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PFRR Reactors for Bulk Polymerization

Temperature control

Final conversion

MWD control

PFRR combines controlled backmixing in the loop with the defined residence time of a plug-flow section.

Neftenbach, Switzerland • www.fluitec.ch

Why PFRR?

The reactor separates start-up / heat management and final conversion into two optimized apparatus functions.

Concept

Challenge in bulk polymerization

- highly exothermic
- increasing viscosity
- diffusion / gel effect
- MWD and quality window
- esidual monomer / devolatilization

Loop

mixing + heat removal
pre-conversion

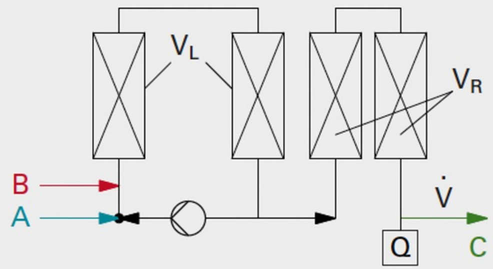
\+

PFR section

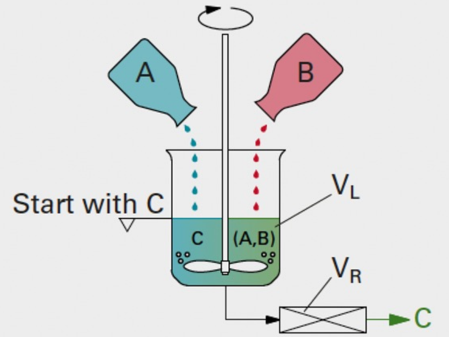
narrow RTD
final conversion

Result

- controlled local heat generation
- robust dosing of initiator / catalyst / additives
- defined final conversion without an oversized loop
- controllable molecular weight distribution
- scalable via CSE-X / CSE-XR



Continuous recycle reactor + residence time section (PFRR)



CSTR + residence time reactor

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How to Scale?

The development is being carried out through experiments using the Contiplant reactor.

Loop task

Dilution of the feed, safe reaction start, high heat transfer and uniform local conditions.

PFR task

Same post-reaction time for all fluid packets, high final conversion and reduced backmixing.

Design

The boundary between loop and PFR is set by the heat balance, kinetics, viscosity and MWD target.

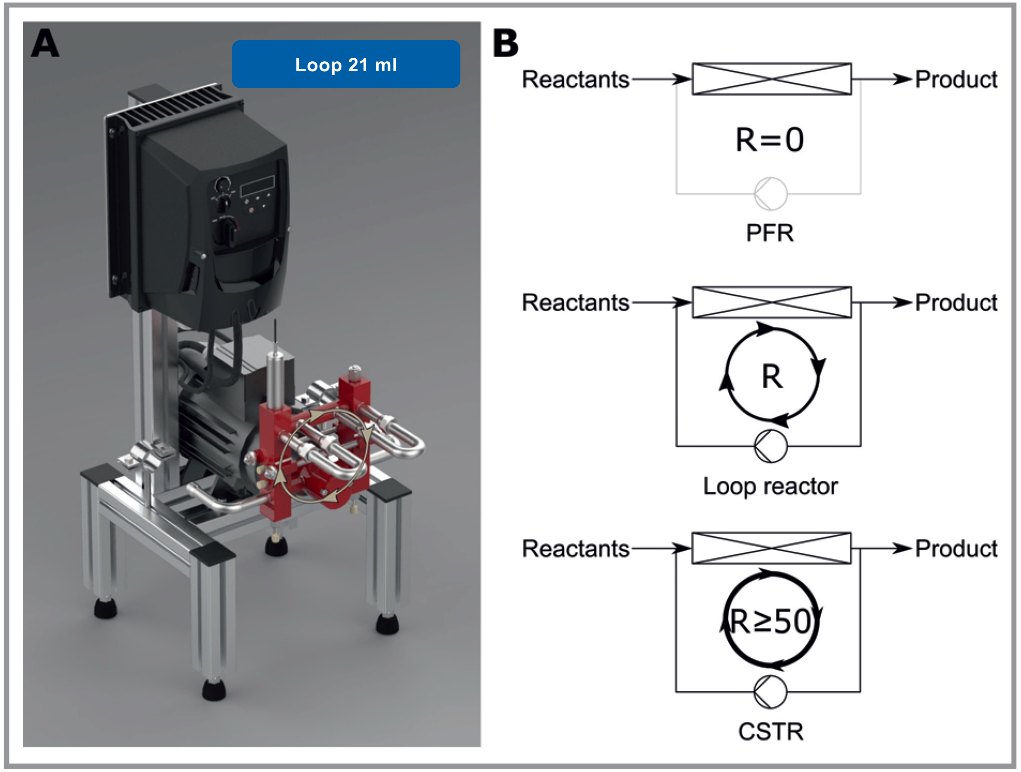
Loop reactor: controlled backmixing

The loop establishes robust concentration and temperature conditions at the reaction start.

R = recycle flow / net product flow

- Fresh feed is immediately diluted with already reacted product.
- High R: CSTR-like behavior, well suited to fast / exothermic reactions.
- Lower R: higher space-time yield, but more demanding heat removal.
- In the loop itself, CSE-X / CSE-XR should provide plug-flow characteristics.

As reactor performance decreases with increasing R, the loop is not designed as “maximum”, but for the required mixing and thermal safety.



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Residence time section: controlled final conversion

After the loop, the defined post-reaction takes place in a Fluitec CSE-X / CSE-XR plug-flow section.

Loop outlet → **Zone 1** PFR — **Zone 2** PFR — **Zone 3** PFR — **Zone 4** PFR → Final product + devolatilization

PFR Reactor

• High final conversion without an oversized loop.

• Narrow residence time distribution reduces over- and under-reaction.

• Zoned temperature control governs reaction rate, viscosity and residual monomer.

• Dosing of a second initiator / catalyst / CTA is possible, but must be micro- and macro-mixed.

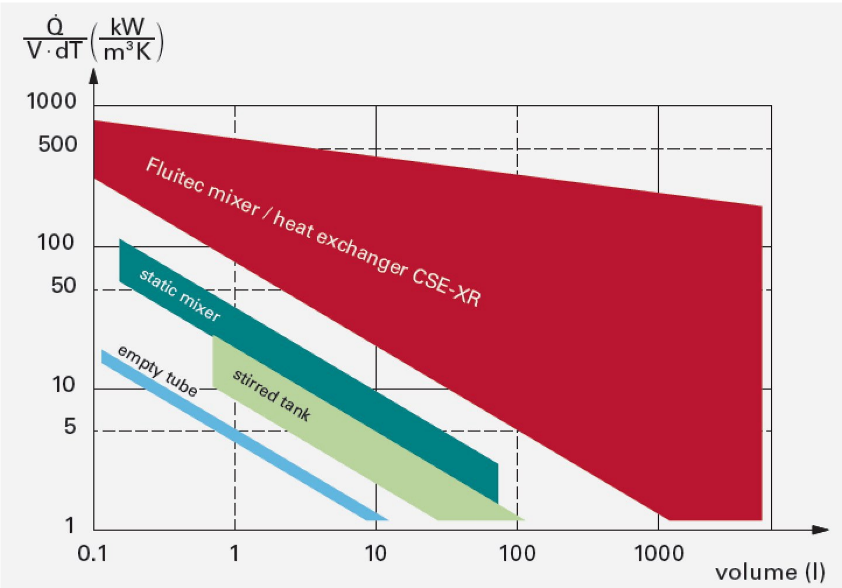
Quality target

Achieve final conversion without creating new undesired chain populations, hot spots or fouling zones.

Fluitec CSE-X and CSE-XR as the reactor core

Mixing, heat transfer and RTD are treated as one integrated design topic.

Scale-up

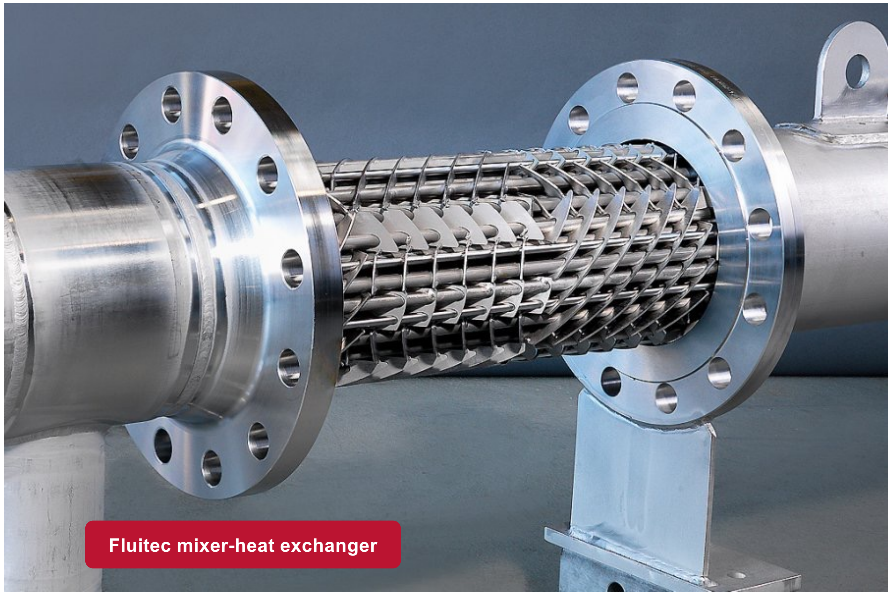


CSE-X Static mixer

Mixing, homogenization, residence time sections

CSE-XR mixer / heat exchander

Mixing + heat exchanger function for high heat loads



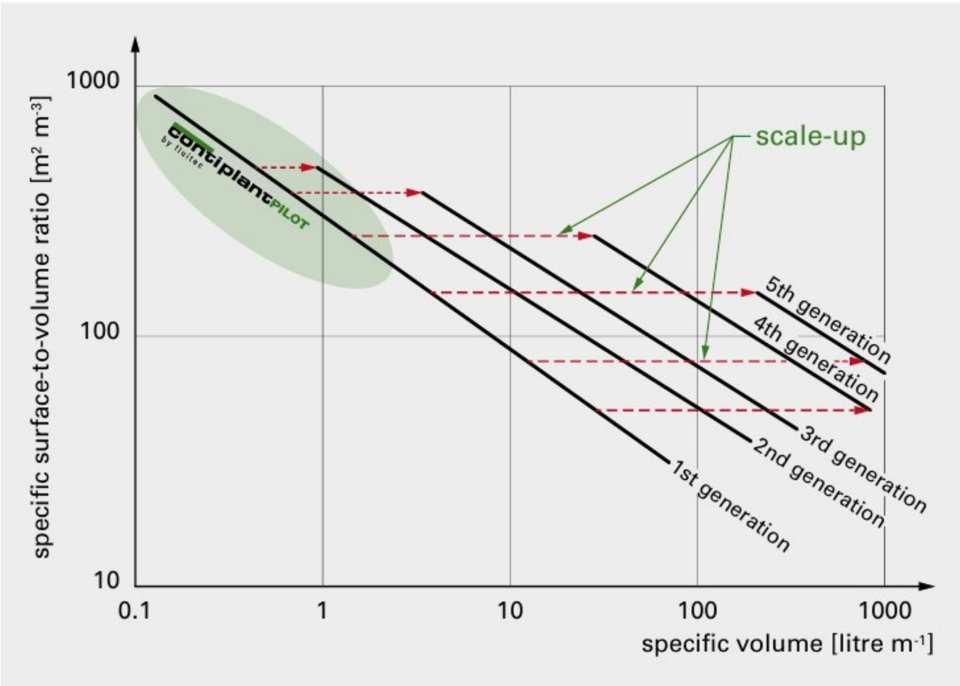
Key functions

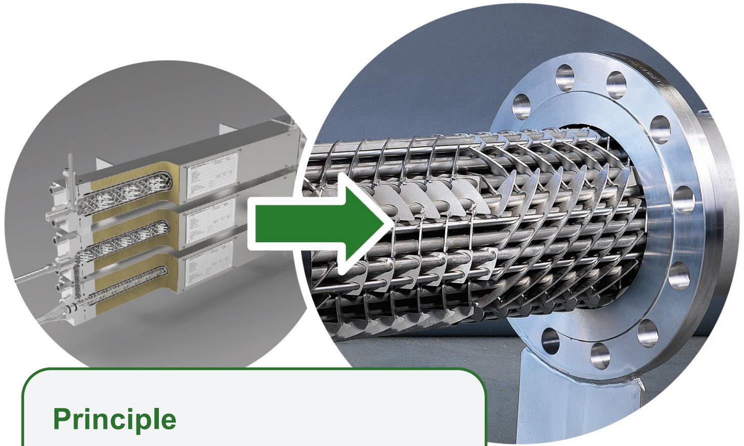
- radial homogenization in laminar and turbulent flow
- narrow RTD / plug-flow character
- heat transfer in CSE-XR via internal exchange area
- scale-up via geometry generations, surface/volume and pressure drop
- suitable for high viscosities and exothermic reactions

Scale-up strategy

The goal is not simply more volume, but equivalent heat transfer, mixing effect and RTD.

Scale-up





Principle

Scale-up via geometry generations and CSE-XR heat-transfer area.

Evidence required for scale-up

- constant or deliberately scaled surface/volume ratio
- same mixing and heat-transfer mechanism
- verified pressure-drop / viscosity curve
- avoidance of maldistribution in parallel strands
- same critical quality parameters: M_w, M_w/M_n, residual monomer

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Laboratory unit: rapid process proof

The laboratory unit provides kinetics, heat and mixing data under continuous, process-relevant conditions.

Laboratory

What is determined in the laboratory

- τ, RTD / CSTR approximation of the loop
- conversion and reaction rate
- temperature profile and adiabatic temperature rise
- pressure drop and viscosity model
- GPC: M_n, M_w, M_w/M_n, bimodality
- start-up, emergency stop, cooling failure, fouling risk

Typical: small hold-up, adjustable recirculation ratio, rapid test series and low material demand before pilot scale.

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Laboratory program for bulk polymerizations

From recipe to robust design: data are validated step by step.

1 Safety data
DSC / FFC, ΔH, ΔTad, MTSR, stability

2 Reaction model
Kinetics, gel effect, initiator / catalyst, CTA

3 Loop screening
R, τ, pre-conversion, mixing time, freedom from hot spots

4 PFR section
τ, Temperature zones, final conversion, pressure drop

5 Product quality
GPC/MWD, residual monomer, color, stability

Key measured variables
X_{Loop}, X_{End}, τ, T-profile, Δp, η(X,T,M_w), M_w/M_n

Scale-up criteria
same heat / mixing window, RTD, stable hydraulics

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Typical throughputs in the Fluitec PFRR program

The stages are orientation values; polymer design is product- and viscosity-specific.

Scale-up

Stage	Net throughput	Annual capacity*	Typical purpose
ContiplantLAB	< 2 kg/h	-	Kinetics, RTD, MWD screening
ContiplantPILOT	1 - 3 kg/h	8 - 26 t/a	Pilot data / customer samples
ContiplantPILOT	5 - 10 kg/h	40 - 80 t/a	Small production
ContiplantMODULE	20 - 500 kg/h	150 - 4,200 t/a	Modular production
Fluitec systems	< 10,000 kg/h	up to 90,000 t/a	Custom / production plants

*Capacities are order-of-magnitude values for continuous operation; actual design is limited by heat release, viscosity, RTD, cleaning and product quality.

Typical conversion windows in the loop and at the reactor outlet

Guideline values from literature / pilot data - in the customer project they are validated by kinetics and GPC.

Design

Polymer / system	Loop conversion	Final conversion before devolatilization	Design note
PS / styrene	approx. 50 - 80 %	> 93 - 96 %	Loop shapes the early MWD; PFR increases conversion.
PMMA / MMA	approx. 40 - 50 %	approx. 60 - 80 %	Gel effect, viscosity and thermal stability are limiting factors.
PLA / PLLA / PCL	Start / mixing phase	high, but observe equilibrium	Further reduce residual monomer via devolatilization.
PU / polyol / reactive systems	reaction-dependent	target-product-dependent	Mixing quality and heat removal dominate.

Rule

Loop conversion as high as needed for stability and MWD - PFR as long as needed for final conversion.

Practice

R, τ, temperature and dosing are always coupled with GPC and residual monomer data.

Applications for PFRR reactors

Expanded based on literature and market review: polymerization, reaction, formulation and downstream polymer technology.

Applications

Free-radical bulk / solution polymerization

PS, HIPS/SAN, PMMA, MMA/MA, acrylates
Focus: exotherm, gel effect, MWD

Ring opening / biopolymers

PLA/PLLA, PCL, lactide / caprolactone systems
Focus: catalyst distribution, equilibrium, residual monomer

Polyaddition / reactive viscous media

PU / polyol systems, epoxy / 2K reactions
Focus: mixing quality, heat removal, viscosity increase

Polymer downstream

Additive / masterbatch incorporation, stripping, devolatilization, recycling streams
Focus: homogenization, residual monomer, product stability

Suitability filter

PFRR is especially strong at high heat flux, high viscosity, large viscosity differences, critical dosing and MWD-sensitive reaction control.

What to pay attention to

Technical release is based on the combination of reaction model, hydraulics and product analytics.

Checklist

Confidential

Critical topic	Apparatus / experimental answer
Heat release and cooling failure	CSE-XR areas and temperature zones
Viscosity increase and pressure drop	$\eta(X,T,Mw)$ model + Δp measurements
Recirculation ratio R and loop performance	R as small as possible, as large as necessary
Mixing at dosing points	CSE-X micro- / macro-mixing
RTD and absence of dead zones	Tracer / RTD and axial sampling
Fouling / cleaning / start-up	Flush / CIP concept and emergency strategy
Devolatilization and residual monomer	Check Statoflash / vacuum / stripping step

Customer approach: from idea to plant

A pragmatic development plan reduces scale-up risks early.

Phase 0
Data package

Recipe, ΔH, safety data, target MWD, target conversion

Phase 1
Laboratory PFRR

Screening of R, τ, T, dosing points, GPC and residual monomer

Phase 2
Pilot

1-10 kg/h: sample production, stability, cleaning, start-up

Phase 3
Scale-up

CSE-XR design, Δp, heat transfer area, basic engineering

Decision point after each phase

Go / No-Go based on safety, reaction control, MWD, residual monomer, plant cleaning and economic space-time yield.

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