Research reference Plastic

Queena Rijke Jerry de Vos Hedde van Hoorn Plastic Scanner

1. Inhoud

1. Goal of the experiment

Plastic Scanner has assembled a box with bags of types of plastic. Each bag had four to six samples of the same type of plastic. These samples were gathered from commercial plastics. The identification of the types of plastic was read of the labelling. The goal of the experiment was to determine whether each sample is the type of plastic indicated on the label and whether the samples could be used as reference to the plastic scanner. Figure 1 shows a photo of the different types of plastic that were used for identification.

Figure 1: The bags of the types of plastic containing four to six samples of the same type of plastic.

To be able to compare the measured data with the theory the reflectance of the samples needs to be determined. This can be done using the following equation,

$$R = \frac{I_s}{I_{ref}} \cdot 100\% \tag{1.1}$$

in which R is the reflectance in %, I_s is the intensity of the plastic sample in counts and I_{ref} is the intensity of the reference tile in counts.

2. Setup

The IR spectrum of the types of plastic is measured with a spectrometer, a broadband light source and a fibre. The fibre is able to illuminate the plastic and detect the reflected IR spectrum. The equipment needed to execute the experiment are as follows:

- Avantes IR spectrometer (AVASPEC-NIR256-2.0TEC)
- Computer/Laptop containing AvaSoft8
- Halogen lamp (AVALIGHT-HAL)
- Optical multimode fibre with beam splitter (FDP-7UVIR400-2-VAR)
- Stand to hold the fibre
- Reference box C with plastic reference samples including three different types of reference tiles
- HHS reference tile

Figure 2 shows a schematic sideview of the placement of the equipment. The optical fibre is connected to the halogen lamp and the IR spectrometer. The detection side of the fibre is placed in a way that it can scan the plastic samples from above. The spectrometer is connected to a computer containing the AvaSoft8 software to read the detected data.

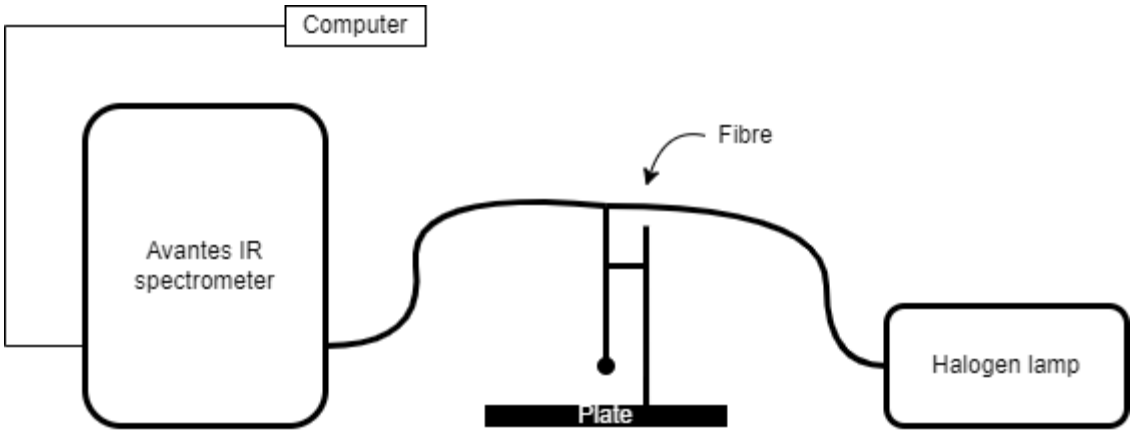

Figure 2: A schematic setup to identify the type of plastic via IR spectroscopy. A split fibre is attached to the Avantes spectrometer and the light source (halogen lamp).

The experiment was conducted in a darkened and lightened room, to compare the effect of the sunlight in the identification of the plastics. A picture of the setup is shown in Figure 3.

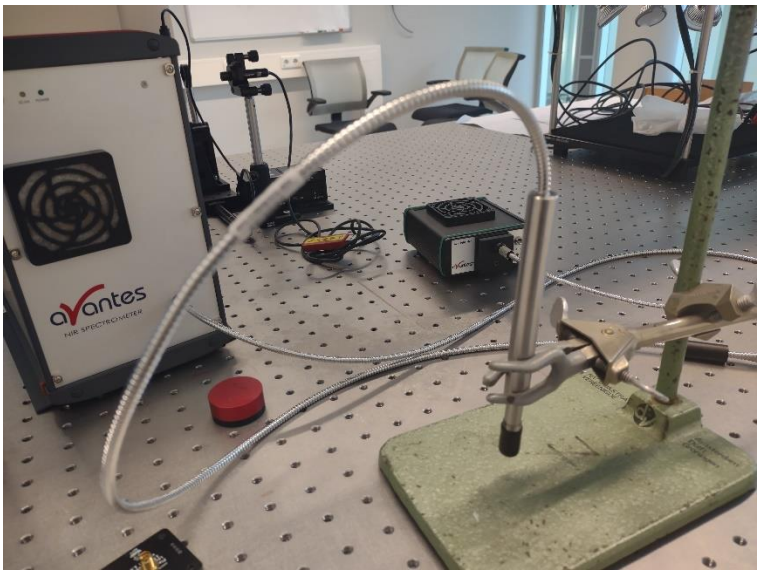

Figure 3: A picture of the setup to identify the different types of plastic via IR spectroscopy. A fibre is attached to a light source and the Avantes spectrometer. The ending of the fibre is held by a clasp.

2.1 Accuracy analyses

Before measuring the reference tiles and the plastic samples, a dark measurement was made. The dark measurement was subtracted from the collected data of the plastic samples.

3. Method

The setup is build according to Figure 2. Before measuring, the integration time and average of the Avantes spectrometer are set. The integration time is set on a value around 100,000 ms and the average is set on a value of 2. The Dynamic Dark in the same settings is disabled. The range of the wavelength in which the spectrometer will measure are set from 800 nm to 1900 nm. A dark measurement is made and saved in AvaSoft.

First the reference tiles are measured. The reference tile is placed under the fibre ending with a distance in between of 10 mm, measured with a triangle ruler with a $\pm$ 2 mm accuracy. The tile is measured five times, where at each measurement a different location on the tile is measured. By measuring the tile five times at different locations, the repeatability can be determined. After measuring each reference tile, the plastic samples provided by Plastic Scanner are measured. Six different plastic types are present in reference box C, PET, HDPE, PVC, LDPE, PP and PS. Each bag consists of four to six samples of one type of plastic. Each sample of the plastic type is measured five times at different locations on the sample. The plastic samples are placed on top of the reference tile that will be used during the experiment. The samples are measured by pressing the 'Single measurement' button in the program.

The data is manually saved in Excel-documents and plotted using python.

4. Expected results

It is expected that the spectra of the scanned plastic will be the same as Figure 4. The spectra of the different types of plastic in Figure 4 are plotted with an offset.

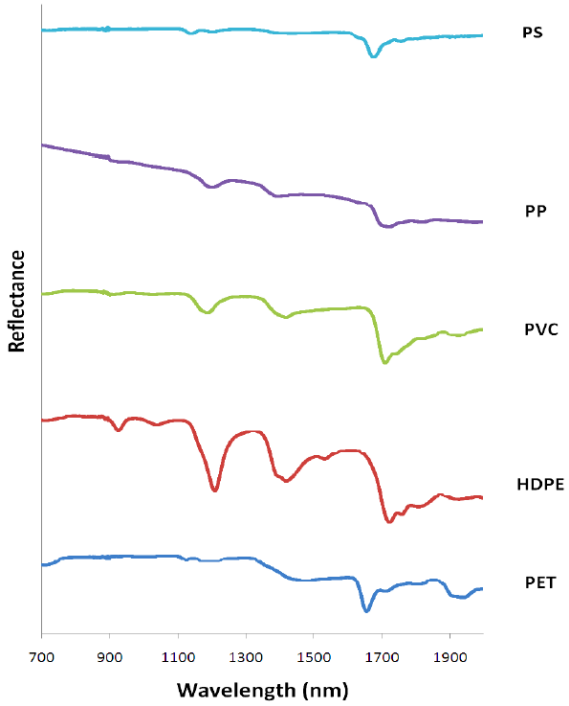

Figure 4: Expected progression of the five most common types of plastic over a wavelength range of 700 nm to 1900 nm [1].

It is also expected that the scanning location on the plastic has no effect on the measurement of the spectra.

5. Results

The experiment was conducted in the Lectoraat lab and Photonics lab at the Hague University. The measurements conducted in the Lectoraat lab were executed in a room lit by ambient light and clear windows in which the sun had an effect on the measurements. The integration time was set on 140 ms and an average of 2. The measurements conducted in the Photonics lab were executed in a darkened room. The integration time was set on 105 ms and an average of 2. The experiment was conducted twice, once in the Lectoraat lab and once in the Photonics lab, to measure the effect of light on the measurement. The raw data of the experiments can be found on Github. A link can be found in the Appendix A: Links to Github. First the results of the reference tiles will be discussed, then the results of the plastic samples will be discussed.

The colours of the data in the figures do not always correspond with the colour of the plastic. The letters at the end of the sample code in the legends indicate the colour of the plastic sample.

Table 1: Explanation of the letters at the end of the sample code in the legends.

Letter	Colour
w	White
t	Transparent
g	Green
wt	White transparent
y	Yellow
gr	Grey
bl	Blue
r	Red
p	Purple

Reference tile

The results of the four different reference tiles are shown in Figure 7.

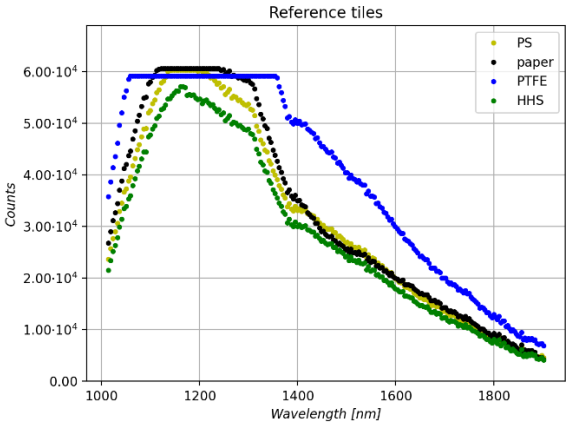

Figure 5: Measurement conducted in the Lectoraat lab. The settings of the Avantes spectrometer were set on a Integration time: 140 ms and an average of 2.

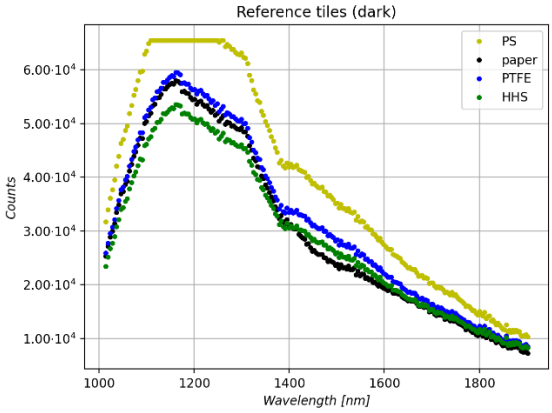

Figure 6: Measurement conducted in the Photonics lab. The settings of the Avantes spectrometer were set on a Integration time: 140 ms and an average of 2.

Figure 7: The counts of the four different reference tile plotted against the wavelength. PS refers to the reference tile provided by Plastic Scanner and HHS refers to the reference tile provided by The Hague University. Paper and PTFE refer to the material of the reference tile.

Figure 5 and Figure 6 show that the lighting in the measurement room has an effect on the intensity of the reflection. It was expected that the reflection of the tiles would be higher in the lightened

room. The figures show that this does not appear to be true. It is not clear what the reason could be for the difference in the intensity of the reflection. Both figures show saturated data, meaning that the integration time has to be altered to a lower value then 140 ms. The experiment needs to be conducted again with the altered integration time to be able to conclude something about the reflectance of the tiles.

Colour measurement

Each type of plastic had four to six different colour samples. The reflection of each of these samples is represented per type. Each type of plastic shows the results of the measurements conducted in the Lectoraat lab and the Photonics lab.

PET

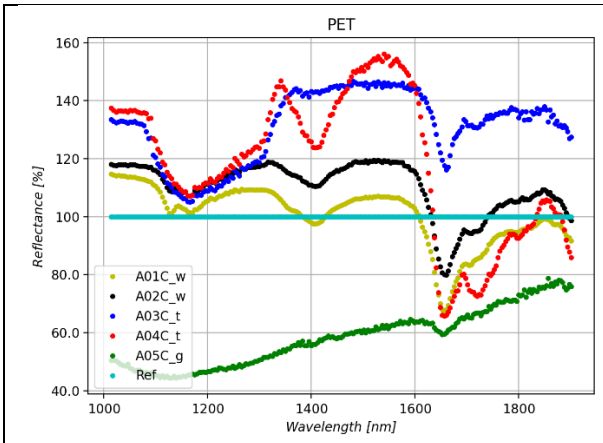

Figure 8: The reference measurement conducted in the Lectoraat lab has been used to determine the reflectance of the plastic. Integration time: 140 ms and an average of 2.

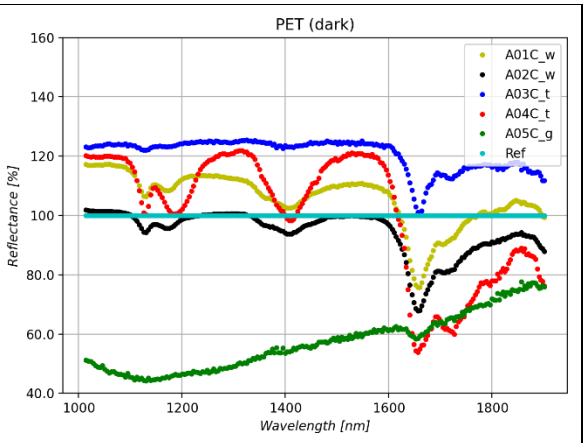

Figure 9: The reference measurement conducted in the Photonics lab has been used to determine the reflectance of the plastic. Integration time: 105 ms and an average of 2.

The blue and red results in Figure 8 show a dip that is caused by saturated data. Both figures, Figure 8 and Figure 9, show an undefined spectrum in the green dataset, however the absorption dip around 1650 nm is still visible.

HDPE

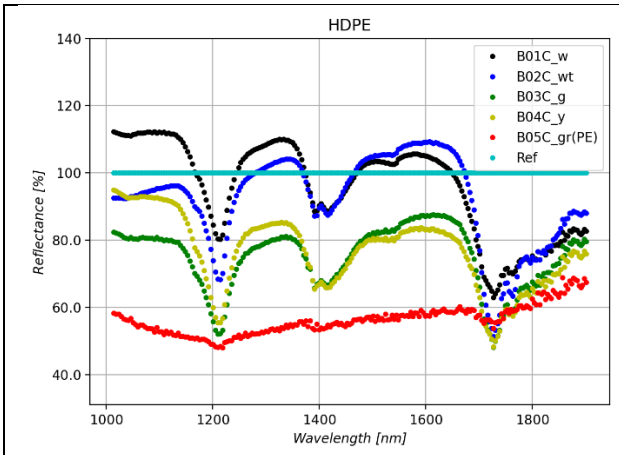

Figure 10: The reference measurement conducted in the Lectoraat lab has been used to determine the reflectance of the plastic. Integration time: 140 ms and an average of 2.

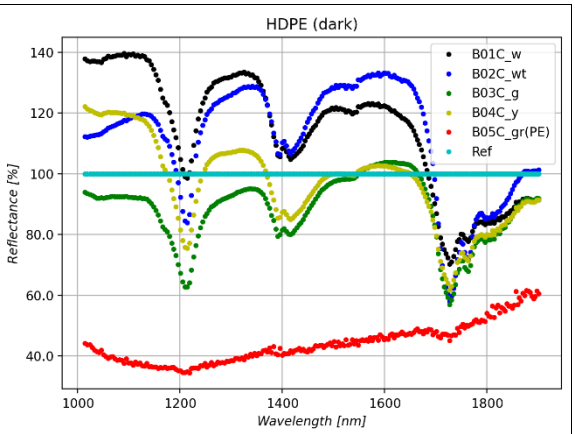

Figure 11: The reference measurement conducted in the Photonics lab has been used to determine the reflectance of the plastic. Integration time: 105 ms and an average of 2.

The grey sample (red coloured line) of PE has an undefined spectrum compared to the other colours of HDPE. The absorption has decreased in a darkened room relative to a lightened room, as visible in Figure 10 and Figure 11. The intensity of the reflection has increased in a darkened room. The spectra of B05C deviates from the other four spectra of HDPE. A cause of this deviation could be the difference in plastic type. B05C is the spectrum of PE instead of HDPE. Another cause could be the colour of the plastic. The absorbance becomes higher and the spectrum less defined.

PVC

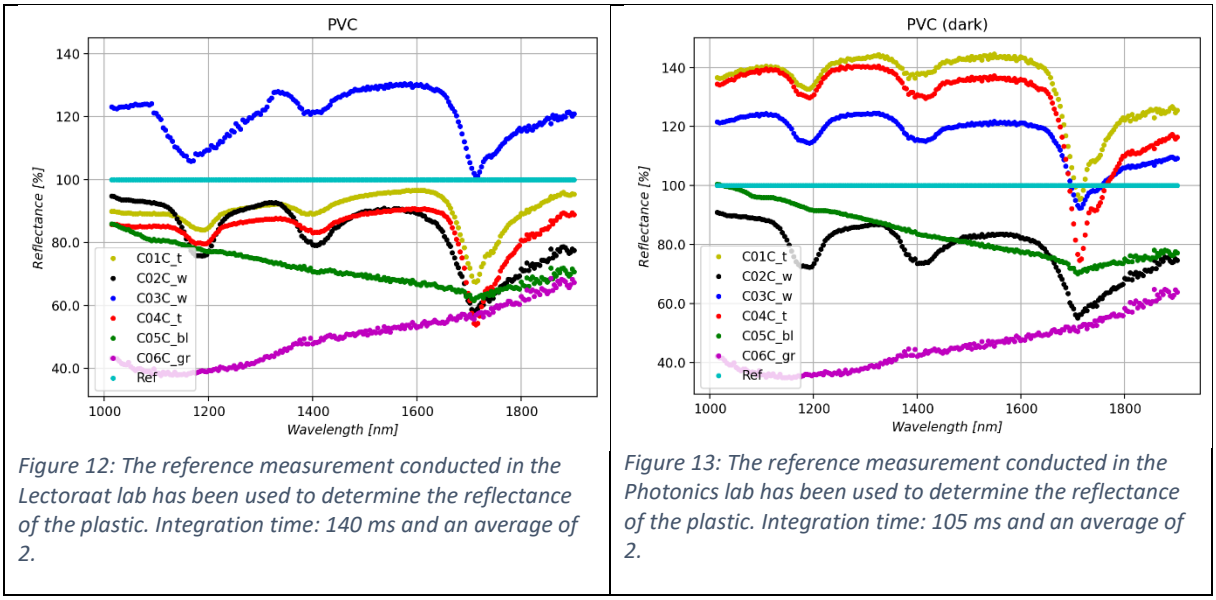

Figure 12: The reference measurement conducted in the Lectoraat lab has been used to determine the reflectance of the plastic. Integration time: 140 ms and an average of 2.

Figure 13: The reference measurement conducted in the Photonics lab has been used to determine the reflectance of the plastic. Integration time: 105 ms and an average of 2.

Both figures show a more undefined spectra of the blue and grey sample of PVC (purple and green lines). The purple line, C06C, shows no absorption dips. The green line, C05C, shows a small absorption dip around 1700 nm. The blue line, C03C, shows a saturation dip around 1150 nm in Figure 12. It is uncertain if the last two samples can be identified as PVC, because of the deviation in the spectra compared to the other four spectra of PVC.

LDPE

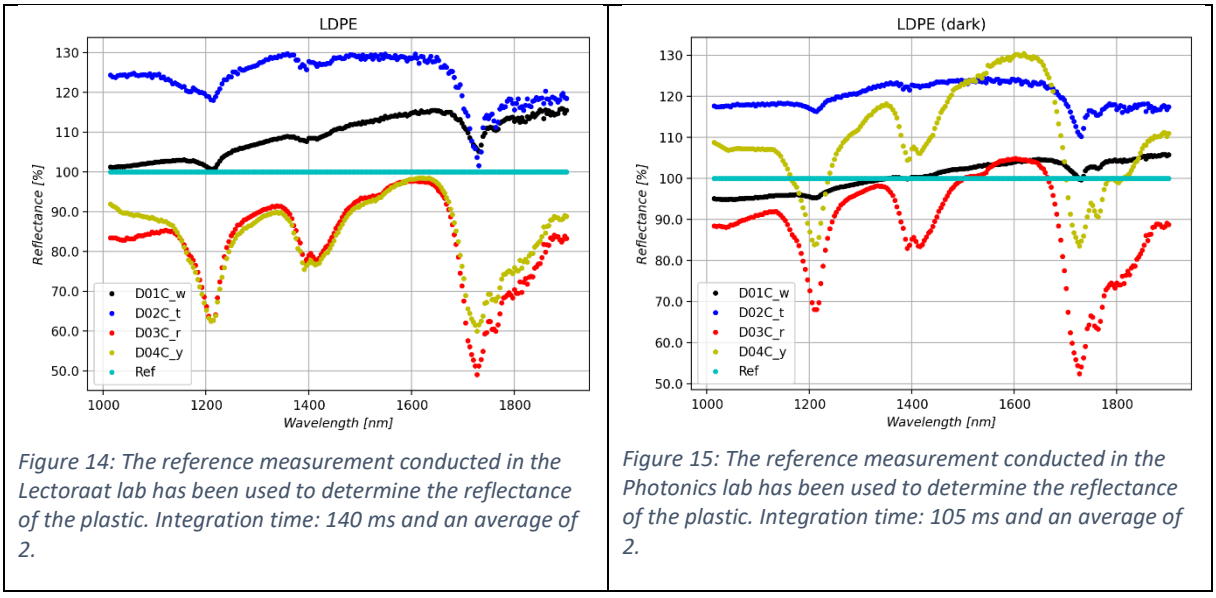

Figure 14: The reference measurement conducted in the Lectoraat lab has been used to determine the reflectance of the plastic. Integration time: 140 ms and an average of 2.

Figure 15: The reference measurement conducted in the Photonics lab has been used to determine the reflectance of the plastic. Integration time: 105 ms and an average of 2.

As opposed to the previous plastic types, the light coloured samples have a less defined spectrum than the darker coloured samples. The dips of the LDPE plastic correspond with the dips of the HDPE plastic, as expected because of the similar molecule structure.

PP

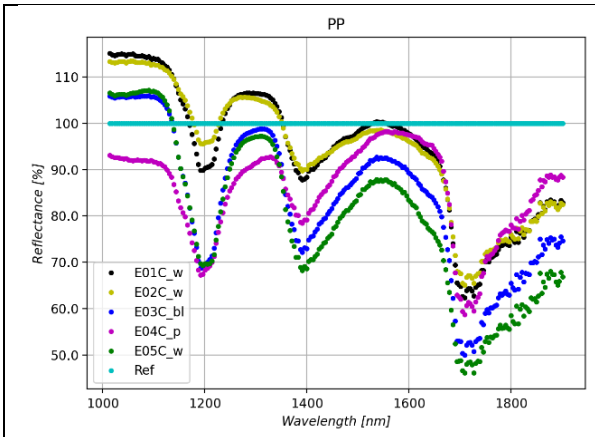

Figure 16: The reference measurement conducted in the Lectoraat lab has been used to determine the reflectance of the plastic. Integration time: 140 ms and an average of 2.

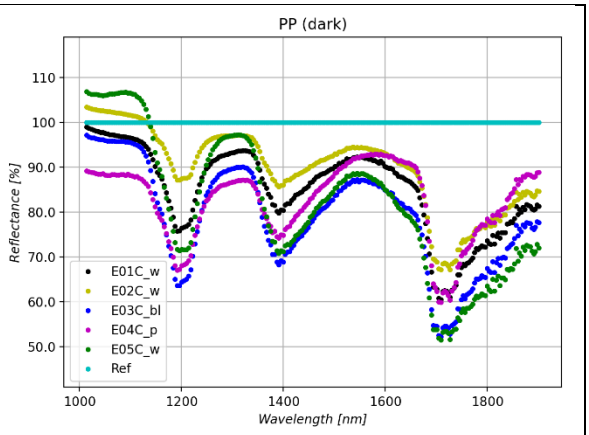

Figure 17: The reference measurement conducted in the Photonics lab has been used to determine the reflectance of the plastic. Integration time: 105 ms and an average of 2.

The uniqueness of Figure 16 and Figure 17 is the well defined spectra and the reflectance. The lines lay close to each other, which ensures that the average does not deviate much from the original data. Both figures don't deviate from one another except for the decrease in reflectance in Figure 17, which can be the result of the darkened room.

PS

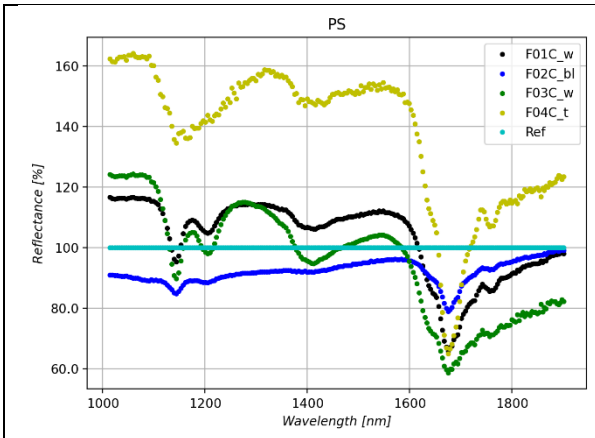

Figure 18: The reference measurement conducted in the Lectoraat lab has been used to determine the reflectance of the plastic. Integration time: 140 ms and an average of 2.

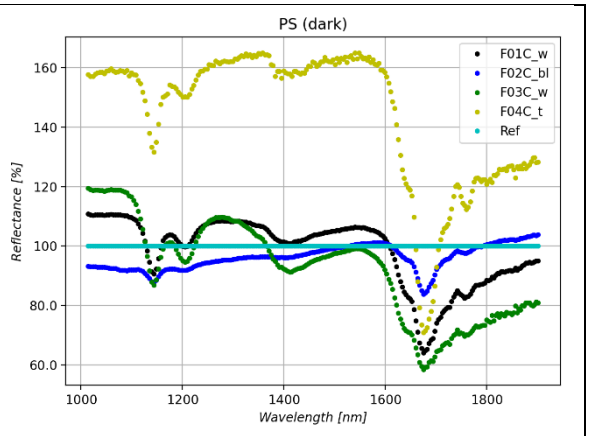

Figure 19: The reference measurement conducted in the Photonics lab has been used to determine the reflectance of the plastic. Integration time: 105 ms and an average of 2.

With both measurements the transparent sample has a higher reflectance than the other coloured samples. As expected is the spectrum of the blue sample less defined. Sample F04C also has a saturation dip around 1150 nm in Figure 18.

All figures have colours that have a higher reflectance than 100%. A cause could be the low reflectance of the reference tile. It is also visible that the colour of the plastic affects the reflectance. The absorption becomes higher with coloured plastic and the defining dips become less visible. This means that these samples are not suitable as reference. As seen in the figures it is very important that the data is not saturated. The spectra of the types of plastic becomes more visible.

Repeatability Photonics lab

Each colour of the plastic samples of each type has been measured five times to measure the repeatability. These results are presented in this section. The results are sorted per type of plastic.

PET

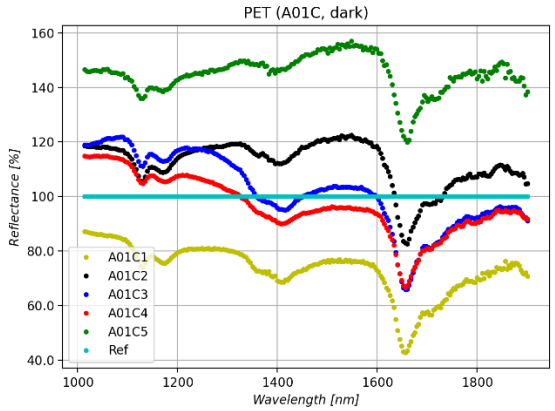

Figure 20: Measurement conducted in the Photonics lab of a white coloured sample. Integration time: 105 ms and an average of 2.

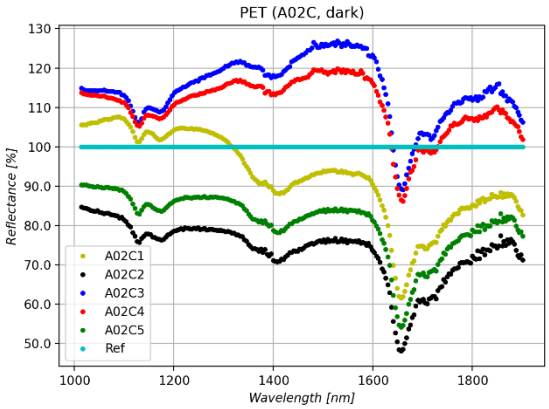

Figure 21: Measurement conducted in the Photonics lab of a white coloured sample. Integration time: 105 ms and an average of 2.

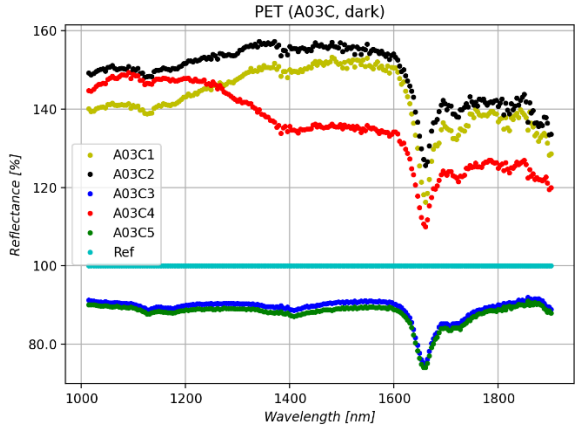

Figure 22: Measurement conducted in the Photonics lab of a transparent sample. Integration time: 105 ms and an average of 2.

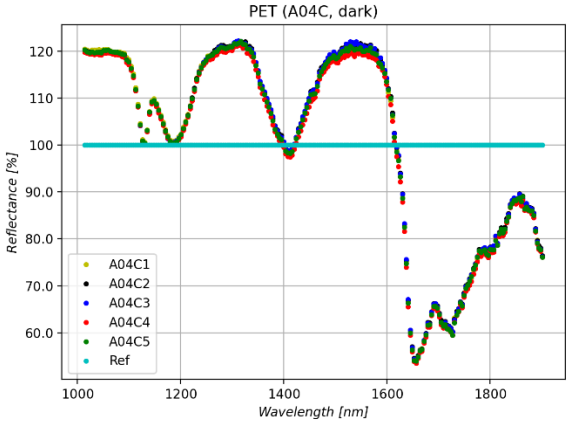

Figure 23: Measurement conducted in the Photonics lab of a transparent sample. Integration time: 105 ms and an average of 2.

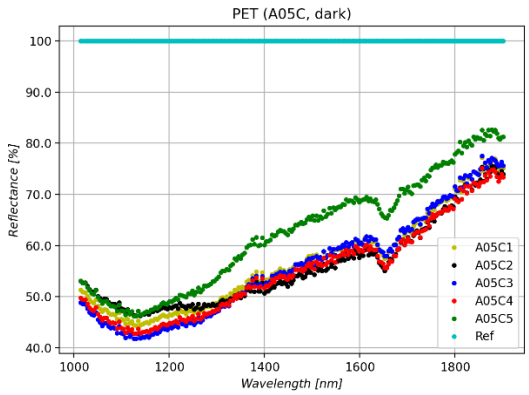

Figure 24: Measurement conducted in the Photonics lab of a green coloured sample. Integration time: 105 ms and an average of 2.

There is no saturation present in this data because of the lowered integration time, therefore the dips in the wavelength range of 1100 nm to 1200 nm have become more clear.

HDPE

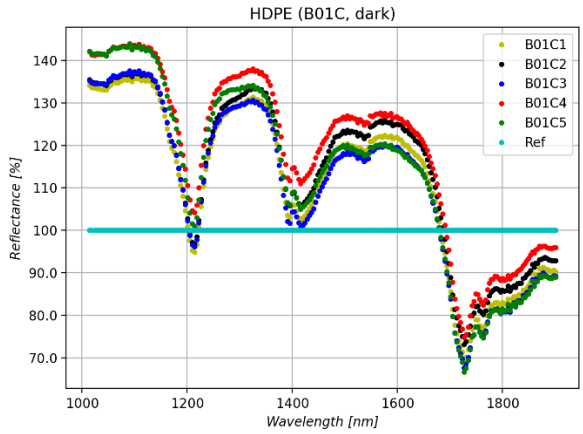

Figure 25: Measurement conducted in the Photonics lab of a white coloured sample. Integration time: 105 ms and an average of 2.

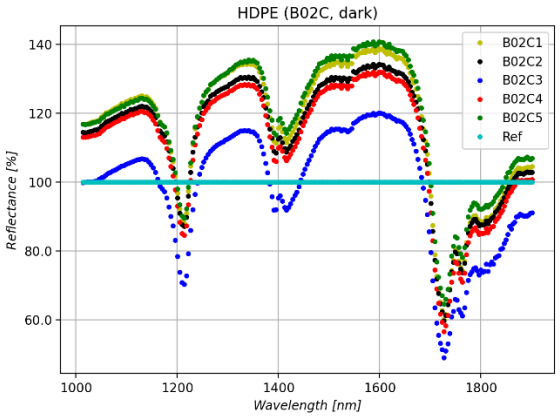

Figure 26: Measurement conducted in the Photonics lab of a white transparent sample. Integration time: 105 ms and an average of 2.

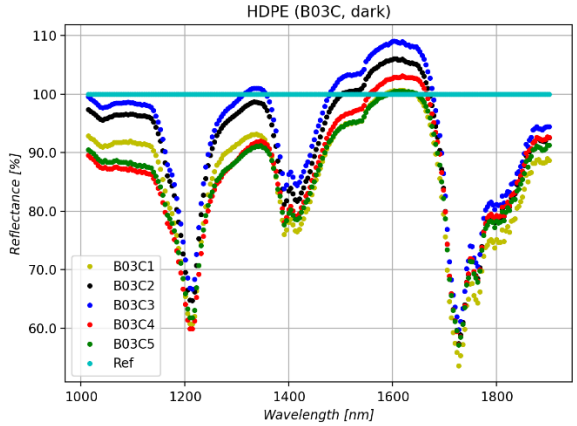

Figure 27: Measurement conducted in the Photonics lab of a green coloured sample. Integration time: 105 ms and an average of 2.

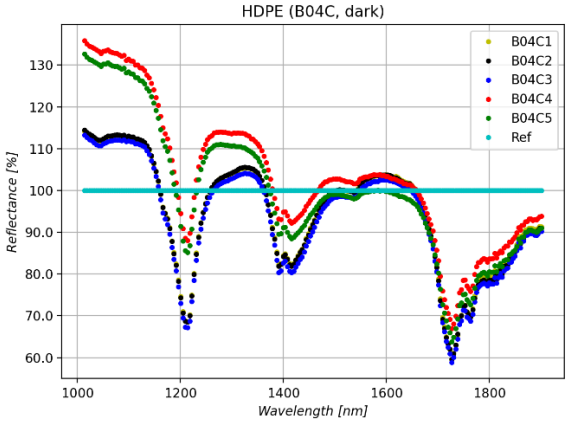

Figure 28: Measurement conducted in the Photonics lab of a yellow coloured sample. Integration time: 105 ms and an average of 2.

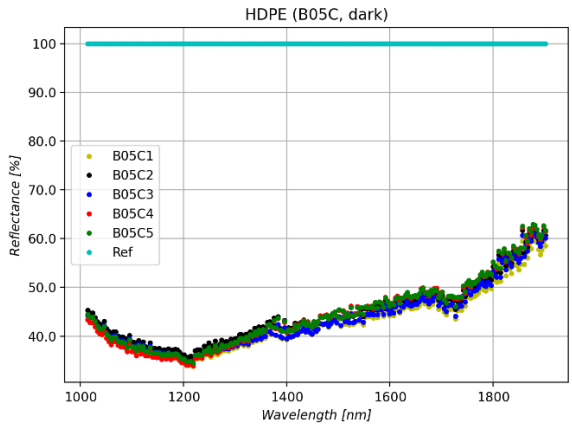

Figure 29: Measurement conducted in the Photonics lab of a grey coloured sample. Integration time: 105 ms and an average of 2.

The difference between the intensity of the reflectance of repeated measurements has decreased compared to the measurements in the Lectoraat lab.

PVC

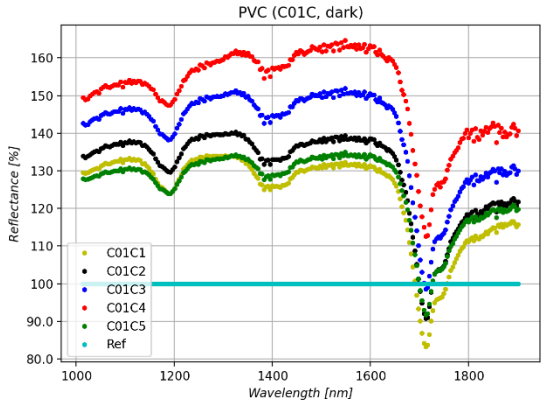

Figure 30: Measurement conducted in the Photonics lab of a transparent sample. Integration time: 105 ms and an average of 2.

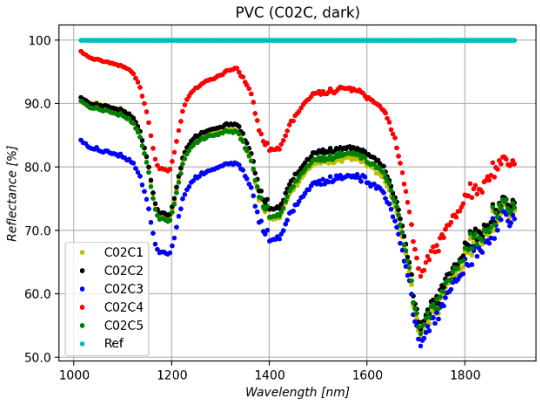

Figure 31: Measurement conducted in the Photonics lab of a white coloured sample. Integration time: 105 ms and an average of 2.

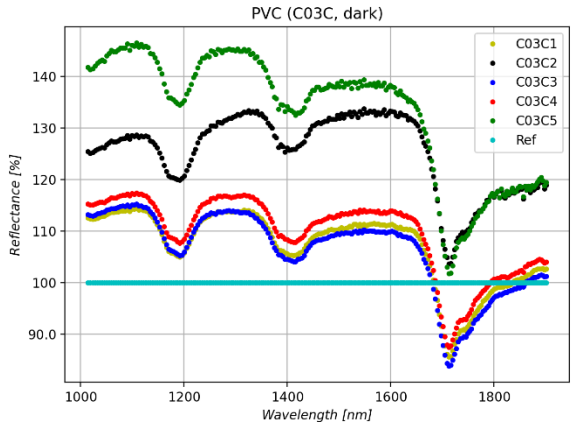

Figure 32: Measurement conducted in the Photonics lab of a white coloured sample. Integration time: 105 ms and an average of 2.

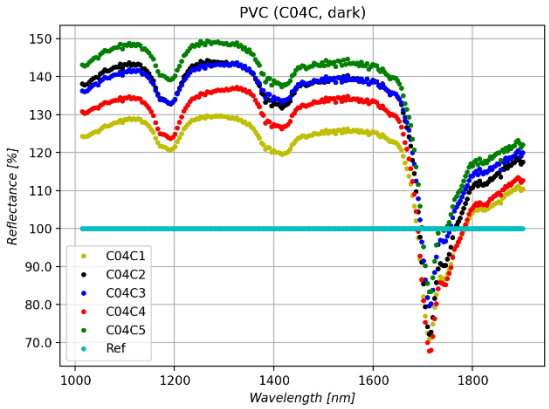

Figure 33: Measurement conducted in the Photonics lab of a transparent sample. Integration time: 105 ms and an average of 2.

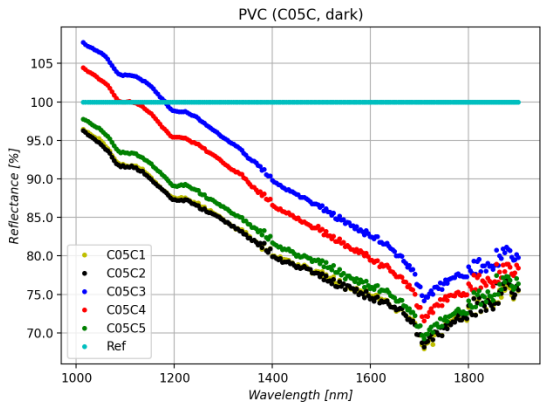

Figure 34: Measurement conducted in the Photonics lab of a blue coloured sample. Integration time: 105 ms and an average of 2.

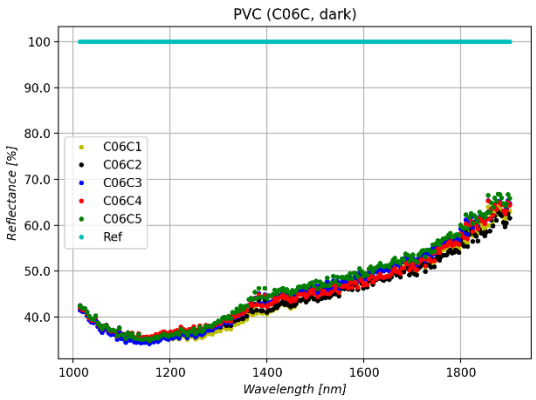

Figure 35: Measurement conducted in the Photonics lab of a grey coloured sample. Integration time: 105 ms and an average of 2.

As shown again the last two samples of PVC are not following the expected spectra for PVC. This could be caused by the material used to colour the samples or that the last two samples are not made out of PVC.

LDPE

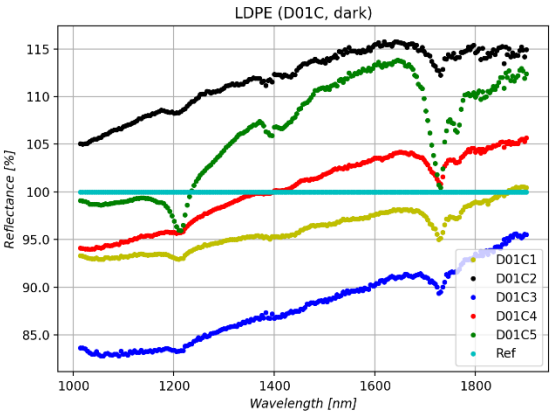

Figure 36: Measurement conducted in the Photonics lab of a white coloured sample. Integration time: 105 ms and an average of 2.

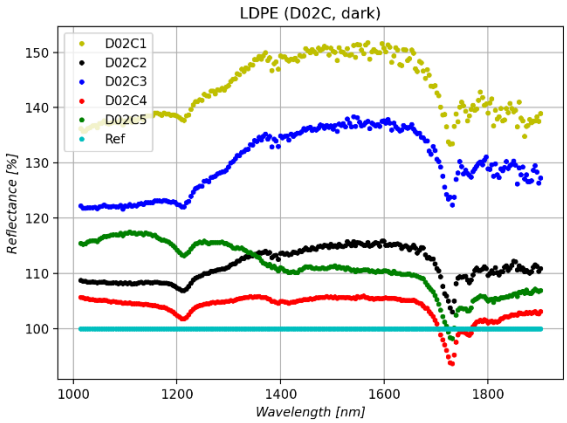

Figure 37: Measurement conducted in the Photonics lab of a transparent sample. Integration time: 105 ms and an average of 2.

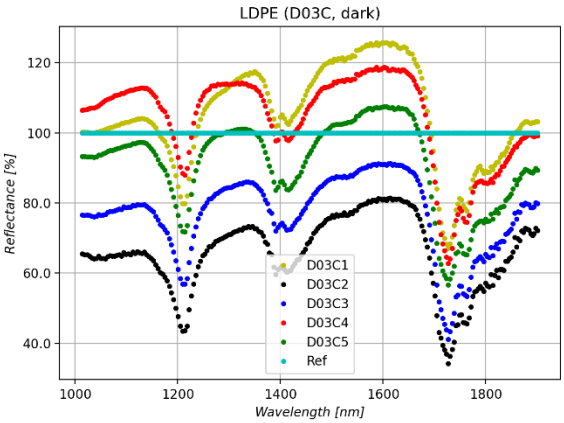

Figure 38: Measurement conducted in the Photonics lab of a red coloured sample. Integration time: 105 ms and an average of 2.

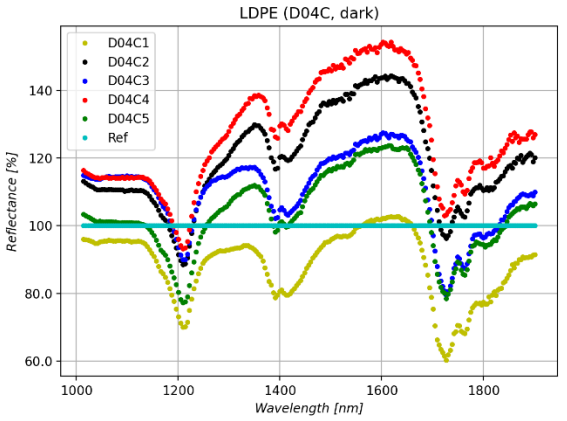

Figure 39: Measurement conducted in the Photonics lab of a yellow coloured sample. Integration time: 105 ms and an average of 2.

The intensity of the reflectance of the repeated measurements differentiate from each other. It would be expected that the lines would overlap for one of the samples. All figures show no difference in spectra compared to the measurements taken in the Lectoraat lab, except for the measurements of sample D01C. The dip around 1200 nm is less visible. Figure 37 shows saturated data in the shape of a wide peak. This could be caused by the less diffuse surface of the plastic sample.

PP

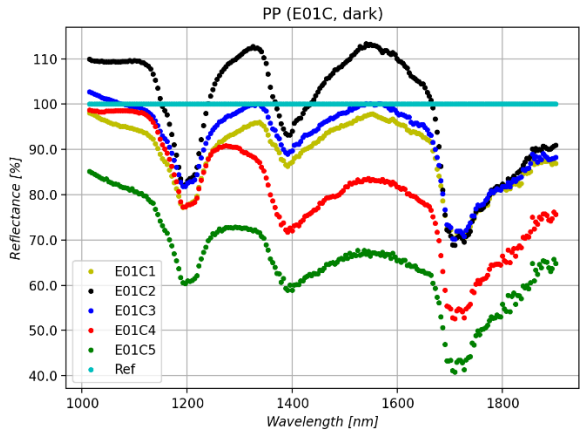

Figure 40: Measurement conducted in the Photonics lab of a white coloured sample. Integration time: 105 ms and an average of 2.

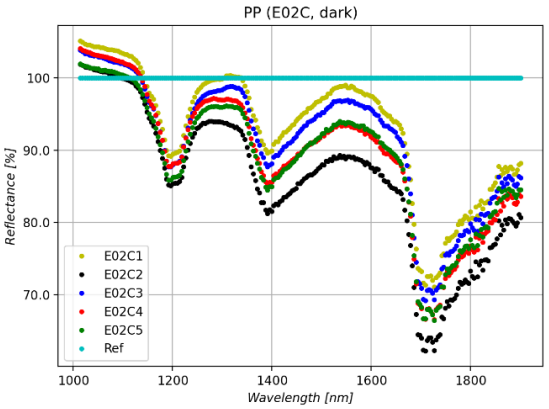

Figure 41: Measurement conducted in the Photonics lab of a white coloured sample. Integration time: 105 ms and an average of 2.

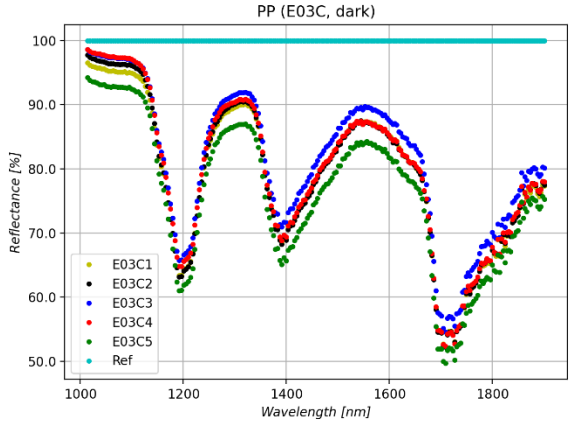

Figure 42: Measurement conducted in the Photonics lab of a blue coloured sample. Integration time: 105 ms and an average of 2.

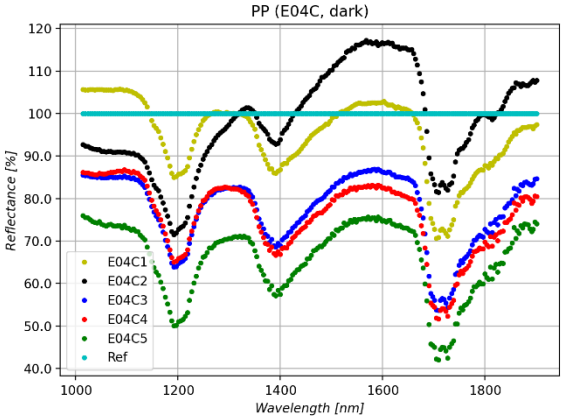

Figure 43: Measurement conducted in the Photonics lab of a purple coloured sample. Integration time: 105 ms and an average of 2.

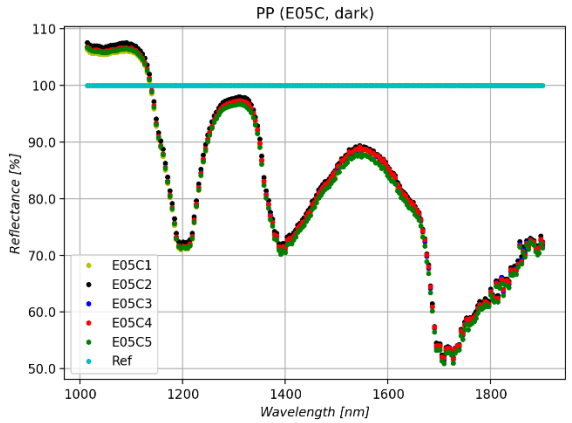

Figure 44: Measurement conducted in the Photonics lab of a white coloured sample. Integration time: 105 ms and an average of 2.

The course of the spectra are as expected except for Figure 40 and Figure 43 where the spectra don't overlap. This could be a cause of a reflective layer coated on the plastic samples measured.

PS

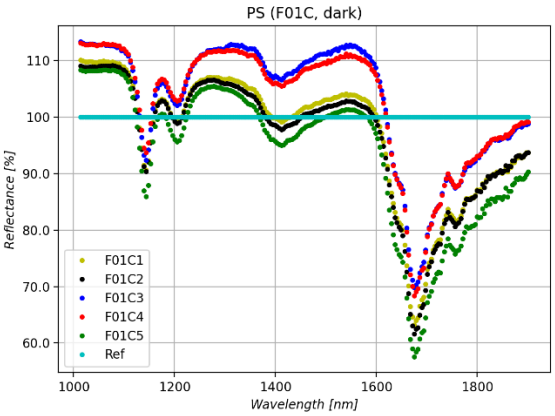

Figure 45: Measurement conducted in the Photonics lab of a white coloured sample. Integration time: 105 ms and an average of 2.

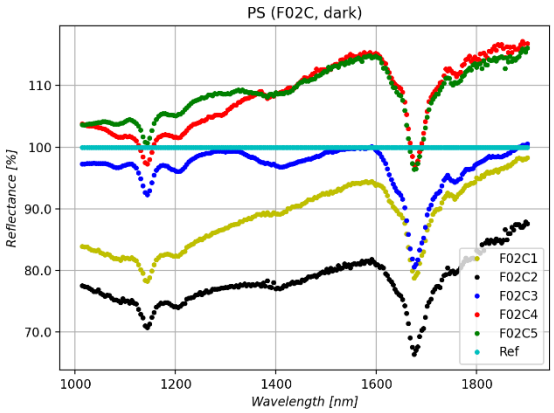

Figure 46: Measurement conducted in the Photonics lab of a blue coloured sample. Integration time: 105 ms and an average of 2.

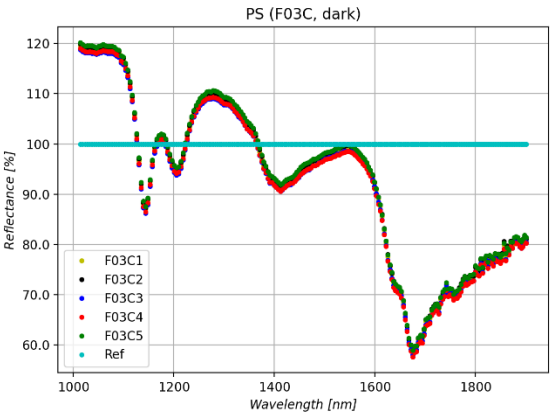

Figure 47: Measurement conducted in the Photonics lab of a white coloured sample. Integration time: 105 ms and an average of 2.

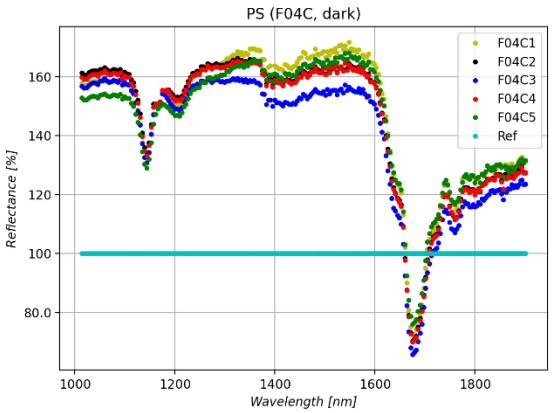

Figure 48: Measurement conducted in the Photonics lab of a transparent sample. Integration time: 105 ms and an average of 2.

All figures of PS show that it is not relevant where you scan the plastic to get a repeated measurement. A reason could be that the all samples had a flatter surface except for sample F02C. The reflectance of the measurements in Figure 46 vary widely. A cause could be the difference in diffuseness of the surface of the plastic sample.

Figure 20 till Figure 48 show that the scanning location on the plastic does not effect the course of the spectra of the types of plastic. The distance of 10 mm between the sample and the fibre could not always be obtained because of the irregular curvature of the samples. This also had effect on the reflection intensity.

Plastics

Figure 49 shows the reflectance of the types of plastics plotted against the wavelength.

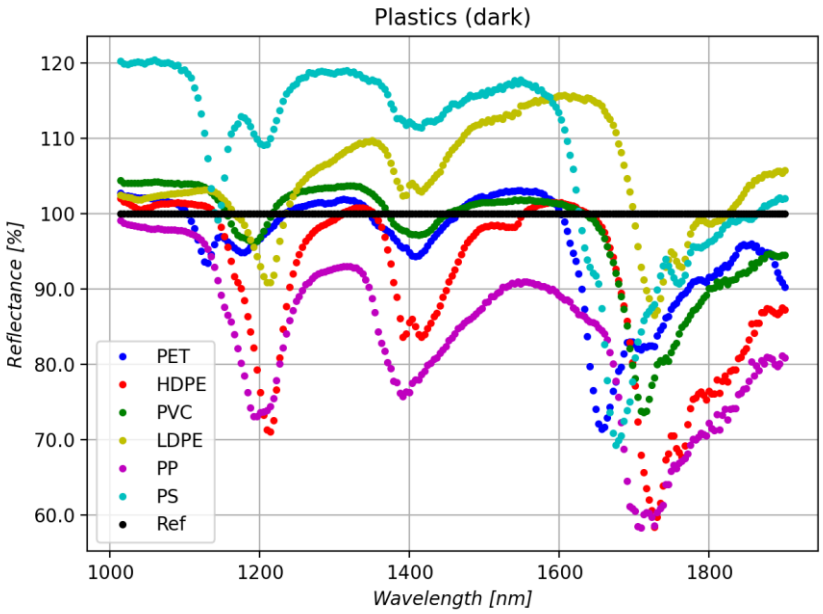

Figure 49: The reflectance of the different types of plastic plotted against the wavelength. Measurements conducted in a dark Photonics lab. The settings of the Avantes spectrometer were set on a Integration time: 105 ms and an average of 2.

A SNV filter should be used to show a better distinction between the spectra of the types of plastic. The filter will be applied to the repeatability data. The measured data of the types of plastic is placed next to the spectra of the theory to determine the correspondence with each other. The comparison is shown in Figure 50.

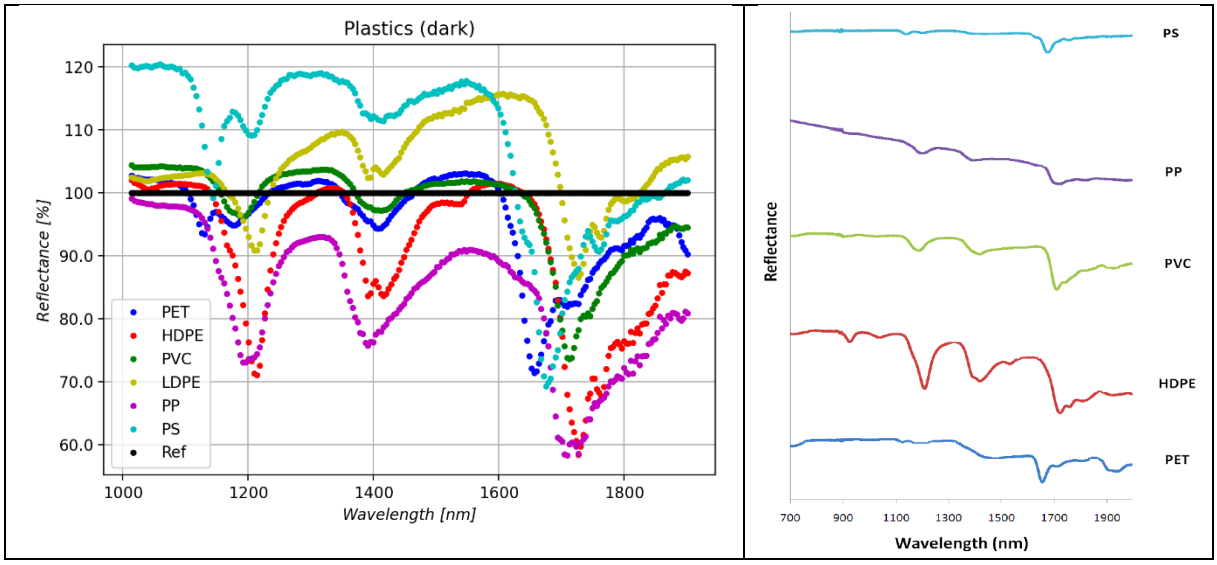

Figure 50: The measured spectra of six different types of plastic next to the spectra of the different types of plastic from the theory.

The spectra of the different types of plastic corresponds with the spectra in the theory. The plastics can be compared with the dips around 1200 nm, 1400 nm and 1700 nm.

6. Conclusion

Most plastic samples have a higher reflectance than 100%. This could be caused due to the mirroring layer on certain plastic samples. To prevent a higher reflectance than 100% the reference tile needs to become more reflective or the plastic samples more diffuse. The offset could also be a cause of the higher reflectance.

Some of the plastic samples measured in the Lectoraat lab have a saturated dataset, which is visible in the large dip around the 1150 nm. By decreasing the integration time the measured data does not become saturated and the spectra of the data becomes more defined. This can be seen in the data measured in an darkened environment where the integration was lowered from 140 to 105 ms.

The only difference between the measurements taken in a lightened and darkened environment is the intensity of the reflectance. The spectra of the types of plastic stays the same allowing the plastic to be identified. Not all samples can be used as reference because of the undefined spectrum. Samples B05C, C05C and C06C show a spectrum not comparable with the other spectra of the type of plastic. A reason could be that the samples are not the type of plastic as indicated on the commercial labelling or the colouring absorbs the wavelengths that are expected to be reflected.

7. Bibliography

[1] H. Masoumi, S. Mohsen Safavi en Z. Khani, „Identification and classification of plastic resins using near infrared reflectance spectroscopy," *International Journal of Mechanical and Industrial Engineering,* pp. 213-220, january 2012.

8. Appendix A: Links to Github

The raw data processed in chapter Results can be found on Github.

The raw data of the experiment conducted in the Lectoraat lab is as follows: https://github.com/Plastic-Scanner/data/tree/main/data/20230222_avantes_spectrometer_second_dataset

The raw data of the experiment conducted in the Photonics lab is as follows: https://github.com/Plastic-Scanner/data/tree/main/data/20230302_avantes_spectrometer_third_dataset