VTT Technical Research Centre of Finland

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Published: 08/09/2021

Document Version
Publisher's final version

VTT

20th INTERNATIONAL METROLOGY CONGRESS CIM2021

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1. Plastics recycling: necessity for sustainability and challenge for metrology

In Europe, plastics was produced 62 million tons in 2018, and 9.4 million tons of plastic post-consumer waste was collected for recycling [1]. To achieve the goals of EU Green Deal aiming at climate neutral Europe in 2050 [2], the plastic recycling needs to be increased through better processes and technologies.

In plastic recycling processes, there is an increasing need for measurements aiding sorting, i.e. for discriminating materials between different plastic types and other waste. Due to variety of materials in waste, measurements are challenging and quality control is difficult. On the other hand, material volumes are large and increasing, which calls for efficient on-line measurement and quality control methods. In this work covering over 180 publications and websites, current sensor technologies used in plastics recycling were reviewed and needs for new measurement and calibration technologies were analysed.

2. Sensor technologies for detecting plastics

Photonic sensor technologies are used for charaterizing materials in sorting units [3]. Due to material specificity, the interaction between electromagnetic radiation and molecules/atoms in the material flow provide spectroscopic fingerprints for different types of plastics. Table 1 summarizes relevant sensor technologies. NIR is most widely used. Hyperspectral technology and machine learning based data analysis methods provide great future development potential.

Table 1 Summary of spectroscopic sensor technologies in plastic recycling applications.
TRL = Technology readiness level estimated in [4] ranging from 1 to 9.

Type	Typical spectral range	Advantages	Disadvantages	TRL[1]
NIR	0.9 – 2.5 µm	Mature technology, non-destructive, applicable for in-line monitoring	water interference, not for black plastic	9
NIR-HSI	0.9 – 1.7 µm	see NIR, spatial distribution data	see NIR	8
MIR-HSI	2.9 – 4.2 µm	spatial distribution data, non-destructive, applicable for in-line monitoring and for inorganic compound detection	Interference with water, CO_2 and glass	7
VIS	0.4 – 0.7 µm	non-destructive,	small penetration depth, not for black plastic	9
Raman	3.6 – 50 µm	no water or CO_2 interference	sample auto-fluoresence, accurate focusing needed, punctual measurement	6
XRF	< 1 nm	atomic information, large penetration depth	ionizing radiation, applicable only to PVC	9
LIBS	0.2 – 1 µm	atomic information, applicable also for metal identification	accurate focusing needed, destructive, punctual measurement	4
FTIR	2.5 – 25 µm	non-destructive	water, CO_2 and glass interference, not for black plastic	
THz	100 – 1000 µm	high penetration range	low specificity, water sensitive	

3. Measurement quality to enhance recycling

Because of a limited number of sorting categories for a single sorting stage, there may be several stages in series in a process to achieve the aimed sorting output (see Fig.1). Further measurements are needed to control the quality of sorted plastic material: these affect both process control and the trade value of the produced secondary raw material.

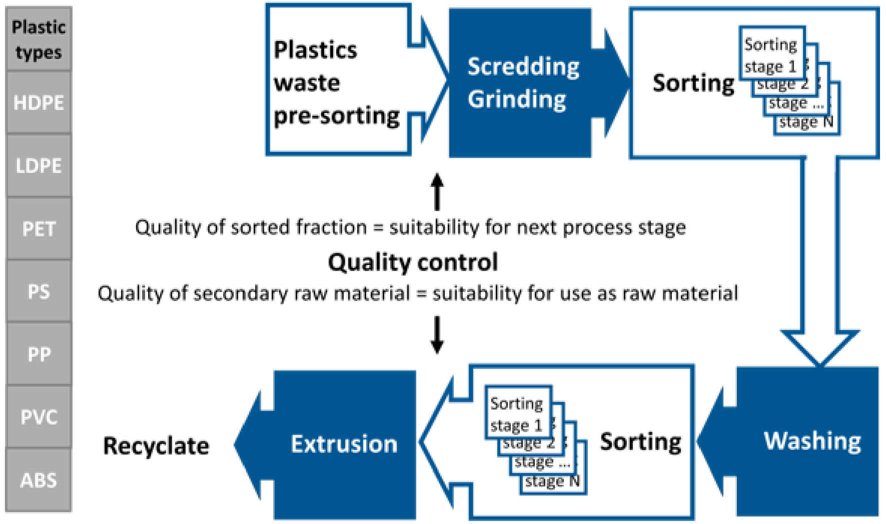

Figure 1. Schematic diagram of a mechanical plastic recycling process and quality control targets. Most relevant types of plastic are listed in the grey column.

According to [5], documentary standards specify target material content mostly 94 % to 98 % depending on the material while the lowest target is 80 % according this survey. The standards provide also further criteria to several other charateristic chemical and physical parameters.

4. Need for metrology

To obtain robust metrological traceability in the plastic recycling, significant developments are needed in sensor and calibration technologies and methods. Table 2 summarizes identified major metrology challenges.

Table 2. Major challenges in developing metrology for plastic recycling domain identified in this work.

In-line measurement technology	Calibration technologies
increased speed	certified reference materials
reduce errors in multi-component measurements	efficient and feasible for in-line and laboratory measurements
improved reliability with validated uncertainty estimations	reduce errors in sampling and sample handling

Conclusion

- **Our review shows that various sensing technologies have been developed for plastics recycling: NIR/VIS are most widely applied in commercial sorting systems.**
- **Hyperspectral and multisensing technologies with AI-based data analysis are considered to have largest future potential.**
- **Significance of proven quality increases with expanding business and with technology development.**
- **Efficient and feasible calibration methods including certified reference material supplies are needed.**

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