



Turning waste into quality: A smart screening approach for optimizing mechanical plastics recycling

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Rapid filter selection and contaminant characterization using twin-screw extrusion, rheology, EDXRF, and XRD contribute to more effective industrial process development

Introduction

Mechanical recycling is becoming increasingly important as stricter regulations, elevated recycled-content targets, and circular-economy requirements increase the demand for high-quality secondary raw materials. At the same time, shorter and more regional supply chains are able to reduce dependence on imported virgin polymers and improve material security. Taken together, these shifts require recyclers to process a broader range of locally available post-consumer waste streams, often with variable or insufficiently documented quality.

The technical and economic performance of mechanical recycling depends strongly on feedstock quality. New waste streams may contain polymeric, mineral, glass, fiber, and metallic contaminants that accelerate screen loading, increase pressure, disturb melt flow, damage equipment, and reduce the value of the recycled material.

Testing every new feedstock directly on a production-scale recycling line is costly and material-intensive, and comes with associated operational risks. This study therefore investigates whether lab-scale melt filtration, combined with complementary analytical methods, can provide a rapid screening approach for selecting suitable filter mesh sizes and characterizing retained contaminants before industrial scale-up. Two real post-consumer waste streams—acrylonitrile-butadiene-styrene from toolboxes (pcABS) and polypropylene from household packaging waste (pcPP)—were investigated.

The workflow combines pressure-based filtration screening with optical microscopy, oscillatory rheology, energy-dispersive X-ray fluorescence spectroscopy (EDXRF), and X-ray diffraction spectroscopy (XRD). Pressure development indicates filter loading; microscopy reveals particle morphology; rheology evaluates changes in melt behavior; EDXRF helps identify the presence of elements; and XRD enables identification and assignment of crystalline compounds. Together, these methods support filter selection, process development, and risk reduction.¹

How the melt filtration screening system works

During melt filtration, solid or insufficiently molten contaminants are retained by the screen while the polymer melt passes through. As the retained material accumulates, the hydraulic resistance of the screen increases and the pressure upstream of the filter rises. A pressure-time curve therefore acts as a direct process fingerprint for contaminant loading under defined operating conditions.

The screening sequence starts without a filter to establish the background pressure. The coarsest screen is then inserted, the die pressure is monitored, and the screen is replaced by a finer mesh only when the pressure remains below the predefined operating limit. This stepwise approach rapidly identifies whether contamination is predominantly coarse or fine and avoids beginning with a screen that blinds immediately.

Key findings

- The pcABS stream contained a substantial fine contaminant fraction between 26 and 154 micrometers.
- The pcPP stream contained a much higher and coarser contamination load, causing rapid pressure build-up even with the 264 micrometer screen.
- The PP rheology showed no meaningful shift of the G' / G'' crossover due to filtration, while the low-frequency response remained sensitive to contamination-related flow effects.
- EDXRF and XRD linked the retained inorganic elements to pigments, fillers, minerals, metallic fragments, and iron oxides.

Materials and methods

Post-consumer materials

Two common post-consumer materials supplied by a cooperation partner were used. The streams were selected because they are regularly available in relevant waste fractions and represent distinctly different contamination profiles, thereby providing a useful comparison for the screening approach.

Material	Source	Pretreatment	Particle size	Purpose in study
pcABS	Post-consumer toolboxes	Shredding, magnetic separation, and drying	6 mm	Assessment of a comparatively cleaner, pretreated stream
pcPP	Household packaging waste (DSD yellow-bag fraction 324)	No pretreatment	6 mm	Assessment of a heterogeneous, highly contaminated stream

Table 1. Characteristics of materials used in the study.



Melt-filtration setup and filter screening workflow

The trials were performed using a Thermo Scientific™ Process™ 16 Parallel Twin-Screw Extruder equipped with a filtration die and connected to a water bath and pelletizer. A gravimetric twin-screw feeder supplied the 6 mm ABS and PP shreds at a throughput of 1 kg/h. The filtration die was designed for rapid screen exchange: A clean insert was used to push the loaded insert out of the die, reducing the process downtime to approximately 10-30 seconds (see Figure 2).

For each material, the extruder was first purged without a filter screen, and the background pressure was recorded. Screens were then evaluated from coarse to fine, using nominal mesh openings of 264, 154, and 26 micrometers. Die pressure was monitored continuously. A stable pressure below the selected limit triggered the next finer screen; a rapid or sustained pressure rise indicated screen loading and an unsuitable filter condition for that contaminant load (see Figure 3).

Lab-scale melt filtration set-up

Process 16 Parallel Twin-Screw Extruder + water bath + pelletizer.



Filter insertion and exchange.

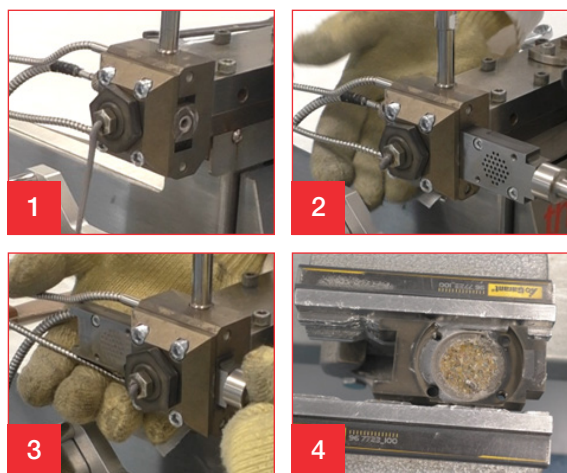
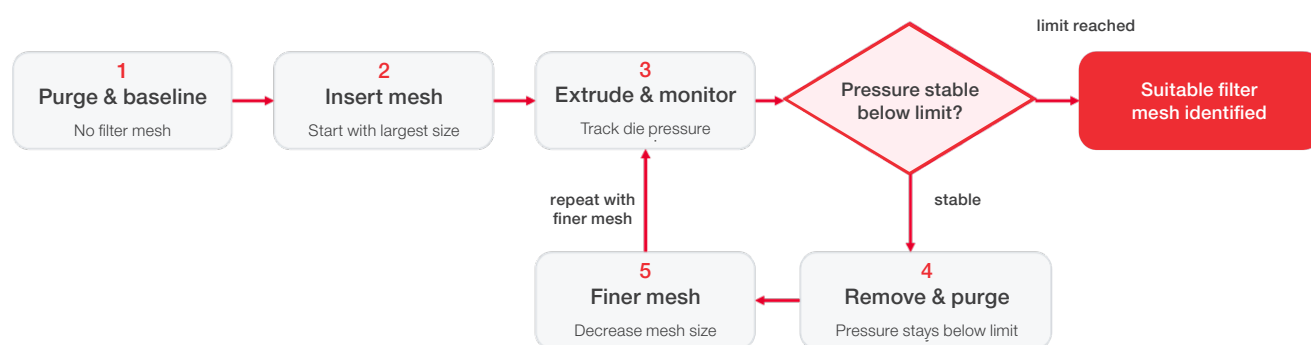


Figure 2. Process 16 extruder, water bath, pelletizer, filtration die, and rapid filter-insert exchange.



Coarse-to-fine screening loop: continue while pressure remains stable; stop when the pressure limit is reached.

Pressure development indicates filtration efficiency & contamination loading | **Rapid mesh-size selection**

Figure 3. Filter screening workflow: baseline without screen, coarse screen, pressure evaluation, purge, and progression to finer mesh sizes.

Rheological characterization

For this study, a Thermo Scientific™ HAAKE™ MARS™ iQ Air Rotational Rheometer equipped with a model TM-CR-O450 temperature chamber was used to compare the viscoelastic behavior of the PP before and after filtration. All rheological measurements were performed using a parallel-plate geometry with a diameter of 25 mm and a measuring gap of 1 mm. A strain amplitude γ within the linear viscoelastic range of the samples of 1% was selected based on preceding strain amplitude sweeps, so that the test characterizes the material without disrupting its structure. Frequency sweeps ranging from 100 rad/s to 0.1 rad/s were performed at a temperature of 205°C matching the extruder processing temperature. The tests were done in a triplicate.

In rheological measurements in oscillation, the storage modulus G' represents the elastic contribution, and the loss modulus G'' represents the viscous contribution. Their dependence on angular frequency describes the response of the melt at different time scales, while the crossover point at $G' = G''$ is sensitive to changes in the polymer relaxation spectrum, molecular weight, and molecular-weight distribution.^{2,3}

The low-frequency region is particularly informative because it probes long-time relaxation and is sensitive to small structural differences, high-molecular-weight fractions, dispersed phases, agglomerates, and other sources of melt elasticity. Literature on recycled PP also shows that contaminants and reprocessing can alter crossover behavior, complex viscosity, and modulus values through changes in molecular structure and entanglement density.^{4,5} In the present study, the rheological comparison was therefore used for two purposes: to check for processing-related polymer degradation, and to detect contamination-related changes in the melt response.

Optical, elemental, and phase analysis

The residue retained on the ABS filter was inspected by three-dimensional digital microscopy to classify the visible contaminants by morphology. Elemental screening was performed using a Thermo Scientific™ ARL QUANT'X™ Energy Dispersive X-ray Fluorescence Spectrometer. EDXRF provides information about the elemental composition of the area analyzed but does not, by itself, distinguish the chemical or crystalline form of an element.

Crystalline phase identification was performed using a Thermo Scientific™ ARL™ X'TRA Companion X-ray Diffractometer. The instrument uses Bragg-Brentano theta/theta geometry with a 160 mm radius and a 600 W X-ray generator. The samples were hot-pressed into discs and measured using bulk sample cups. Filter residues were measured as-is.

Results and discussion

Filter-screening behavior of pcABS

The background pressure for pcABS was 16-18 bar (see Figure 4, left side). With the 264 and 154 micrometer screens installed, pressure remained close to this baseline. The result indicates that the pretreated ABS contained zero or only a very small quantity of contaminants larger than 154 micrometers under the sampled conditions.

A distinctly different response was observed with the 26 micrometer screen (see Figure 4, right side). The pressure rose continuously, with an approximately 81 bar pressure increase recorded after about 16 minutes. Because the coarser screens remained stable while the 26 micrometer screen loaded, the dominant retained population can be assigned to an approximate particle-size window between 26 and 154 micrometers. This is a useful practical result: a 154 micrometer screen would offer low pressure demand but would not remove the fine inorganic and glass-related fraction, whereas a 26 micrometer screen provides greater purification at the cost of a finite operating window and higher pressure.

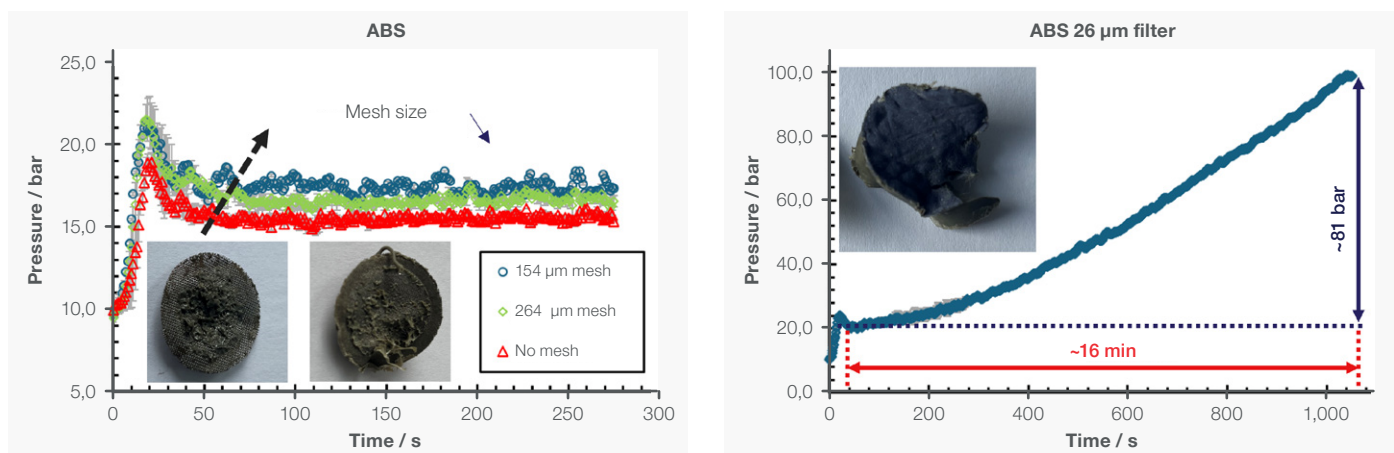


Figure 4. Die-pressure development for pcABS with no screen and 264, 154, and 26 micrometer screens.

Filter-screening behavior of pcPP

The untreated household-packaging PP behaved substantially differently (see Figure 5). Even the coarsest 264 micrometer screen showed a rapid pressure increase of approximately 84 bar within a few minutes. The 154 micrometer screen exhibited similarly severe loading, and the 26 micrometer screen ultimately failed by breakage. The response demonstrates that this feedstock contained a much higher contaminant concentration and a significant coarse fraction above 264 micrometers.

The PP results also illustrate why filter selection cannot be based on a desired nominal fineness alone. For a highly contaminated stream, installing a fine screen without upstream removal of coarse material may cause immediate blinding, excessive pressure, or mechanical failure. The appropriate development route is therefore hierarchical: Improve sorting or washing where possible; remove coarse particles first; and then evaluate finer filtration only after the contaminant load has been reduced. At industrial scale, the observed loading behavior would favor a larger active filter area, staged filtration, or a continuous/self-cleaning filtration concept rather than a small static screen pack.

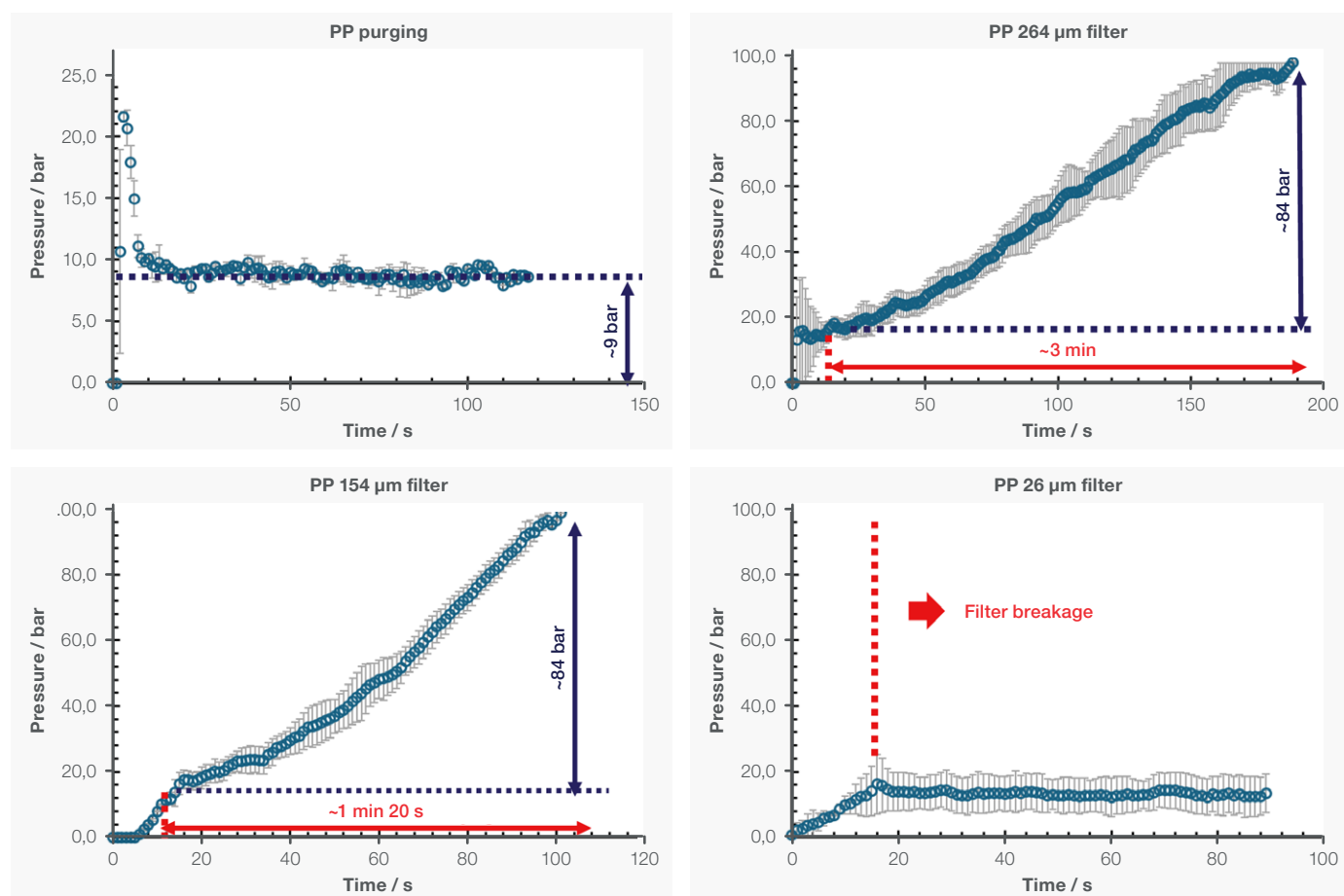


Figure 5. Die-pressure development for pcPP, showing background pressure during purging, rapid loading of the coarse screens and breakage of the 26 micrometer screen.

Comparison of the two waste streams

Stream	Observed filtration response	Dominant screening result	Process-development implication
pcABS	Stable at 264 and 154 micrometers; sustained pressure rise at 26 micrometers	Fine contamination mainly between 26 and 154 micrometers	Fine filtration is feasible, but screen life and acceptable pressure rise must be balanced against target purity
pcPP	Rapid loading even at 264 micrometers; failure at 26 micrometers	High load and coarse contaminants above 264 micrometers	Pretreatment, coarse prefiltration, increased area, or continuous filtration is required before fine filtration

Table 2. Observations for the pcABS and pcPP streams.

Rheology: Polymer integrity and contamination sensitivity

The PP frequency sweeps showed essentially no change in the crossover of G' and G'' after filtration (see Figure 6). Because shifts in the crossover can reflect changes in molecular weight or molecular-weight distribution, the stable crossover indicates that the extrusion and filtration step did not cause a measurable change in the bulk polymer relaxation behavior under the applied test conditions. This supports the conclusion that the screening process did not substantially damage the PP molecular structure.

At angular frequencies below approximately 1 rad/s, however, the slope of G' changed between the compared samples. The low-frequency region represents long observation times and is highly sensitive to weak network formation, dispersed domains, particle-polymer interactions, agglomerates, and differences in the high-molecular-weight tail.^{2,3} In this context, the observed slope change is consistent with contaminants influencing long-time flow behavior even though the main G'/G'' crossover remains unchanged.

The combined interpretation is important. The unchanged crossover argues against significant chain scission or broad molecular degradation caused by the lab process, while the low-frequency difference shows that the material is not rheologically identical before and after contaminant removal. Rheology therefore acts as a sensitive quality-control tool for contamination effects, but it should be described as detecting the rheological consequence of heterogeneity rather than identifying the contaminant itself. Chemical identification requires complementary methods such as EDXRF and XRD.

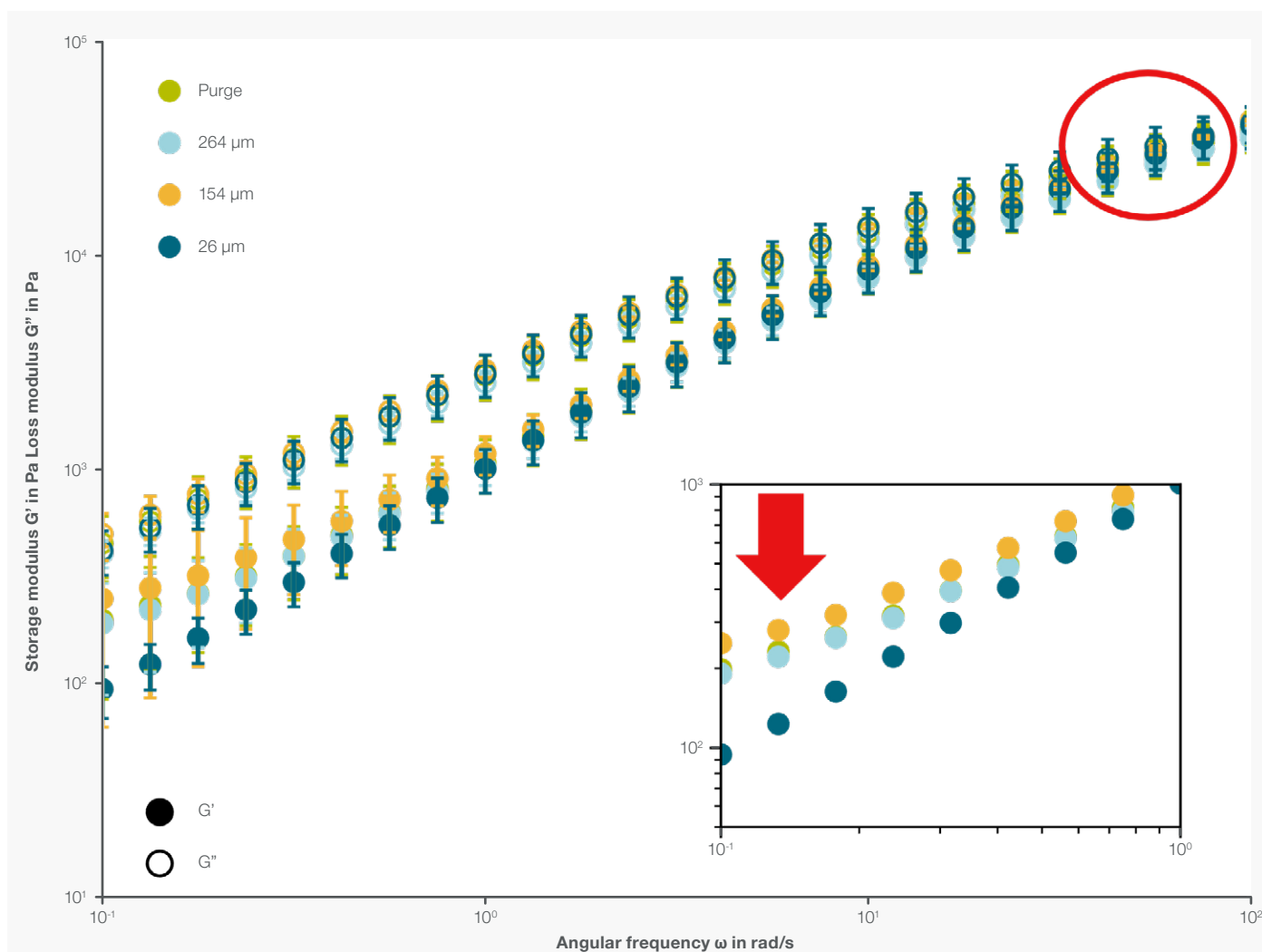


Figure 6. Oscillatory frequency sweeps of PP before and after filtration, showing the G'/G'' crossover and the low-frequency G' response below 1 rad/s.

Microscopy, EDXRF, and XRD: Composition of the ABS filter residue

Digital microscopy of the 26 micrometer ABS screen confirmed that the pressure increase was caused by a diverse population of retained foreign material (see Figure 7). The residue included glass fragments, glass fibers, and metallic particles. This morphology is consistent with the origin of the feedstock and shows that the retained fraction was not a single additive or filler, but a mixed contamination population.

EDXRF analysis of the ABS filter residue, compared with virgin ABS, detected iron, titanium, calcium, barium, and additional inorganic elements (see Figure 8). EDXRF established which elements were present, while XRD assigned the crystalline phases associated with these elements (see Figure 9). The XRD pattern identified rutile and anatase (TiO₂), magnetite (Fe₃O₄), calcite (CaCO₃), an FCC iron-containing phase described as austenitic Fe, hematite (Fe₂O₃), periclase (MgO), wuestite (FeO), barite (BaSO₄), and quartz (SiO₂).

The analytical techniques are complementary rather than interchangeable. Microscopy captures particle shape and can directly reveal fibers and glass fragments. EDXRF is sensitive to elemental composition, including phases that are poorly crystalline or present in mixtures. XRD provides compound-level identification only for crystalline phases. The agreement between the three methods strongly supports the filtration interpretation: The 26 micrometer ABS screen retained a heterogeneous fine fraction containing pigment and filler particles, mineral matter, glass-related debris, and metallic or oxidized metal fragments.

These results also explain why the ABS pressure response was only observed with the finest screen. Many of the identified phases are compatible with small pigment, filler, or abrasion-derived particles. Their presence may not cause immediate blockage at 154 micrometers, but they can accumulate efficiently on a 26 micrometer mesh. The combined size, morphology, elemental, and phase information therefore provides a more useful basis for filter selection than pressure data alone.

Elemental indication	Crystalline phases identified by XRD	Interpretation in the recycling context
Ti	Rutile and anatase, TiO ₂	Consistent with titanium-dioxide pigments or pigment-containing fragments from mixed plastic articles
Ca	Calcite, CaCO ₃	Consistent with a common mineral filler or extender used in polymer formulations
Ba	Barite, BaSO ₄	Consistent with a dense inorganic filler or additive-containing fragment
Fe	Magnetite, hematite, wuestite, and FCC Fe	Consistent with metallic fragments and oxidized ferrous contamination; an FCC phase may also reflect the filter mesh
Si	Quartz, SiO ₂	Consistent with mineral dirt or crystalline silica; microscopy additionally showed glass, which may be partly X-ray amorphous
Mg	Periclase, MgO	Consistent with a mineral residue or an inorganic additive-containing fragment

Table 3.

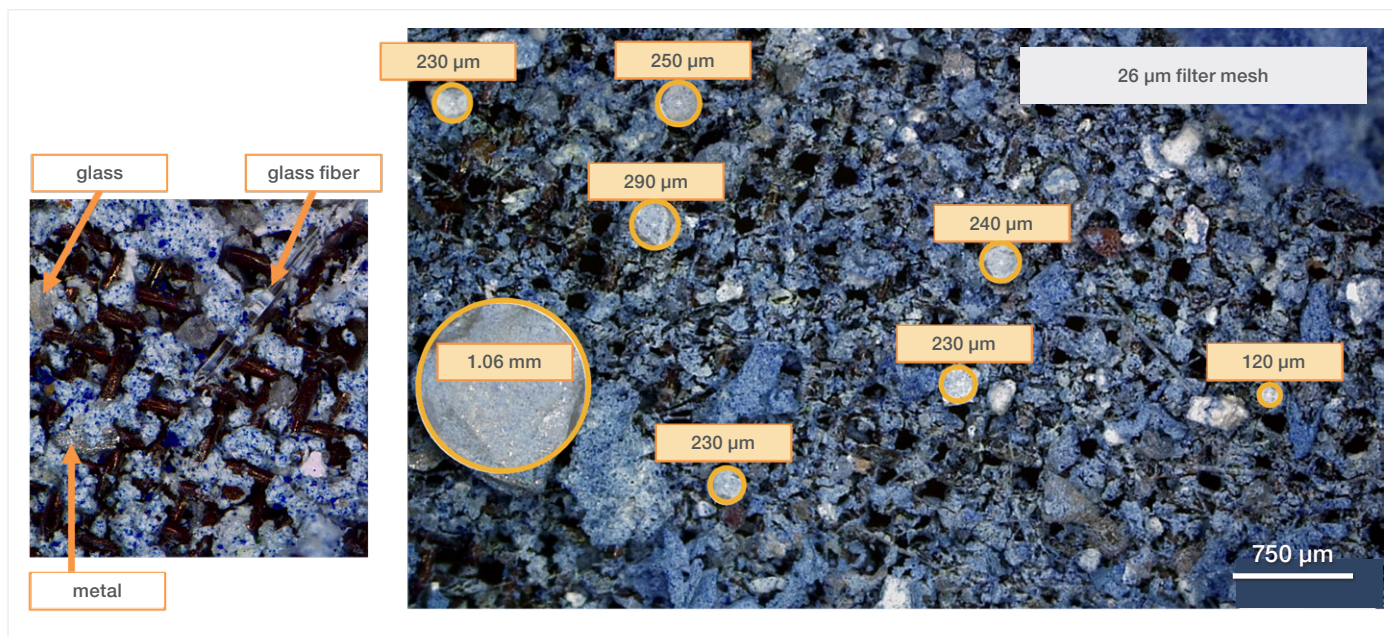


Figure 7. Digital-microscopy overview of the retained ABS contaminants, including glass, glass fibers, and metallic particles.

EDXRF of pcABS – Virgin versus filter residue

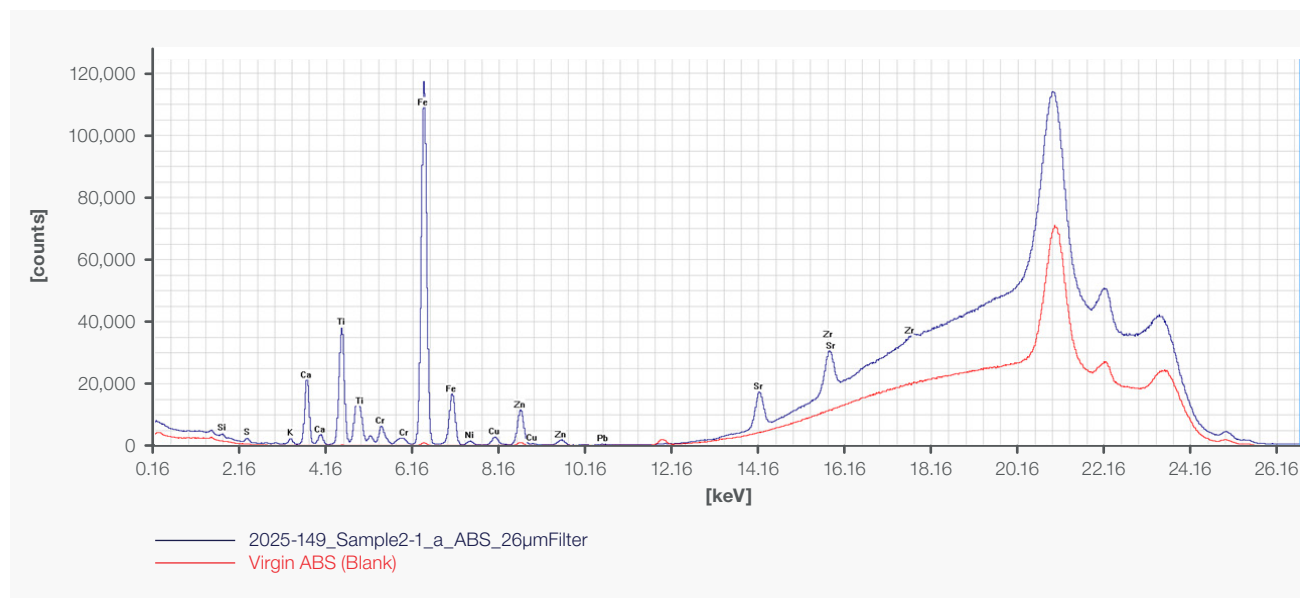


Figure 8. EDXRF comparison of virgin ABS and the ABS filter residue.

XRD of pcABS filter residues

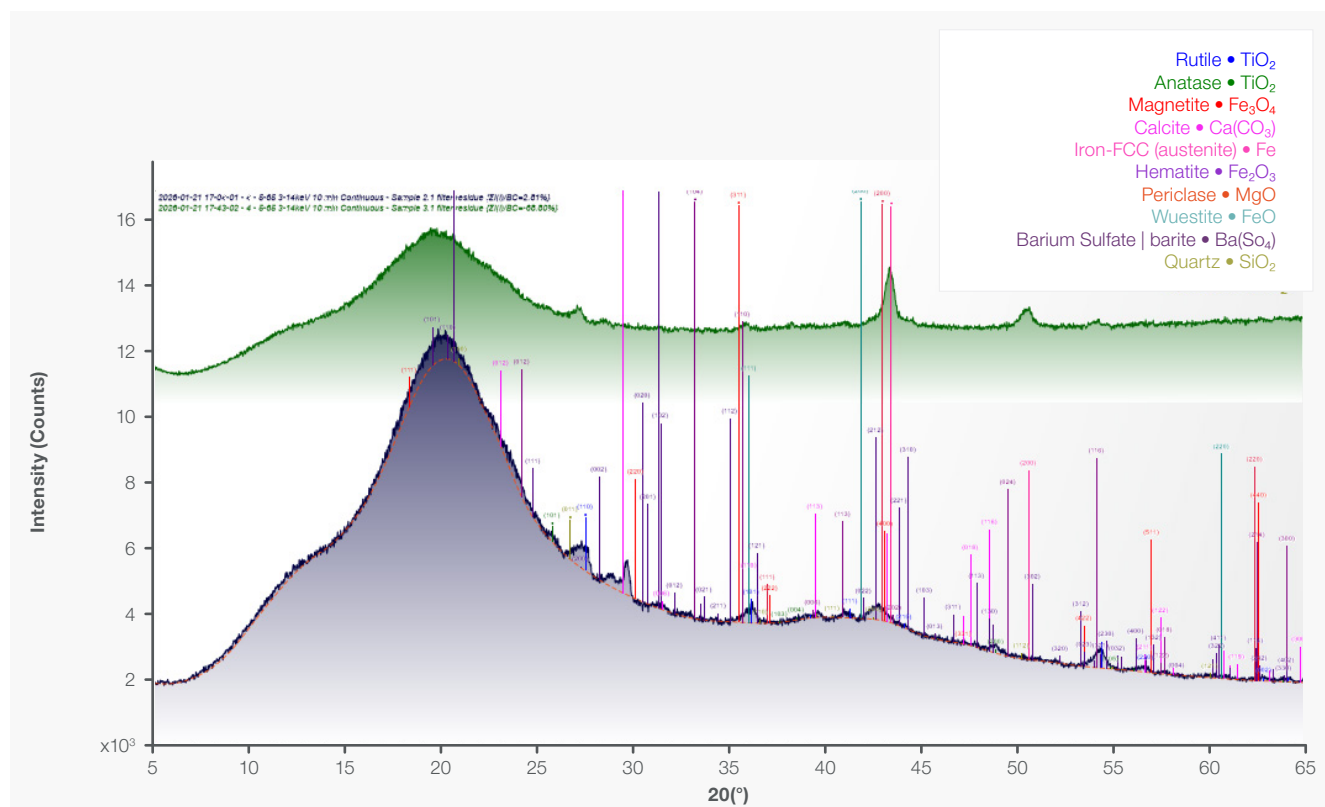


Figure 9. XRD pattern and phase identification for the ABS filter residue, using the ARL X'TRA Companion diffractometer for style of observed pattern, calculated/identified phases, and phase markers as applicable.

Scalability and industrial transfer

The principal value of the lab-scale filtration method is not to transfer the absolute screen-change interval to an industrial line, but to quickly evaluate feedstock contamination and filtration concepts using small material quantities. A mesh that remains stable in the lab is a candidate for pilot validation; a mesh that blinds or fails immediately identifies a process boundary before time and material are committed at larger scale.

Direct transfer of the filtration-specific criteria determined here is only valid to a limited extent because industrial filtration performance depends on active screen area, melt throughput, contaminant concentration, particle shape, screen-pack architecture, melt temperature and viscosity, permitted pressure drop, and the mechanism used to remove retained material. For more robust comparison, the pressure rise has to be evaluated against the mass processed and, where possible, normalized to active filter area.

The extrusion process itself has also to be transferred to a situation with a comparable material history. Thermo Fisher Scientific scale-up studies identify residence-time distribution and specific mechanical energy as important anchors, together with melt temperature, screw configuration, filling level, torque, and die pressure.^{6,7} The Process 16 platform is intended for R&D, process development, and small-scale production and offers a modular screw and barrel design that supports systematic variation of these parameters.⁸ For a recycling application, these extrusion criteria have to be combined with the filtration-specific criteria.

For the pcABS stream, the results support pilot testing of a fine filtration step between 26 and 154 micrometers, with the final selection determined by the required product purity and acceptable screen life. For the pcPP stream, the rapid loading of the 264 micrometer screen indicates that scaling a static fine screen directly would carry a high risk. Upstream sorting, washing, or coarse removal should be evaluated first, followed by staged or continuous filtration with sufficient active area. In both cases, the lab workflow narrows the industrial design space and reduces scale-up risk, even though pilot validation remains necessary.

Benefits for process development

- Rapid ranking of filter fineness and feedstock contamination severity
- Lower material consumption than pilot- or production-scale screening
- Early identification of pressure, blockage, and screen-failure risks
- Integrated understanding of particle size, morphology, elemental composition, crystalline phases, and melt behavior
- A more focused and data-driven route to pilot validation and industrial scale-up

Conclusion

Lab-scale melt filtration provides a fast and material-efficient method for screening post-consumer plastics before industrial process development. The pressure response clearly distinguished the two investigated streams: the pretreated pcABS contained mainly fine contaminants between 26 and 154 micrometers, whereas the untreated pcPP contained a substantially higher load with coarse contaminants above 264 micrometers.

The analytical methods placed the filtration results into context. Rheology indicated that PP filtration did not measurably shift the main viscoelastic crossover, while low-frequency G' remained sensitive to contamination-related flow behavior. Microscopy confirmed glass, fiber, and metallic residue on the ABS screen. EDXRF and XRD then linked the inorganic fraction to TiO_2 pigments, CaCO_3 and BaSO_4 fillers, quartz and MgO mineral phases, and metallic or oxidized iron-containing particles.

The combined workflow supports smarter filter selection, more targeted feedstock upgrading, and lower-risk scale-up. It does not replace pilot trials, but it substantially reduces the number of industrial conditions that need to be tested. Lab-scale melt filtration combined with rheology, microscopy, EDXRF, and XRD is therefore a powerful screening approach for accelerating mechanical-recycling process development and improving the quality of secondary raw materials.

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