

Scale-Up of Photoresin Blending: Mixing Regimes, Addition Order, Heat, Air Entrainment and Batch Equivalence

From laboratory blend to production batch: preserving material state while scale, geometry and mixing history change

Juan Segurola

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Correspondence: info@3Dresyns.com · www.3Dresyns.com

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Abstract

Geometric enlargement does not preserve mixing automatically. A final composition can be identical while the path to it is not. Mechanical dissipation, dissolution heat and reaction-sensitive additives can raise local temperature during blending. Vortex formation, surface drawdown and powder charging can entrain bubbles that persist in viscous resins. Single-point viscosity is not enough to establish equivalence. Qualification therefore depends on preserving the measured state, configuration and exception history needed to distinguish these mechanisms in production rather than relying on nominal recipe identity alone.

Keywords: photoresin blending; scale-up; mixing; addition order; heat generation; air entrainment; batch equivalence

1. Significance and scope

Geometric enlargement does not preserve mixing automatically. The engineering question is whether a blending process can be scaled while preserving composition uniformity, mixing time, thermal history, bubble content and batch equivalence despite changes in vessel and impeller hydrodynamics. The review focuses on evidence that supports repeatable manufacturing decisions and excludes proprietary recipes, supplier-specific settings and undocumented operator heuristics.

1.1 Corpus boundary

ER-341 owns scale-up of liquid photoresin blending and the evidence needed to show that a larger batch is materially equivalent to the qualified smaller-scale state. It does not own raw-material lot acceptance, general storage stability or downstream printer process capability. ER-342 owns inline spectroscopic PAT, ER-344 owns machine-capability studies, and ER-349 owns electronic execution records.

2. Scale-up is a state-equivalence problem

Geometric enlargement does not preserve mixing automatically. Vessel aspect ratio, impeller diameter, clearance, baffles, free-surface behaviour and rheology alter circulation and local shear. Classical scale-up criteria such as power per volume, tip speed, mixing time or Reynolds number cannot generally be held constant simultaneously; the criterion must be selected against the failure mode that matters for the formulation [1,2].

3. Addition order changes the transient formulation

A final composition can be identical while the path to it is not. Pigments, fillers, photoinitiators, inhibitors and high-viscosity oligomers can create local concentration excursions, agglomeration or transient exotherm when addition order or feed rate changes. Production instructions should therefore define the sequence, addition window and required state before the next addition rather than only the bill of materials [2,3].

4. Heat generation and heat removal scale differently

Mechanical dissipation, dissolution heat and reaction-sensitive additives can raise local temperature during blending. Surface-area-to-volume ratio falls with scale, so a laboratory batch that remains nearly isothermal can develop gradients at production scale. Temperature history should be monitored at more than one location during scale-up and linked to viscosity, inhibitor stability and spectral response where relevant.

5. Air entrainment is a process variable

Vortex formation, surface drawdown and powder charging can entrain bubbles that persist in viscous resins. Vacuum degassing after mixing may not reproduce a low-air process if dissolved gas, foam stabilisation or filler wetting has already changed. A scale-up package should therefore record free-surface regime, charging method, mixing speed trajectory, pressure history and a defined bubble or density acceptance check [1,3].

6. Batch equivalence requires orthogonal measurements

Single-point viscosity is not enough to establish equivalence. Identity, viscosity over a relevant shear window, density, optical absorbance where the formulation is spectrally sensitive, sedimentation tendency and cure-response measurements should be chosen according to the formulation risks. The aim is to show that scale changed equipment, not the material state [2,4].

7. Qualification architecture

A defensible scale-up protocol freezes raw-material identity, defines the laboratory reference state, states the chosen similarity criteria, records transient variables during the large batch and then compares independent outputs. Failed equivalence should trigger investigation of mixing physics or addition history rather than retrospective widening of specifications [2-4].

8. Evidence hierarchy and transfer

The strongest evidence combines process-state monitoring with independent batch measurements and repeated large-scale runs. One successful batch establishes feasibility; repeated equivalence across operators, lots and normal equipment variation establishes transfer robustness [2,4].

Table 1. Qualification matrix for scale-up of photoresin blending.

Control variable	Why it matters	Minimum evidence
Impeller/vessel regime	Controls circulation and local shear	Geometry, speed history, selected scale criterion
Addition order	Controls transient local composition	Sequence, feed rate, hold points
Temperature	Affects viscosity and reactive stability	Spatial temperature history
Air content	Affects bubbles, density and printing	Charging regime plus bubble/density check
Batch output	Tests material equivalence	Orthogonal property panel

9. Interpretation matrix

For photoresin blending scale-up, a batch deviation should be separated into mixing-regime, thermal-history, air-entrainment and sampling causes. Interpretation should compare blend time and power, temperature trajectory, void or foam evidence and spatial sampling before equivalence or corrective action is assigned.

Table 2. Diagnostic interpretation matrix for photoresin blending scale-up.

Observed deviation	Competing cause	Discriminating check
Higher viscosity	Temperature, composition drift, incomplete dispersion	Conditioned rheology plus mass balance
More bubbles	Surface vortex or powder charging	Free-surface record and density
Cure shift	Spectral composition or inhibitor state	Absorbance and cure-response test
Sedimentation	Dispersion energy or filler wetting	Particle-size/settling comparison

10. Limitations and evidence gaps

Published scale-up studies rarely report a complete set of transient mixing, temperature, gas-content and batch-equivalence measurements for highly filled or strongly absorbing photoresins. Similarity criteria therefore remain formulation- and equipment-specific, and this review does not define universal impeller, power-density, mixing-time or degassing thresholds. Transfer should be demonstrated by measured material-state equivalence rather than by geometric scale factors alone.

11. Conclusions

Scale-up of photoreซิน blending should be accepted only when the larger process reproduces the material state that matters to printing and final performance. Addition order, heat history, gas entrainment and mixing regime are causal variables, while batch-equivalence measurements provide the release evidence. Geometric similarity alone is not a sufficient scale-up argument.

References

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Competing interests

The author is Founder, CEO and CTO of 3Dresyns by Resyner Technologies S.L. No comparative product recommendation is made.

Data availability

No new experimental dataset was generated for this review.