

Factory-Level Material-Flow Analysis for Photopolymer Manufacturing: Yield, Losses, Recovery and Inventory Reconciliation

Closing physical mass balances across resin preparation, printing, washing, rejects, solvent and recovered streams

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Abstract

Circularity claims at factory level depend on knowing where material actually flows. Photopolymer manufacturing includes formulation losses, vat hold-up, failed prints, supports, uncured carryover to wash solvent, filters, purge streams, packaged product and recovered material. This review defines a factory-level material-flow analysis framework for photocurable manufacturing, centred on conserved mass, explicit system boundaries, reconciled inventories, yield definitions, recovery streams, uncertainty and chain-of-custody accounting when recycled molecules become indistinguishable from virgin feedstock.

Keywords: material flow analysis; photopolymer manufacturing; mass balance; yield; scrap; solvent; inventory reconciliation; circularity

1. Significance and scope

Material-flow analysis turns circularity from a narrative into a conserved accounting problem. MFA has been widely used to map polymer flows and circularity indicators, demonstrating the value of explicit stocks, inputs, outputs and losses [1].

This review owns factory-level physical material accounting for photopolymer manufacturing. It complements lifecycle assessment but does not replace it: MFA asks where mass goes before environmental weighting is applied.

2. System boundaries define the answer

The system boundary should identify raw-material receipt, formulation, filling, printing, post-processing, recovery, waste dispatch and finished-product shipment. Excluding a wash or purge step can make yield appear higher without changing physical performance.

Define the reporting period and inventory opening/closing stocks. Resin in drums, vats, transfer lines, wash tanks and recovery equipment can be large enough to distort short-period balances if stock change is ignored.

Flow definitions should use mutually exclusive categories. Material counted as recovered input should not also remain in waste or inventory, and the same reject should not be counted once at printing and again when it enters solvent treatment.

Measurement hierarchy should separate directly weighed flows from estimated or model-derived flows. The reconciliation residual should preserve that distinction so an apparently closed balance does not hide several uncertain conversion factors cancelling one another.

3. Yield must separate product from internal circulation

Yield should distinguish good product mass from printed-but-rejected mass, supports and sacrificial structures. Internal reuse of resin is circulation, not new recovered output.

Process losses include spills, container residues, filters, wipes, volatilisation, purge material and samples. Small individually unmeasured losses can accumulate into a material balance gap that matters at scale.

4. Wash and purge streams carry hidden material

Wash solvent can carry significant uncured resin out of the printer stream. If solvent is regenerated, the resin-rich residue remains part of the polymer balance and should not disappear behind a solvent-recovery metric.

Recovered material needs a defined return point. If it re-enters formulation, the ledger should identify when it becomes indistinguishable from virgin material and what chain-of-custody rule is used.

Mass-balance accounting for circular polymers addresses precisely this attribution problem when recycled and virgin molecules are mixed and cannot be physically traced to individual products [2]. Physical MFA and attribute accounting should remain separate but reconciled.

Sampling and conversion factors should be documented where direct weighing is impossible. Solids concentration in wash residue, for example, should come from a measured method with uncertainty rather than a fixed assumed fraction.

Time resolution should match the process. Daily balances can expose purge or reject excursions that disappear in an annual total, while longer periods are needed to reconcile drum, vat and wash-tank inventories whose stock changes dominate short runs.

5. Inventory reconciliation exposes missing flows

Inventory reconciliation compares measured inputs and outputs with stock change. A persistent unexplained difference should trigger metrology review rather than being silently allocated to “process loss”.

Meters and scales should be matched to the uncertainty needed. Bulk resin purchase records may be adequate for annual material accounting but too coarse for a small recovery trial.

Dynamic factory operation introduces feedback: recycling rates, reject generation, inventory and production demand influence one another over time. Integrated MFA/system-dynamics work shows how mass conservation and feedback modelling can be combined [3].

Axis	Measurement	Failure mode
Boundary	included operations and period	loss stream excluded from denominator
Stocks	opening/closing inventory	inventory change treated as loss
Flows	product, rejects, wash, purge, waste	hidden carryover omitted
Recovery	return point and quality state	internal circulation treated as recovery
Reconciliation	uncertainty and residual	balance gap silently allocated

Table 1. Domain-specific qualification matrix for factory-level material-flow analysis in photopolymer manufacturing.

6. Device-level verification of accounting rules

Device-level verification of the accounting method should select one product family and reconcile resin from incoming formulation through good parts, rejects, wash carryover, recovered streams and waste.

The exercise should be repeatable by another analyst from source records. Manual correction factors and undocumented spreadsheet adjustments should be treated as control risks.

Circularity indicators should be defined from measured flows: virgin input, recovered input, recovery output, waste and useful product. Avoid ratios whose numerator and denominator use different boundaries.

Device-level verification of the accounting system should trace one defined production campaign from incoming resin to shipped good parts and every residual stream. The exercise tests both physical mass conservation and whether the information system preserves identity across transfers.

7. Minimum qualification framework

Report boundary, period, opening and closing inventories, all measured input/output streams, good-product mass, reject/support mass, recovery and waste streams, and measurement uncertainty.

Document chain-of-custody rules for mixed recycled/virgin feedstocks, reconciliation residuals, data ownership and the corrective-action threshold for unexplained mass.

8. Engineering conclusions

Factory-level circularity becomes auditable when mass conservation, inventory change and attribute accounting are explicit. Yield, recovery and recycled content should emerge from one reconciled ledger rather than from disconnected sustainability metrics.

References

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Competing interest

Juan Seguro is founder, CEO and CTO of 3Dresyns by Resynr Technologies S.L., which develops and commercialises photopolymer materials and related additive-manufacturing technologies. This review is an engineering analysis and does not constitute a product-performance claim or a device qualification.