

Printer Changeover, Cleaning Validation and Cross-Contamination Control

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Statement of Significance

Changing a vat-photopolymerisation system from one resin to another is not merely a housekeeping operation. Residual liquid resin, pigments, fillers, photoinitiator-containing material, cleaner, or particulate can be transferred into the next build and alter the state of the incoming formulation. The resulting defect may be visible, such as colour carryover, or effectively invisible until cure response, dimensional stability, surface quality, mechanics, optics, or biological-contact risk is affected. The engineering question is therefore not whether equipment appears clean, but whether the changeover process has reduced relevant carryover below a scientifically justified and analytically demonstrable acceptance limit for the next material and use case.

This review develops a qualification architecture for printer, vat, build-platform, tooling and accessory changeover. It separates cleaning action from cleaning validation, links residue limits to credible next-product failure modes, and treats sampling location and analytical capability as part of the decision. Direct vat-photopolymerisation evidence is used to establish relevance [1,2], while general cleaning-validation guidance is used only for verification principles and not for importing pharmaceutical residue limits into photoresin processing [3,4].

Abstract

Background. Multi-material and sequential-resin vat photopolymerisation require deliberate resin removal between material states. Published VPP work describes washing, cleaning and drying during material switching [1], while direct experimental evidence shows that resin contamination in a rinse medium can alter dimensional outcomes in a resin-specific system [2]. Because optical absorbers can change light transport at loadings below those required to produce obvious bulk colour, carryover can be functionally significant before it is visually obvious.

Approach. This Engineering Review defines printer changeover as a controlled state transition. It combines direct VPP evidence with authoritative cleaning-validation principles concerning documented procedures, scientifically justified limits, representative sampling and method capability [3,4]. Numerical pharmaceutical or medical-device residue limits are not transferred into photoresin manufacture.

Findings. A defensible changeover requires five linked demonstrations: the residue classes and carryover pathways are identified; the cleaning sequence is capable of removing or displacing them; sampling interrogates credible worst-case locations; the analytical method can detect the residue at or below the acceptance level; and the acceptance level is tied to the next material's failure mechanism rather than to a universal cleanliness number. High-viscosity, strongly coloured, highly filled, reactive, or difficult-to-solvate systems can require different cleaning and sampling strategies. Cleaner carryover itself is a separate residue class and must not be treated as evidence of successful resin removal.

Implications. A printer should be returned to service for a new resin only when the complete changeover route is reproducible and its residual state is shown to be acceptable for the intended next process. Where that evidence cannot be obtained reliably, dedicated vats, platforms, tooling, fluid paths or complete equipment may be the lower-risk engineering route.

Keywords: vat photopolymerisation; printer changeover; cleaning validation; cross-contamination; resin carryover; residue limit; swab sampling; rinse sampling; analytical detectability; equipment dedication

1. Scope, exclusions and state definitions

ER-175 owns the measurable carryover created when a printer or associated hardware changes from one resin system to another. The controlled object may include a vat, build platform, recoater or wiper where present, drain or feed feature, removable tooling, handling accessories and any surface that can retain the previous material and later contact the next one.

The paper does not own part washing or extraction after printing, facility-wide contamination control, occupational toxicology, or intentional multi-material interface design. Those are separate questions. ER-175 also does not prescribe a

universal solvent, universal purge sequence, or universal residue threshold. Its subject is the evidence required to show that a defined changeover route is fit for a defined next material and use.

For this review, **residue** means material remaining from the prior state after a cleaning operation; **carryover** means transfer of that residue into the subsequent material or process; **cleaning procedure** means the physical and chemical sequence intended to remove residue; and **cleaning validation** means evidence that the procedure reproducibly achieves an acceptance state under specified conditions.

The distinction matters. A procedure can remove most visible resin and still leave a functionally relevant residue. Conversely, a trace analytical signal does not automatically imply unacceptable risk. The acceptance decision depends on what the residue can do to the next material, what concentration or loading becomes consequential, and whether the measurement method can resolve the required level [3,4].

2. Why changeover is a materials-state problem

Multi-material VPP literature treats cleaning and drying between resins as part of the process architecture rather than as an optional cosmetic step [1]. This is physically necessary because the next formulation is introduced into equipment that has just contained another reactive liquid. Any retained material becomes, in effect, an undeclared additive to the incoming resin.

The consequences are formulation dependent. A residual clear resin may dilute pigment concentration or filler loading. A pigmented residue can alter optical attenuation. A strongly absorbing or scattering filler can change cure depth or lateral exposure. Residual reactive diluent can change viscosity or network composition. Residual cleaner can alter solvation, oxygen transport, photochemistry or phase state. Particulate or cured debris can create local defects or interfere mechanically with the vat-film interface.

The engineering failure therefore begins before the next exposure. The incoming resin no longer has the composition or physical state represented by its qualified process window. The changeover question is whether the residual perturbation is small enough, and sufficiently controlled, that the next qualified state remains valid.

3. Residue classes that must be considered

A single phrase such as "resin residue" is too coarse for qualification. At least six classes can require separate consideration.

First, **base resin and reactive diluents** can alter composition, viscosity and network stoichiometry. Second, **pigments, dyes and optical absorbers** can modify light transport at concentrations far below those required to produce obvious bulk colour. Third, **fillers and dispersed solids** can remain in corners, films or dead zones after the lower-viscosity liquid fraction has been removed. Fourth, **photoinitiator-containing or inhibitor-containing residues** can perturb cure kinetics. Fifth, **cleaning agents** can remain after the prior resin has apparently been removed. Sixth, **particulate debris**, including cured fragments, support debris and dried deposits, can survive a liquid-only cleaning route.

These classes need not share the same critical limit or analytical method. A gravimetric or total-organic measure may be adequate for one residue and blind to another. Colourimetry can be sensitive to a strongly coloured carryover yet irrelevant to a clear resin. A filler may be detected by microscopy or elemental analysis while its organic carrier has already been removed. Cleaning validation therefore begins with residue identity, not with method selection.

4. Carryover pathways in printer hardware

Carryover is governed by where material can remain and how the next process mobilises it. Flat, accessible surfaces are usually easier to clean and sample than corners, fasteners, grooves, porous seals, elastomeric interfaces, drainage features, undercuts and surfaces shielded during wiping. A vat can retain a continuous thin film even after bulk drainage. A build platform can trap liquid around mounting features or textured surfaces. Tools used to scrape or handle the prior resin can reintroduce it after the printer itself has been cleaned.

The material can also move during cleaning. A solvent wipe may spread a residue before removing it. A rinse can dilute a residue and carry it into another feature. A high-viscosity formulation may drain slowly enough that nominally identical hold times produce different residual masses. Filled systems can separate during drainage so that the remaining film is compositionally different from the original bulk formulation.

A useful changeover map therefore identifies both **retention sites** and **transfer routes**. The worst location is not necessarily the visually dirtiest point. It is the location from which a residue can plausibly reach the next material or contact-critical surface.

5. Cleaning mechanisms and their failure modes

Cleaning can act by draining, displacement, dissolution, dilution, wiping, mechanical removal, flushing, or combinations of these mechanisms. The multi-material VPP literature demonstrates that washing and drying strategies can be engineered into material-switching workflows [1]. What cannot be inferred is that one sequence is generally valid across resin families.

Failure modes follow directly from the mechanism. Drainage alone can leave a surface film. A solvent can dissolve the liquid carrier while leaving insoluble pigment or filler. Wiping can clean exposed planes and miss recesses. Repeated rinses can reduce bulk residue yet leave a persistent local pocket. Drying can remove cleaner but concentrate nonvolatile residue. An aggressive cleaner can attack vat films, seals or coatings and create a different contamination or equipment-state problem.

For that reason, cleaning validation should demonstrate the performance of the complete sequence, including order, contact time, mechanical action where relevant, rinse or wipe replacement logic, drainage, drying, inspection and the controlled condition at which the next resin is introduced.

6. Sampling strategy: the measurement must interrogate the risk

Health Canada cleaning-validation guidance emphasises representative sampling and a scientifically justified relation between sampling strategy and residue risk [3]. The principle transfers directly even though the regulated context and numerical limits do not.

Swab sampling can target a known surface and can be useful for accessible worst-case sites. Its limitations include incomplete recovery, operator dependence and poor access to complex geometry. **Rinse sampling** can interrogate larger or inaccessible areas but may average a local hotspot into a larger volume. **Witness surfaces or removable coupons** can provide a reproducible test surface where direct sampling of the equipment is impractical, but only if they represent the actual retention and cleaning mechanisms. **Process surrogates** can be useful when the residue itself is difficult to measure, provided the surrogate is demonstrably conservative for the intended mechanism.

A robust validation can combine methods. For example, a rinse result may show that the overall system is low in soluble residue while targeted swabs challenge corners or textured areas. The sampling plan should be established before the validation run so that passing evidence is not selected retrospectively from whichever location happened to look cleanest.

7. Analytical methods and detection capability

A cleaning result is only meaningful relative to the capability of the method used to measure it. If the justified acceptance level is below the method's practical detection or quantification capability, a "not detected" result does not demonstrate acceptance.

Method selection should follow the residue and failure mechanism. Options can include gravimetry, spectroscopy, chromatography, total organic measurements, colourimetry, microscopy, elemental methods, particle counting or material-specific markers. ER-175 does not privilege one method. It requires evidence that the chosen method is sufficiently selective, sensitive and reproducible for the decision being made.

Recovery also matters. A method may be analytically sensitive in a standard solution and still recover residue poorly from the actual vat film, platform texture or seal material. Validation therefore needs a connection between analytical capability and sampling recovery. The measurement system should be challenged on representative surfaces where practical rather than assumed to behave identically on glass, metal, polymer film and elastomer.

8. Acceptance limits: no universal cleanliness number

The core decision is not "how much residue is left?" but "how much residue can remain without invalidating the next process or intended use?" ASTM E3418-23e1 provides a framework for calculating scientifically justifiable residue limits rather than relying on arbitrary visual or analytical targets [4]. ER-175 applies that principle without importing pharmaceutical HBEL, PDE or other sector-specific numerical limits.

A photoresin acceptance limit can be based on a credible failure mechanism in the next system. If the relevant risk is colour or optical attenuation, the limit should be tied to the level at which the next resin's optical response becomes unacceptable. If the risk is filler contamination, the criterion may relate to visible defects, sedimentation, dielectric behaviour, mechanical response or another relevant endpoint. If the next application has a biological-contact requirement, the changeover assessment must be consistent with that product's own qualification rather than claiming that cleaning validation alone establishes biocompatibility.

The limit must also be measurable. A nominal specification below the demonstrated capability of the sampling and analytical method is not a valid control. Conversely, a method can be much more sensitive than required; a trace signal below the justified acceptance level should not automatically be escalated into a failed changeover.

9. Direct evidence that contamination can alter VPP outcomes

Direct evidence is limited but sufficient to show that contamination can become consequential once a system-specific threshold is crossed. In a 2025 VPP study using Model V2 resin and IPA post-rinsing, no significant dimensional deviations were reported up to 10 wt% resin contamination; deviations appeared in small structures and inclined planes at 20 wt%, and 30 wt% contamination produced significant deviations across all evaluated areas [2]. These concentrations and outcomes are specific to that resin, rinse medium, geometry and experimental design and are not transferred here as universal printer-changeover thresholds.

The engineering value of that study is narrower and stronger: material carried from one resin-bearing state into a subsequent liquid-processing state can measurably change the resulting part once a system-specific threshold is passed. Independently of that study, optical absorbers can modify light transport at loadings below those required to produce obvious bulk colour. A changeover validation therefore cannot rely solely on visible cleanliness when the next material has performance variables that can respond to composition before a residue is visually obvious.

The multi-material VPP literature provides the complementary process observation that switching between materials requires removal of the prior resin and often an explicit wash/dry sequence [1]. Together, these sources establish relevance without pretending that the field already provides a universal contamination specification.

10. High-viscosity, pigmented and filled systems

Worst-case changeover selection should consider properties that make residue removal difficult or consequences severe. High viscosity slows drainage and can increase film retention. Strong colour or optical absorption can make small carryover consequential for clear or lightly coloured successor resins. Filled systems can retain solids in recesses after the carrier phase has been diluted away. Dense particles can accumulate at local low points. Thixotropic or yield-stress materials can remain where a low-viscosity resin would drain.

The cleaning route should therefore be challenged using representative difficult-to-clean and difficult-to-detect states, not merely the most convenient resin in a family. Family grouping is legitimate only when the grouping logic is explicit. A successful changeover from one clear low-viscosity resin does not automatically qualify a highly filled opaque formulation on the same machine.

11. Cleaner carryover is its own contamination problem

A changeover can remove the prior resin successfully and still fail because cleaning fluid remains. This is particularly important when the cleaner is miscible with the incoming resin or can become trapped as a surface film, in a corner or within a porous or swollen polymer component.

The final drying or displacement step therefore needs its own acceptance logic. "No previous resin detected" is not equivalent to "equipment returned to a qualified next-use state." Where cleaner residue can plausibly affect cure, viscosity, phase behaviour, adhesion or biological-contact qualification, the cleaner itself must be included in the residue assessment.

This is also why simply increasing the number of rinse cycles is not necessarily a validated solution. Additional cleaning can reduce one residue while increasing exposure of hardware to solvent, generating more waste, or leaving a larger quantity of a different residual liquid. The route must be optimised as a state transition, not as an indefinite pursuit of zero analytical signal.

12. Visual inspection: necessary in some routes, insufficient as the sole gate

Visual inspection remains useful for gross residue, obvious pigment streaks, cured debris, damaged films and incomplete drainage. It can be a rapid process control and a prerequisite for further sampling. It should not be treated as universally sufficient.

Clear reactive species, low-level pigment, photoinitiator-containing residue and cleaner can remain below the threshold of visible detection. A surface may also appear clean under one lighting condition while retaining material in a recess or under an edge. The acceptance architecture therefore distinguishes **visual cleanliness** from **analytical or functional cleanliness**.

A validated changeover may legitimately use visual inspection as one gate where the failure mode is itself visible and the method has been shown to be adequate. What is rejected is the unqualified equation "looks clean = qualified for any next resin."

13. Worst-case selection and family grouping

It is rarely efficient to validate every possible resin pair independently. A family strategy can reduce the burden, but only when it is based on the mechanisms that govern cleaning and carryover.

Potential worst-case attributes include high viscosity, strong adhesion to hardware, high pigment or filler loading, difficult solubility, low volatility of residual components, strong colour, high analytical response interference, and a successor material with high sensitivity to contamination. The worst **previous material** and the worst **next material** need not be the same pairing for every failure mechanism.

A rational family matrix can therefore separate cleaning difficulty from consequence severity. One resin may be the hardest to remove; another may be the easiest to detect; a third may be the most sensitive successor. Bridging evidence should show why the tested combinations cover the untested members rather than merely declaring a family by product name.

14. Reproducibility and revalidation

A one-off successful cleaning run is development evidence, not necessarily validation. The changeover route should demonstrate reproducibility under representative conditions and operators, with predefined acceptance criteria and documented deviations [3].

Revalidation or targeted bridging becomes appropriate when the state transition changes materially. Examples include a new vat-film material, altered surface finish, new cleaner, new cleaning tool, different resin family, modified pigment/filler package, new sampling method, analytical-method change, substantially different dwell time before cleaning, or hardware wear that creates new retention sites.

The purpose is not bureaucratic repetition. It is to prevent a validation result from being carried across a changed mechanism. If the residue retention, removal, transfer or detection process changes, the original evidence may no longer represent the current system.

15. Equipment dedication as an engineering alternative

Cleaning is not always the lowest-risk route. Where a residue is difficult to remove, difficult to detect, highly consequential to the next material, or repeatedly generates borderline results, dedicated equipment can reduce uncertainty.

Dedication can be partial. Separate vats, build platforms, tools, funnels, feed containers or fluid-path components may be enough when the printer architecture allows them to isolate the credible carryover route. In other cases, especially where internal or inaccessible paths cannot be sampled or cleared convincingly, a fully dedicated machine may be justified.

The decision should compare the burden of validated changeover with the cost and operational complexity of dedication. A dedicated vat that eliminates a high-risk residue path can be more defensible than a long cleaning procedure supported by a method that cannot measure the required limit.

16. Decision gates for a qualified changeover

A printer or hardware set should not be released to the next resin merely because the cleaning procedure was executed. The following gates form a minimum evidence chain.

Gate 1 - residue identity: credible residue classes and retention sites are identified for the prior and next material pair or justified family.

Gate 2 - cleaning capability: the defined sequence addresses the relevant residue mechanisms on the actual hardware.

Gate 3 - sampling representativeness: sampling covers credible worst-case locations and does not rely only on easy-to-reach surfaces.

Gate 4 - analytical capability: the measurement method and recovery are capable at or below the justified acceptance level.

Gate 5 - acceptance logic: the limit is linked to the next material's failure mechanism and intended use, not to an imported universal number.

Gate 6 - reproducibility: repeated execution demonstrates a stable route under defined conditions.

Gate 7 - change control: triggers are defined for bridging or revalidation when materials, hardware, cleaners, methods or operating conditions change.

Failure of any load-bearing gate should result in re-cleaning, route redesign, stronger measurement, narrower family claims, or equipment dedication rather than an unsupported declaration of cleanliness.

17. Minimum reporting set

A technically useful changeover record should identify the previous resin or family, the next resin or family, hardware included in scope, residue classes considered, cleaning materials and sequence, critical timings or drying conditions where relevant, sampling locations and method, analytical method, recovery or capability evidence, acceptance criteria and their rationale, results, deviations, disposition and revalidation triggers.

Where a visual inspection is used, the lighting and inspected surfaces should be defined sufficiently for repetition. Where a rinse or swab result is used, the sampling area or rinse volume and the analytical basis should be traceable. Where family grouping is used, the worst-case logic should be documented.

The minimum record is therefore not a cleaning checklist alone. It is an evidence package linking the prior state, the cleaning action, the measured residual state and the qualification of the next state.

18. Limitations

Direct peer-reviewed literature specifically quantifying printer-to-printer or vat-to-vat resin carryover in commercial VPP changeover remains limited. The VPP review evidence establishes that material switching requires explicit cleaning/drying architecture [1], while the direct experimental study establishes that contamination in a VPP liquid-processing step can measurably affect outcome once a system-specific threshold is crossed [2]. Neither provides a universal printer-changeover residue threshold.

The more mature cleaning-validation sources come from pharmaceutical and medical-device manufacturing [3,4]. Their transferable value is methodological: scientifically justified limits, representative sampling, documented procedures and analytical capability. Their sector-specific health-based or product-specific numerical limits are not transferred into photoresin processing.

This review therefore proposes an engineering qualification architecture rather than a universal validated cleaning recipe. Each resin family, printer architecture and intended next use remains responsible for establishing its own acceptance state.

19. Conclusions

Printer changeover in vat photopolymerisation is a controlled materials-state transition, not a cosmetic cleaning task. Residual resin, pigment, filler, cleaner or particulate can become an undeclared component of the next process. VPP evidence shows that cleaning during material switching is part of the process architecture [1] and that contamination can alter part outcome once a system-specific threshold is crossed [2], while authoritative cleaning-validation frameworks provide a mature structure for verification [3,4].

The defensible route is therefore to identify residue mechanisms, clean by a defined process, sample representative worst-case locations, use an analytically capable method, set limits against the next material's credible failure modes, and demonstrate reproducibility. Visual cleanliness can support but does not universally replace analytical or functional evidence. No generic pharmaceutical residue threshold should be converted into a photoresin specification.

Where the required residual state cannot be demonstrated reliably, dedication of vats, platforms, tools, fluid paths or printers is not a failure of cleaning technology. It is a valid engineering control that removes an uncertain carryover path from the qualified process.

References

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Related Engineering Review boundaries

ER-033 and ER-086 own part washing/extraction. ER-175 does not convert part-cleaning guidance into equipment-changeover acceptance. Facility-wide contamination control and occupational toxicology remain outside scope. Intentional multi-material interface design remains outside scope. ER-175 owns only the measurable carryover created by equipment changeover and the evidence required to accept or reject the resulting next-use state.

Competing interests

The author is Founder and Scientific Director of 3Dresyns by Resyner Technologies S.L. No comparative product recommendation is made.

Data availability

No new experimental dataset was generated. Scientific statements derive from the cited literature, official guidance and standards record. The Engineering Review architecture and corpus boundaries follow the controlled 3Dresyns project sequence.

AI-assistance disclosure

Generative AI assisted drafting, literature synthesis and document QA but is not an author. Juan Segurola retains authorship responsibility and final human authority.