

The Coflore™ ACR Flow Reactor

**An alternative to Continuous Tubular
Reactors (CTR) and Oscillatory Baffled
Reactors (OBR)**



Flow reactors can deliver substantial commercial benefits through improved quality, yield and cycle time. Depending on the process type however, reactor performance will be sensitive to such factors as temperature, pressure, reactant ratios, reaction time, mixing, heat transfer and plug flow. Success relies on identifying the right process method and equipment for the job.

Micro reactors are ideal for fast reactions with clean fluids. For many processes however, larger diameter channels are preferable or essential. For these, achieving the right combination of reaction time, mixing conditions and plug flow can present a much bigger challenge. Users have 4 common options:

1. Continuous tubular reactor (CTR)

CTRs are pipes, channels or modified plates which rely on axial movement of the product to promote mixing, heat transfer and plug flow. Increased axial velocity improves performance but at the cost of higher minimum throughputs, longer channels and greater pressure drops. The performance of CTRs can be enhanced with static mixing elements or baffles (however the use of these has implications for cost, pressure drop, cleaning and propensity to block).

2. Oscillatory Baffled Reactors (OBR)

Like CTRs, OBRs (also referred to as oscillatory flow reactors) rely on axial movement for efficient mixing, heat transfer and plug flow. The benefit of oscillatory flow is that higher levels of axial movement can be generated at low net velocities. This makes them more compact and flexible than CTRs. Plug flow in the OBR however is still linked to net velocity and channel length. Mixing intensity is also constrained by channel length, pump spec, fluid properties and the need to maintain plug flow.

3. Single stage continuously stirred tank reactor (CSTR)

The CSTR is a stirred tank used in continuous flow mode. Dynamic mixing gives the CSTR the compelling advantage that high mixing efficiencies can be achieved independently of reactor length or reaction time. A single stage CSTR however is not a plug flow device.

4. Multi stage continuously stirred tank reactor (multi stage CSTR)

When a number of CSTRs are connected in series, the result is plug flow. Small channels between the reaction stages serve as efficient barriers to back mixing irrespective of reactor length, reaction time or mixing conditions. The combination of dynamic mixing and stage separation give the multi stage CSTR greater flexibility and fewer performance constraints than either CTRs or OBRs.

Despite their obvious benefits, CSTRs are less frequently used for reasons of cost and complexity. The Coflore Agitated Cell Reactor (ACR) was developed to address this. It is a 10 stage CSTR with reaction stages cut within a single monolithic block. Free floating agitators provide high mixing efficiency without the use of rotating shafts, seals or multiple drives. Mixer sets can also be replaced within a matter of minutes to change agitation characteristics or optimise residence time distribution for non zero order reactions.

ACR - Process benefits

Mixing

Both CTRs and OBRs rely on axial movement of product to generate mixing. The ACR uses dynamic mixing and can therefore sustain efficient mixing with or without axial movement. ACR benefits:

- ✓ *Mixing intensity can be changed without altering channel length*¹, net velocity*¹ or pressure drop.*
- ✓ *Mixing intensity is not constrained by reaction time*¹, channel length or pump capability*
- ✓ *Reaction time can be changed without affecting mixing intensity *¹*

Plug flow

Plug flow in CTRs and OBRs is linked to reactor length and fluid velocity. Axial dispersion in OBRs is affected by mixing intensity. Small inter stage channels in the ACR prevent back mixing irrespective of reactor length, velocity (within limits) or mixing intensity. ACR benefits:

- ✓ *Near zero back mixing between stages irrespective of reaction time or throughput*
- ✓ *Plug flow quality is independent of channel length*
- ✓ *Plug flow quality is independent of mixing intensity*²*

Pressure drop

In CTRs and OBRs, good plug flow is associated with long reactor lengths and good mixing is associated with high pressure drops (ΔP can exceed 1 bar/m). In the ACR there is no link between plug flow and reactor length and no link between pressure drop and mixing efficiency. With optimum mixing and maximum flow (based on water), the pressure drop through a 100 ml ACR is typically less than 25 mm water gauge. ACR benefits:

- ✓ *Low/stable pressure drop simplifies pump selection and flow metering calibration*
- ✓ *Gravity transfer can be used as an alternative to pump transfer for many applications*
- ✓ *Pressure drop declines as the reaction time is increased (without affecting mixing efficiency)*

Cavitation and gas/liquid mixtures

Gas bubbles in CTRs can accumulate in slugs, pockets or layers. Gas bubbles or cavitation in OFRs can impair the intensity and uniformity of mixing. Dynamic mixing in the ACR maintains uniform and well mixed dispersions independently of gas concentration. ACR benefits:

- ✓ *Efficient and uniform mixing when gas or vapour is present*

Reactor optimisation

OFRs and CTRs are fixed geometry systems. The ACR uses interchangeable agitator sets to optimise residence time distribution, mixing intensity and heat transfer capacity (per unit volume of product). ACR benefits:

- ✓ *Plug flow comparable to long CTRs (equivalent to >50 ideal stages) for 1st and 2nd order reactions*
- ✓ *Improved control of hot spots for 1st and 2nd order reactions*

Solids handling

As a general rule, slurries need large diameter channels, simple internal geometry and good mixing. CTRs only offer these characteristics in large high throughput systems. OBRs have a wider flow range by virtue of sustaining mixing in shorter (larger diameter) channels. OBRs however have to contend with a trade off between solids handling (which favours short channels and high mixing intensity) and good plug flow (which benefits from long thin channels and less intense mixing). Plug flow in the ACR is independent of length or mixing intensity and there is no conflict between good solids handling and good plug flow: ACR benefits:

- ✓ *Good solids handling characteristics*¹*

*¹ Similar claims can be made for the OFR

*² Similar claims can be made for CTR

ACR - Cost benefits

Dynamic mixing combined with stage separation gives multi stage CSTRs greater versatility and fewer performance constraints than either CTRs or OBRs. The ACR is a simple way of assembling and using multi stage CSTRs. The benefits it offers can make significant contributions towards higher productivity in process development plus improved yield, quality and cycle time in manufacturing operations.

ACR – Optimum performance for a broad range of reaction types and residence times

- ✓ *Reactor volume profile can be optimised for 0, 1st or 2nd order reactions by selecting different mixer sizes*
- ✓ *Reactor can be adapted for viscous liquids, slurries, catalysts etc by selecting different mixer types*
- ✓ *Reactor capacity can be altered by changing mixer sizes*
- ✓ *One reactor configuration can cover a very wide range of reaction times*
- ✓ *A wide range of fabrication materials can be used*

ACR - Lower peripheral costs

- ✓ *The ACR requires much lower pump heads*
- ✓ *The ACR can use gravity transfer for many applications*
- ✓ *Reduced build costs due to lower pressure drops*

ACR - Improved productivity

- ✓ *Reaction time can be changed without altering the reactor length*
- ✓ *Reaction time and mixing intensity can be changed without affecting pump flow calibration*
- ✓ *Reactor volume can be changed without changing the reactor block*
- ✓ *Reaction time can be changed on line with minimal effect on mixing or back mixing*
- ✓ *Mixing intensity can be changed without affecting reaction time or plug flow*
- ✓ *Reactor can be dismantled and reconfigured within 15 minutes*

ACR - Reduced raw material waste

- ✓ *Low minimum flow rates*
- ✓ *Short run times (1 reactor volume)*
- ✓ *Reduced start up/shut down losses (due to normal functionality when >10% full)*

