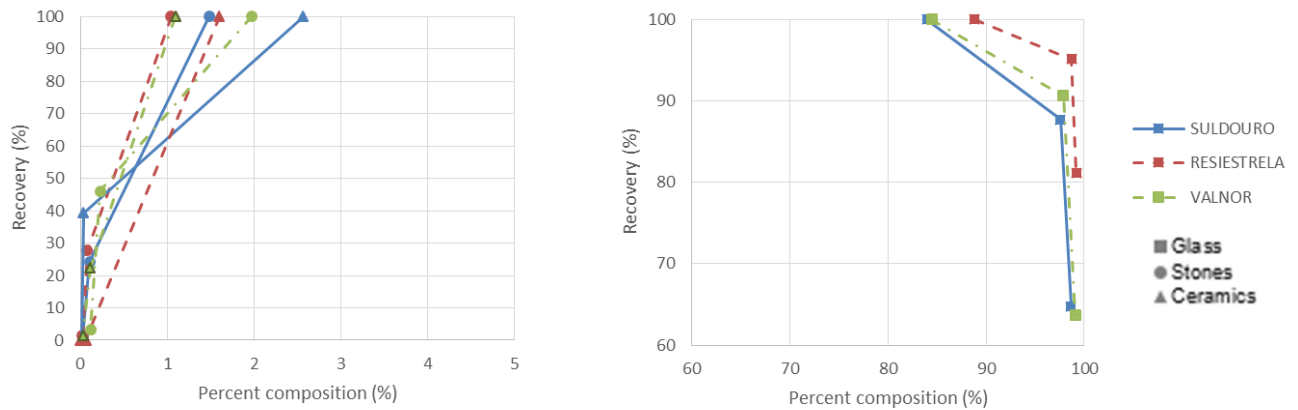
Figure 3-6 Graphs of percent composition vs recovery of glass and contaminants for samples of the feed, first treatment and additional treatment of samples of particle size 6-16 mm (SULDOURO, RESIESTRELA and VALNOR)

The results show that, regardless of the composition of the sample, as before, the additional treatment makes the recovery of glass decrease and altering nothing in the percent composition in glass.

The results were compared to those obtained in previous studies of the project RecGlass to see if they had, in fact, improved with the optimization of the optical sorting. The results are presented in

Table 3-2 Maximum percent composition in glass obtained in the present study and in previous studies

MBT plant	Particle size	Max. Percent composition in glass in previous studies (%)	Max. Percent composition in glass in the present study (%)
SULDOURO	Above 16 mm	78,3	99,3
	6-16 mm	96,4	98,6
RESIESTRELA	Above 16 mm	94,8	98,9
	6-16 mm	98,0	99,2
VALNOR	6-16 mm	86,3	99,1

The optimization of the optical sorting proved to be beneficial to improve the results previously obtained during the project RecGlass. These results might, however, have been influenced by some differences in the material fed and in operation of the equipment.

4. Conclusions

Although the objective of this study was to optimize the optical sorting for the recovery of glass in the heavy reject of MBT plants, what was done was find a local optimum using the knowledge form VIDROCICLO to process this reject.

The parameters intensity of the emitted radiation and level of received radiation do not affect the optical sorting as much as the filters do.

It was possible to find the values that produced a percent composition in glass higher than 98% for each parameter. Even though the specification require a percent composition in glass above

98%, the output produced still has a higher quantity of infusible materials that prevents it from being accepted to be recycled.

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