# Horizon Europe (HE MSCA-SE)

## Deliverable D.1.2

## A sorting process for MPW

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# Deliverable D.1.2. A sorting process for MPW

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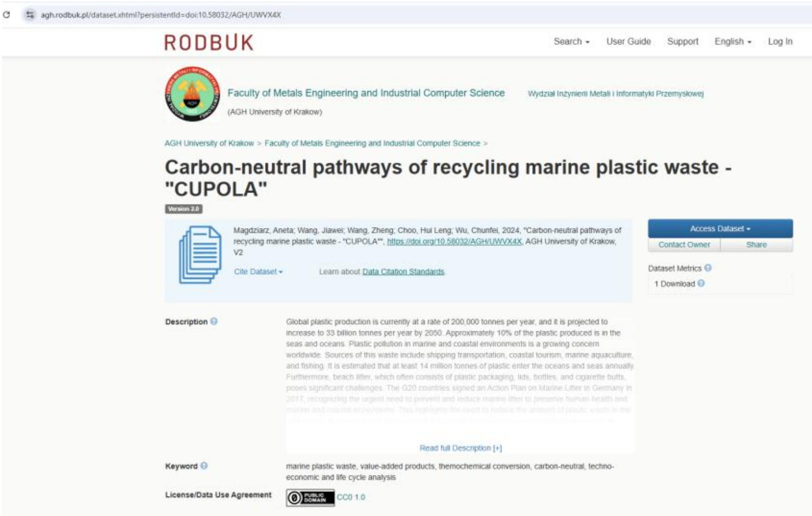
**Introduction to Deliverable D.1.2**

Marine plastic waste poses a significant environmental challenge, necessitating efficient sorting and recycling processes to mitigate pollution and promote sustainability. This deliverable, A Sorting Process for MPW, presents a systematic approach for sorting marine plastic waste (MPW) using density-based separation techniques. The methodology focuses on classifying plastics based on their physical properties to enhance recycling efficiency. The raw plastics found in marine waste include Polypropylene (PP), Polyethylene (PE), Polyethylene Terephthalate (PET), and smaller fractions of Polyamide (PA) and Polystyrene (PS). These materials, with densities ranging from 0.8 to 1.4 g/cm$^3$, can be separated using Dense Medium Separation (DMS) techniques, specifically leveraging strontium chloride (SrCl2) solutions. The process involves pre-treatment steps such as shredding and washing to ensure effective sorting and prevent contamination. This report details the experimental validation of separation efficiency using lab-scale Vorsyl and Larcodems separators. The study explores the impact of different separation media and multi-stage purification techniques to improve the quality and recovery rates of sorted plastics. This project contributes to the broader EU goals of reducing plastic pollution and promoting circular economy practices by implementing a structured sorting process. The findings and methodologies presented provide a foundation for scalable solutions in managing and recycling marine plastic waste.

The deliverable D1.2 – A Sorting Process for MPW is available in open access in the RODBUK AGH University of Krakow (repository) and can be accessed at the following link: https://doi.org/10.58032/AGH/UWVX4X.

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**Deliverable D.1.2**

Collected marine waste plastics are predominantly bottles and fishery tools in various shapes made from Polypropylene (PP), Polyethylene (PE) and Polyethylene terephthalate (PET), a few Polyamide (PA), Polystyrene (PS). The absolute density of these plastics are in the range of 0.8 to 1.4 g/cm$^3$, which makes Dense Medium Separation (DMS) techniques using Strontium chloride ($SrCl_2$) solution applicable for high efficiency separation. Prior to separation, samples were cut into pieces smaller than 4 cm x 4 cm using a twin-screw shredder and washed with a industrial washing machine to remove the dirt and other contaminants attached to the pieces. This cleaning is essential to safeguard against contaminants altering the density of plastic pieces and tainting the separation medium.


***Figure 1**. Twin screw shredder for size reduction of collected marine waste plastic*

Dense Medium Separation (DMS) is a widely used technique in the recycling industry for sorting plastics based on their density. Two prominent systems employed in this process are the Vorsyl Separator and the Larcodems Separator. Both systems utilize a dense medium, typically a solution or suspension of fine magnetite in water, to separate lighter plastics from heavier plastics. The Vorsyl Separator is a dynamic, cylindrical-based system that uses centrifugal force to enhance separation efficiency. It is particularly effective for processing large volumes of material and is known for its high throughput and consistent performance. In contrast, the Larcodems Separator employs an inclined trough design, relying on gravity and the natural flow of the dense medium to achieve separation. In addition, this design provides a suction effect on the feed which smooth the intake of both light and heavier pieces into the separator, while eliminating the bubble attached to irregular surface of plastic pieces created by cutting. The variety material and colour nature of waste plastics brings challenges to quantify the separation efficiency, therefore artificial flaky samples with better colour contrast were prepared for experimental purpose. Separation experiment on selected pieces of waste marine plastics with known density and colour difference as shown in Figure 1 were also conducted to verify the separation efficiency obtained using artificial samples.

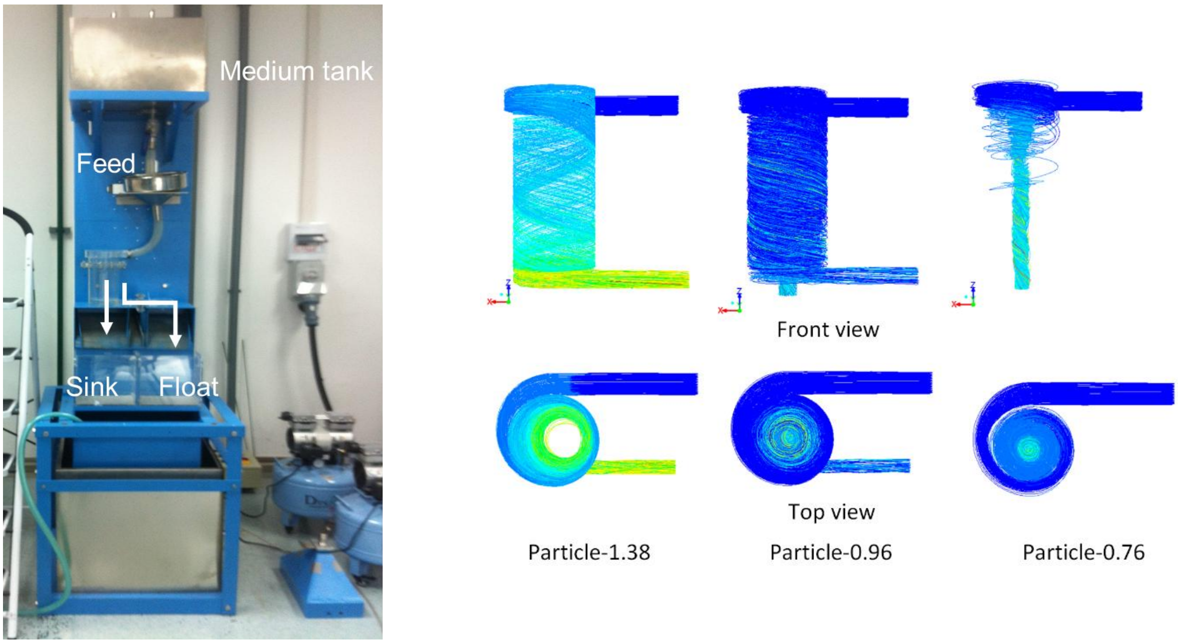


***Figure 2.*** *Vorsyl Separator for plastic separation*

The lab-scale Vorsyl separator were made with two medium tanks, one at the bottom to collect separation solution to be pumped to the overhead tank for separation. Plastic pieces were fed into the hopper by vibration feeder and separated into sink material, collected in the left collection box, and float material to the right collection box. Both collection boxes were made with screen bottom to serve as filter. The samples were classified into light and heavy fractions using separation medium such as water with a density of 0.995 g/cm$^3$ and a strontium chloride (SrCl2) solution with a density of 1.195 g/cm$^3$. For example, a sample consisting of high-density polyethylene (HDPE) and polypropylene (PP) showed that 99.56% of the HDPE settled in the heavy fraction, while 99.12% of the PP floated in the light fraction. Similar results were observed for other material combinations, highlighting the efficiency of the separation process in distinguishing between different types of plastic based on their densities. The separation efficiency for materials with density closer to the separation medium, such as the combination of Acrylonitrile Butadiene Styrene (ABS) and PP, were difficult to be separated due to the attachment of bubbles onto the plastic pieces and insufficient separation effect from the hydraulic streamlines within the Vorsyl separator.

***Table 1.*** *Vorsyl separator experimental result - Separation medium: water, density: 0.995 g/cm³*

| | Sample Material | Mean Density | Weight | Percentage by weight | Light | Percentage | Heavy | Percentage |
|---|---|---|---|---|---|---|---|---|
| | | g/cm³ | g | % | g | % | g | % |
| 1 | HDPE (black) | 1.43 | 250 | 50 | 0.1 | 0.04 | 248.9 | 99.56 |
| | PP | 0.91 | 250 | 50 | 247.8 | 99.12 | 1.4 | 0.56 |
| 2 | PC (black) | 1.26 | 250 | 50 | 1.6 | 0.64 | 248.3 | 99.32 |
| | PP | 0.91 | 250 | 50 | 246.6 | 98.64 | 1.9 | 0.76 |
| 3 | ABS (black) | 1.06 | 250 | 50 | 86 | 34.4 | 163.6 | 65.44 |
| | PP | 0.91 | 250 | 50 | 248.1 | 99.24 | 1.2 | 0.48 |

***Table 2.*** *Vorsyl separator experimental result - Separation medium: $SrCl_2$ Solution Density: 1.195 g/cm³*

| | Sample Material | Mean Density | Weight | Percentage by weight | Light | Percentage | Heavy | Percentage |
|---|---|---|---|---|---|---|---|---|
| | | g/cm³ | g | % | g | % | g | % |
| 1 | PVC | 1.36 | 400 | 80 | 18.1 | 4.5 | 381.4 | 95.4 |
| | ABS (black) | 1.06 | 100 | 20 | 99 | 99 | 0.5 | 0.5 |
| 2 | PVC | 1.36 | 100 | 20 | 5.4 | 5.4 | 94.2 | 94.2 |
| | ABS (black) | 1.06 | 400 | 80 | 398.7 | 99.7 | 0.8 | 0.2 |
| 3 | PC (white) | 1.29 | 400 | 80 | 189.5 | 47.38 | 208.5 | 52.1 |
| | ABS (black) | 1.06 | 100 | 20 | 98.7 | 98.7 | 0.2 | 0.2 |
| 4 | PC (white) | 1.29 | 100 | 20 | 37.5 | 37.5 | 62.3 | 62.3 |
| | ABS (black) | 1.06 | 400 | 80 | 398 | 99.5 | 0.5 | 0.13 |

A two-stage Larcodem separator as shown in Figure 3 was developed to enhance the separation of near medium density materials. The medium tank locates at the bottom as this separator employs gravity and the natural flow of the dense medium to achieve separation. Separation medium will be pumped into the primary separator to create a tangential flow and create a path for low density particles along the longitudinal axis of the separator. The medium and heavy particles will be taken into the secondary separator to be further classified by the flow field. Before load samples into the separator via the top hopper, stable vortex should be formed in both separators by adjust the pumping power. Water was used as the separation medium in the

Larcodem separator to investigate the separation efficiency for various plastic combinations. Table 3 and 4 show some representative results.

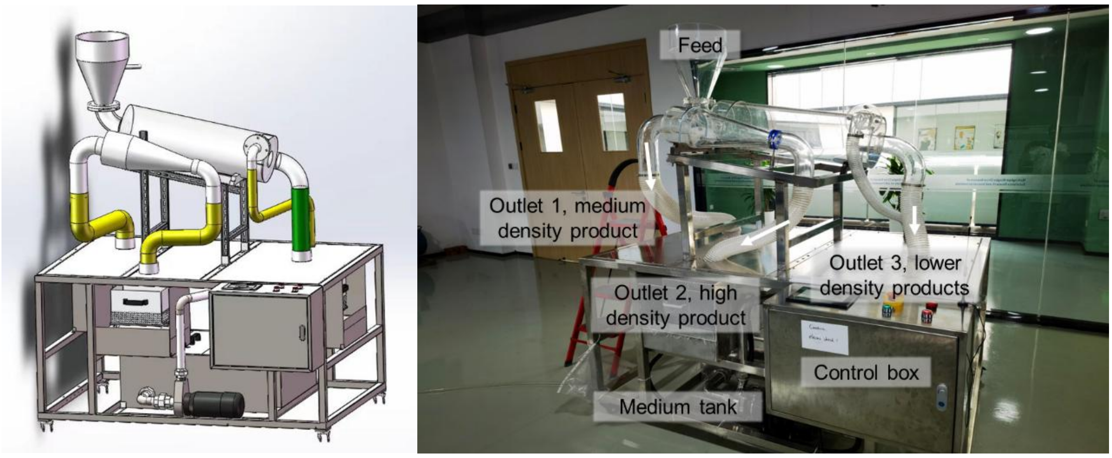


***Figure 3***. *The lab-scale Larcodem separator*

***Table 3.*** *Separation results of PP and other 4 plastics*

| Group | Material | Density | Mass | Percentage | Outlet 1 | | Outlet 2 | | Outlet 3 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | g/cm³ | g | wt. % | g | wt. % | g | wt. % | g | wt. % |
| 1 | PP | 0.91 | 250.29 | 50 | 0.044 | 0.02 | 0.032 | 0.01 | 248.607 | 99.33 |
| | PET | 1.36 | 250.06 | 50 | 0.086 | 0.03 | 248.533 | 99.39 | 0.279 | 0.11 |
| 2 | PP | 0.91 | 250.406 | 50 | 0 | 0.00 | 0 | 0.00 | 250.322 | 99.97 |
| | PVC | 1.35 | 250.03 | 50 | 0.046 | 0.02 | 249.644 | 99.85 | 0.154 | 0.06 |
| 3 | PP | 0.91 | 249.964 | 50 | 0.015 | 0.01 | 0 | 0.00 | 249.891 | 99.97 |
| | PC (white) | 1.29 | 250.337 | 50 | 0.121 | 0.05 | 249.585 | 99.70 | 0.27 | 0.11 |
| 4 | PP | 0.91 | 250.069 | 50 | 0 | 0.00 | 0 | 0.00 | 249.506 | 99.77 |
| | ABS (black) | 1.06 | 250.015 | 50 | 29.501 | 11.80 | 22.549 | 9.02 | 197.959 | 79.18 |

***Table 4.*** *Separation results of PE and other 4 plastics*

| Group | Material | Density | Mass | Percentage | Outlet 1 | | Outlet 2 | | Outlet 3 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | g/cm³ | g | wt. % | g | wt. % | g | wt. % | g | wt. % |
| 1 | PE | 0.94 | 250.145 | 50 | 0.021 | 0.01 | 0.116 | 0.05 | 251.568 | 100.57 |
| | PET | 1.36 | 250.112 | 50 | 0.086 | 0.03 | 247.683 | 99.03 | 0.035 | 0.01 |
| 2 | PE | 0.94 | 250.021 | 50 | 0 | 0.00 | 0 | 0.00 | 249.648 | 99.85 |
| | PVC | 1.35 | 250.103 | 50 | 0.262 | 0.10 | 245.419 | 98.13 | 4.324 | 1.73 |
| 3 | PE | 0.94 | 250.055 | 50 | 0.054 | 0.02 | 0.235 | 0.09 | 248.571 | 99.41 |
| | PC (white) | 1.29 | 250.064 | 50 | 0.078 | 0.03 | 249.181 | 99.65 | 0.516 | 0.21 |
| 4 | PE | 0.94 | 250.046 | 50 | 0 | 0.00 | 0.265 | 0.11 | 249.047 | 99.60 |
| | ABS (black) | 1.06 | 250.036 | 50 | 62.049 | 24.82 | 77.186 | 30.87 | 110.067 | 44.02 |

The two-stage Larcodem separator demonstrated superior separation capability for the first three groups in both PP and PE experiments. Compared to the Vorsyl separator, it also offers a solution to separate near medium density plastic combination of PP and ABS. ABS with density of 1.06 g/cm$^3$ could be recovered from the outlet 1 and 2 product with almost zero contamination of PP. Separated sample from outlet 3 contains both plastic, which could be recycled back into the separator for further classification. This multi-stage purification technique is a common practice in mineral process industry designed to improve the quality and concentration of valuable minerals by progressively removing impurities and gangue materials. This approach involves a series of sequential separation stages, each targeting specific particle sizes, densities, or surface properties to achieve a high-purity final product. Multiple Larcodem separators could be connected in series to achieve higher recovery rates, improved product purity, and to handle complex feed with varying plastic compositions. The separation experiments demonstrated that the sorting process could effectively classify various types of plastics, which is crucial for subsequent recycling and material recovery efforts. The design and implementation of a two-stage Larcodem separator further improved the separation efficiency, ensuring a higher purity of sorted plastic fractions.

To support the training and knowledge exchange purpose of this project, a mixed reality version of two-stage Larcodem separator, as shown in Figure 4, was developed. Common industrial standard digitalisation techniques were adopted to develop this platform. From the equipment design stage, a 3D model of the separator was developed using SolidWorks to capture all the structural details. The user interface of this mixed reality platform was developed by Unreal Engine where 3D model could be imported with minimal rendering requirements. An industrial control computer was used for data communication between the separator and mixed reality platform for user interaction functionality. A 4G router was used to upload and download data to the cloud server to allow remote interaction with the separator. Three digital balances were adopted to collect real-time mass data from three outlets of the separator. Animation based on real-time mass data will be shown in the mixed reality platform to illustrate the distribution of sample particles in different zones of the separator. A camera was also installed for better visualisation of the separation process.

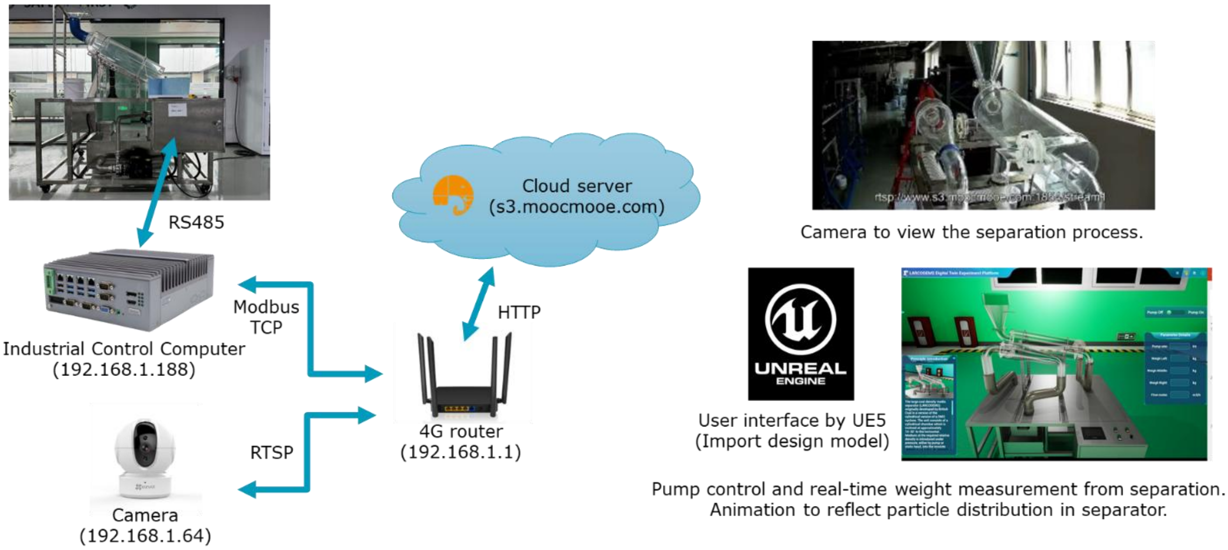


***Figure 4.*** *Mixed reality set-up of the lab-scale Larcodem separator*

Overall, the comprehensive approach adopted by UNNC for marine plastic waste collection and sorting showcases a robust methodology for tackling plastic pollution. The combination of manual classification, advanced shredding, and density-based separation techniques provides a pathway for effective recycling and management of marine plastic waste, contributing to environmental sustainability and pollution mitigation efforts.