

# Vat-Printed Microreactors for Chemical Processing: Residence-Time Distribution, Mixing, Compatibility and Scale-Out

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ER-281 · Engineering Review · Version 0.3 · 23 September 2026

## Abstract

Vat-Printed Microreactors for Chemical Processing is evaluated as the bounded decision of whether a vat-printed microreactor delivers a known hydrodynamic and materials state under the intended chemistry and flow rate. The controlled state comprises channel geometry, roughness, orientation, wash/cure state, wettability, fluid properties, flow rate, pressure, temperature and reaction chemistry. For ER-281, both cited sources are confined to their stated point-of-use evidence roles. ER-281 defines measurements, transfer logic, failure modes and release gates specific to this subject; no universal process window, product recipe or compliance conclusion is inferred.

**Keywords:** microreactor; vat photopolymerisation; residence-time distribution; mixing; chemical compatibility; scale-out; flow chemistry

## 1. Significance, scope and ownership

ER-281 owns whether a vat-printed microreactor delivers a known hydrodynamic and materials state under the intended chemistry and flow rate. The review is organised around the decision-specific evidence chain and leaves neighbouring ownership intact.

### 1.1. Corpus boundary

ER-281 is not a general microfluidics review and does not own analytical-device bias or vacuum service. ER-282 retains sample-handling measurement bias and ER-283 retains vacuum-compatible components. The boundary is the chemically used printed reactor, where realised channels, RTD, mixing, compatibility and scale-out must be qualified together.

## 2. Subject-specific state model and causal chain

For ER-281, causal interpretation begins by freezing channel geometry, roughness, orientation, wash/cure state, wettability, fluid properties, flow rate, pressure, temperature and reaction chemistry. Channel distortion, roughness and chemistry history can change both residence-time distribution and pressure behaviour, so CAD volume alone cannot define the reactor state.

## 3. Direct evidence and point-of-use source map

García-López, Águeda and Garrido-Escudero validated residence-time-distribution behaviour in an SLA-printed microreactor and showed that complex bending geometries can approach plug-flow behaviour while generating secondary vortices. Lohse and co-workers demonstrate why RTD measurement itself requires careful stimulus and microscale interpretation. Reference [1] is used for direct SLA microreactor RTD/hydrodynamic evidence. Reference [2] is used for methodological evidence for measuring RTD in intricate microreactors.

## 4. Measurement architecture

The measurement architecture for ER-281 is built around channel metrology, pressure drop, RTD, mixing index or tracer homogenisation, temperature, leakage, sorption/leaching and chemical compatibility before/after exposure. RTD, pressure drop and post-exposure compatibility are read together because scale-out is credible only when the hydrodynamic state survives replication across channels or units.

## 5. Qualification and transfer

A new reactor size or parallelisation scheme must preserve the accepted RTD and pressure behaviour, not merely nominal residence time. Chemistry changes additionally require compatibility and thermal checks because wall interaction or heat release can invalidate a hydrodynamic bridge.

## 6. Failure modes and interpretation traps

The central interpretation trap in ER-281 is that nominal volume divided by flow is substituted for measured RTD; CFD is accepted without physical validation; chemical compatibility is inferred from one short exposure. The release gates distinguish realised geometry, RTD, pressure, compatibility and scale-out so that one favourable tracer curve cannot conceal a material or integrity failure.

## 7. Non-compensatory release gates

| Gate          | Minimum evidence                                     | Blocking failure                         |
|---------------|------------------------------------------------------|------------------------------------------|
| Geometry      | Realised channels/roughness measured                 | CAD geometry assumed                     |
| RTD           | Tracer RTD over operating window                     | Nominal volume/flow substituted          |
| Mixing        | Relevant mixing metric or tracer homogenisation      | Secondary flow assumed sufficient        |
| Pressure/leak | Pressure drop and leakage bounded                    | Flow achieved without integrity evidence |
| Compatibility | Representative chemistry/time/temperature challenged | One short soak generalized               |
| Thermal state | Reaction/ambient thermal conditions measured         | Heat effects ignored                     |
| Scale-out     | Parallel-unit RTD/pressure distribution verified     | One channel copied numerically           |
| Post-exposure | Performance rechecked after chemistry history        | Pristine device only                     |

## 8. Minimum verification experiment

Print a declared geometry, measure realised channels, obtain pressure-drop and tracer RTD over the intended flow window, challenge representative chemistry and temperature, then repeat the flow measurements after exposure. Scale-out must preserve the accepted distribution of RTD, pressure and thermal states across parallel units.

## 9. Knowledge boundary

Published demonstrations remain geometry-, resin-, chemistry- and flow-specific. Long-term fouling, solvent ageing, reaction heat and parallel scale-out are not sufficiently general to yield transferable RTD or compatibility limits.

## 10. Conclusions

ER-281 qualifies a printed chemical microreactor only through the realised hydrodynamic and material state, with RTD, pressure, compatibility and scale-out evidence tied to the same configuration.

## References

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