

Solvent-Recovery Mass Balances in Photopolymer Processing: Contaminant Build-Up, Separation Efficiency and Reuse Limits

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Abstract

Wash solvent in photopolymer processing changes state as uncured resin, monomers, oligomers, photoinitiator-derived species, water, particles and process residues accumulate. Recovery therefore cannot be demonstrated by visual clarity or nominal solvent concentration alone. This review defines a mass-balance and requalification architecture for solvent recovery from photopolymer washing operations. It distinguishes fresh solvent, contaminated wash, separated concentrate, recovered solvent, make-up solvent and unrecovered loss; requires measured stream masses and composition; and separates separation efficiency from reuse suitability. Primary vat-photopolymerisation studies show that resin/monomer contamination in isopropanol can alter dimensional accuracy during post-rinsing [1,2], while an institutional VPP process-chain study describes a solvent-recovery prototype and the practical challenge of polymerising and mechanically separating resin-laden solvent [3]. The framework does not prescribe a universal distillation, filtration or UV-treatment recipe and does not treat solvent recovery as proof of waste reclassification or environmental benefit.

Keywords: solvent recovery; isopropanol; photopolymer washing; mass balance; contamination; separation efficiency; reuse; vat photopolymerisation

1. Significance and scope

Post-rinsing transfers uncured photopolymer species into the wash liquid. Flierl and co-workers experimentally varied resin/monomer contamination in isopropanol and showed that contamination state can affect dimensional outcomes in VPP workflows [1,2]. Mendez Ribo documented solvent-recovery development within a VPP process chain, including irradiation/crosslinking and mechanical separation concepts [3]. These sources justify treating wash solvent as a changing process material whose identity, loading and performance must be measured before reuse.

1.1 Corpus boundary

ER-175 retains washing-system engineering and part-cleaning performance; ER-178 retains solvent, wash-water and contaminated-waste classification and disposal; ER-198 retains material-loop closure; ER-17 retains LCA and environmental-superiority claims. ER-272 owns only the solvent-recovery material balance: contaminant build-up, separation yield, recovered-solvent identity, make-up accounting and evidence for reuse limits. ER-273 and ER-274 are future roadmap subjects and provide no evidentiary authority.

2. Define every solvent stream as a controlled material state

At minimum distinguish fresh solvent, active wash bath, spent solvent removed from service, pretreatment stream, recovered solvent, concentrate/sludge, evaporative or handling loss and make-up solvent. Record container identity, resin families washed, time, temperature, water ingress and cross-contamination. A single label such as used IPA destroys the genealogy needed for mass balance.

3. Contaminant loading is a process variable

Flierl, Spies, Rothlauf, Vach, Kohal and Luchtenborg deliberately prepared isopropanol with defined resin/monomer contamination levels and observed contamination-dependent dimensional effects in VPP post-rinsing [1,2]. Their dental-resin results do not establish a universal replacement threshold, but they demonstrate that wash-bath contamination can be functionally relevant and must be measured rather than inferred from age or appearance.

4. Close the mass balance before claiming recovery

For a batch recovery operation, the basic accounting is $m_{in} = m_{recovered} + m_{concentrate} + m_{loss}$, with each term defined on a consistent mass basis. If fresh solvent is added before or after separation, make-up must be reported separately. Volume measurements require density and temperature control when converted to mass. A recovery percentage without the denominator and loss term is not an auditable material balance.

$$M_{feed} = M_{recovered} + M_{concentrate} + M_{loss}$$

$$M_{solvent,feed} = M_{solvent,recovered} + M_{solvent,concentrate} + M_{solvent,loss}$$

The first balance closes total mass; the second closes the solvent component. If only total mass is measured, solvent recovery and contaminant rejection cannot be distinguished.

5. Separation efficiency and solvent purity are different endpoints

A process can recover a high fraction of solvent while leaving enough dissolved or volatile contaminants to impair washing, or can produce a high-purity fraction at poor overall yield. Mendez Ribo described a VPP solvent-recovery prototype in which irradiation crosslinked photopolymer contamination and mechanical squeezing/filtration were used to separate solvent [3]. That work supports the feasibility of recovery operations but not a universal purity or scale-up rule.

$$R_s = M_{recovered\ solvent} / M_{feed\ solvent}$$

$$J_j = 1 - (M_{j,recovered} / M_{j,feed})$$

R_s is the solvent-component recovery fraction on a declared mass basis. J_j is the rejection fraction for contaminant j , with feed and recovered quantities measured on the same basis. High solvent recovery and high contaminant rejection are independent requirements; neither can be inferred from total recovered mass alone.

6. Distillation, curing/filtration and adsorption solve different separations

Volatility-based separation, photochemical conversion plus filtration, settling/centrifugation, adsorption and membrane approaches address different contaminant classes. Selection requires knowledge of solvent boiling behaviour, water content, resin chemistry, volatile additives, polymerisable species and solids. Combining operations can shift contaminants between streams; therefore every stage needs inlet/outlet sampling if its removal claim is load-bearing.

7. Reuse qualification must test the recovered solvent, not the process name

Recovered solvent should be assessed by properties that control washing: composition or purity, water, nonvolatile residue, colour/UV absorbance where relevant, density, and a functional wash test on a representative part. Manufacturer guidance commonly specifies minimum IPA concentration for particular workflows, but such values are equipment/resin-specific operating guidance rather than universal recovery criteria [4].

8. Material safety and waste status remain separate gates

Ballentine and co-workers demonstrated acute and chronic aquatic toxicity of uncured VPP resin feedstocks, reinforcing the need to preserve uncured-resin identity in waste and recovery decisions [5]. Recovering solvent does not by itself render the concentrate nonhazardous, and a permitted waste route does not qualify the recovered solvent for reuse. Those regulatory decisions remain under ER-178.

9. Non-compensatory qualification matrix

Gate	Required evidence	Blocking failure
G1 Stream identity	Fresh, spent, recovered, concentrate, make-up and loss states segregated	Mixed or unidentified streams destroy genealogy
G2 Mass closure	Input and output masses close within stated uncertainty	Recovery percentage reported without losses or make-up
G3 Composition	Recovered solvent purity/water/residue measured by declared methods	Visual clarity used as purity evidence
G4 Functional reuse	Representative washing performance demonstrated	Chemical analysis accepted without process-function check
G5 Cross-contamination	Resin families and reuse history controlled	Recovered solvent moved across incompatible materials without evidence
G6 Disposal boundary	Concentrate and non-reusable streams routed under ER-178 controls	Recovery assumed to eliminate waste obligations

10. Minimum reporting set

Report solvent identity and fresh specification; wash-bath history and resin families; masses of fresh, spent, recovered, concentrate, make-up and loss streams; sampling points; separation sequence; temperature/pressure where relevant; composition or purity methods; water and nonvolatile residue; functional cleaning test; number of reuse cycles; cross-contamination controls; safety controls; and the rule that retires or diverts solvent from reuse. Report uncertainty and unclosed mass explicitly.

11. Knowledge boundary

The cited evidence establishes that wash-solvent contamination can affect VPP outcomes, that solvent recovery has been explored within a VPP process chain, and that uncured resin streams require controlled hazard and waste handling [1-5]. It does not establish a universal solvent-retirement threshold, separation efficiency, purity target, treatment sequence or safe number of reuse cycles. Nurmi and co-workers provide additional process-specific cleaning evidence [6], but their ceramic VPP system does not set general recovered-solvent acceptance limits. Regulatory classification and environmental-benefit claims remain outside ER-272.

12. Conclusions

Solvent recovery in photopolymer processing is demonstrated by an auditable balance plus recovered-solvent qualification. Contaminant build-up, separation yield and reuse suitability are separate questions. A clear solvent, a high recovery percentage or a successful single wash cannot substitute for composition, mass closure and repeat-use evidence. ER-272 therefore treats recovery as a controlled material transition, not as a disposal shortcut or an environmental claim.

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