AM Technology

AGITATED CELL REACTORS

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16TH PROCESS INTENSIFICATION NETWORK MEETING

9th September 2008

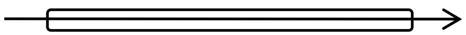
Agenda

- Practical considerations of using continuous reactors
- Agitated cell reactors

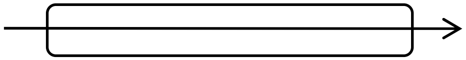
Reactor options

Scaling up reactors

Micro reactors



Tubular plug flow
(non micro) reactors

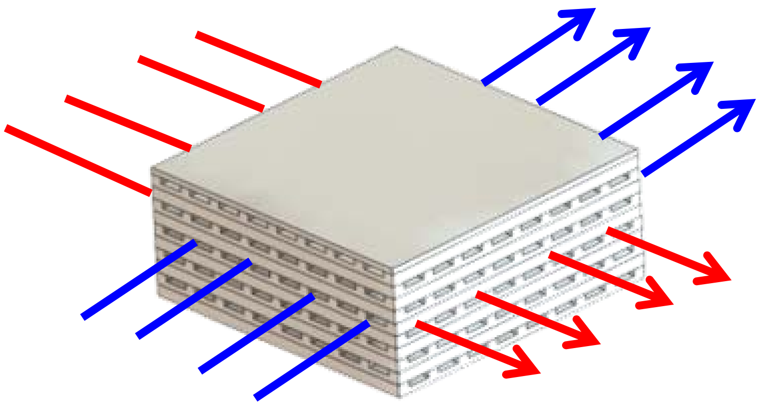


Micro reactors

Micro reactors provide good heat transfer and efficient mixing

But ....

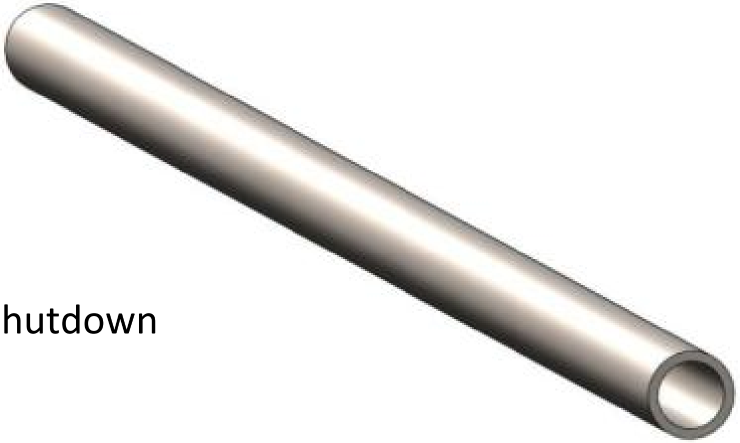
- Low flow capacity
- High pressure drop
- A tendency to block
- Problems with solids and gases
- Difficult to clean



Micro reactors generally have channel diameters of less than 1 mm

Tubular reactors

Larger tubular reactors overcome some of the limitations of micro reactors

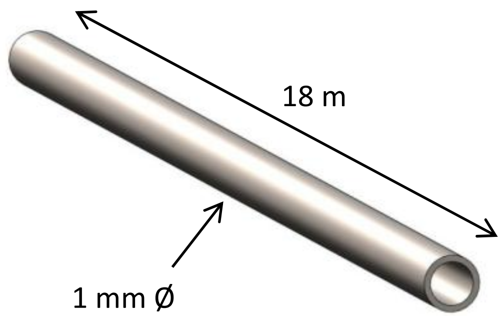


But ....

- Can suffer high pressure drops
- Inflexible
- Can be wasteful during start up and shutdown
- High minimum flow rate
- Can be physically large

Tubular reactors

10 second reaction



Flow	5 litres/h
Pressure drop	10 bar
Reaction time	10 seconds
Viscosity	1 cP
Flow condition	Laminar

Increase flow to 10 litres per hour

Channel length	35 m
Flow	10 litres/h
Pressure drop	**110 bar**

Increase viscosity to 10 cP

Channel length	18 m
Flow	5 litres/h
Pressure drop	**99 bar**

Reduce channel length to 1 metre

Channel length	1 m
Flow	**0.3 l/h**

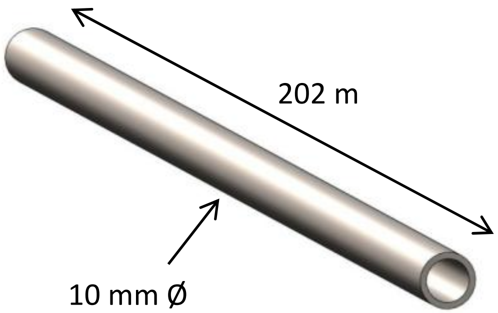
Reduce channel diameter to 0.5 mm

Channel length	1 8m
Flow	5 l/h
Pressure drop	**506 bar**

A channel size of 1 mm limits the capacity to handle solids and is easily blocked.

Tubular reactors

1000 second reaction



Flow 57 litres/h
Pressure drop 0.13 bar
Reaction time 1000 seconds
Viscosity 1 cP
Flow condition Turbulent

Reduce flow to <57 l/h
Flow **Laminar**

Increase reaction time to 2 hours
Flow (57 l/h) Turbulent
Channel length **1454 m**
Minimum flow 57 litres/h
Pressure drop 0.9 bar

Increase the viscosity to 10 Cp
Flow Turbulent
Channel length **2000 m**
Minimum flow **566 litres/h**
Pressure drop **128 bar**

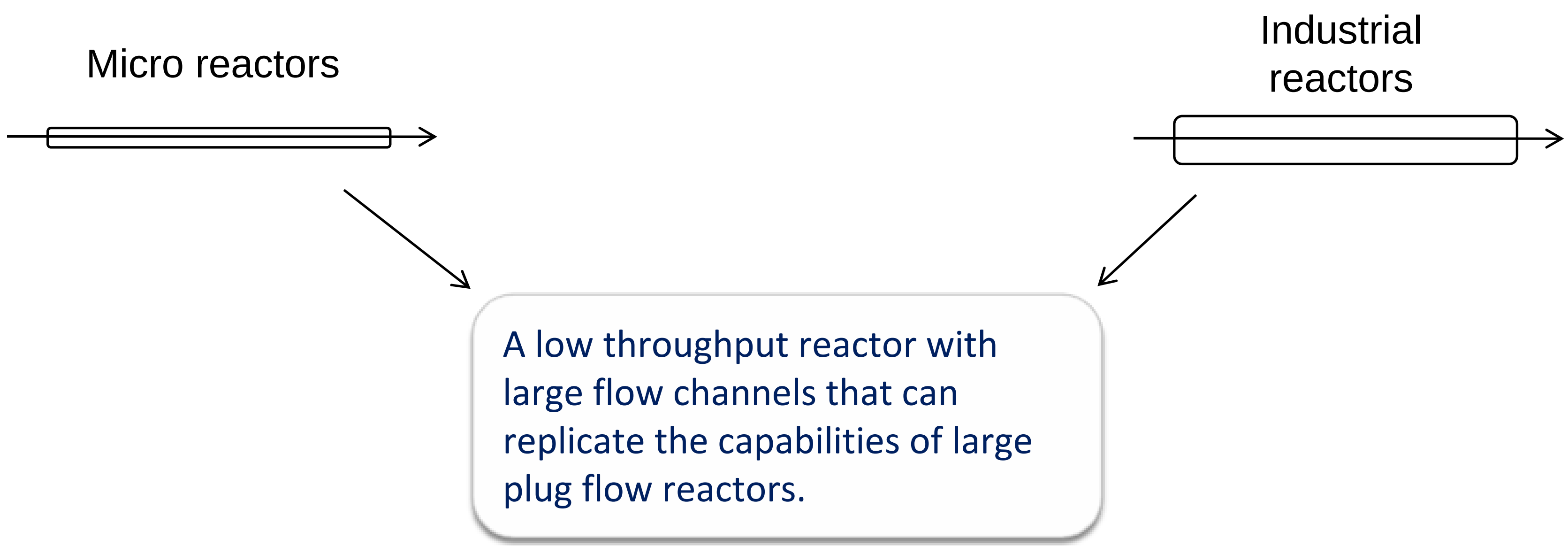
Increase the channel diameter
Bidirectional flow

Reactor options

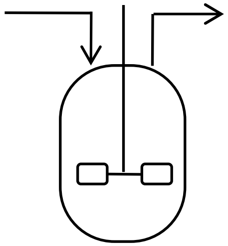
Scale up and scale down

Reactor options

Objective



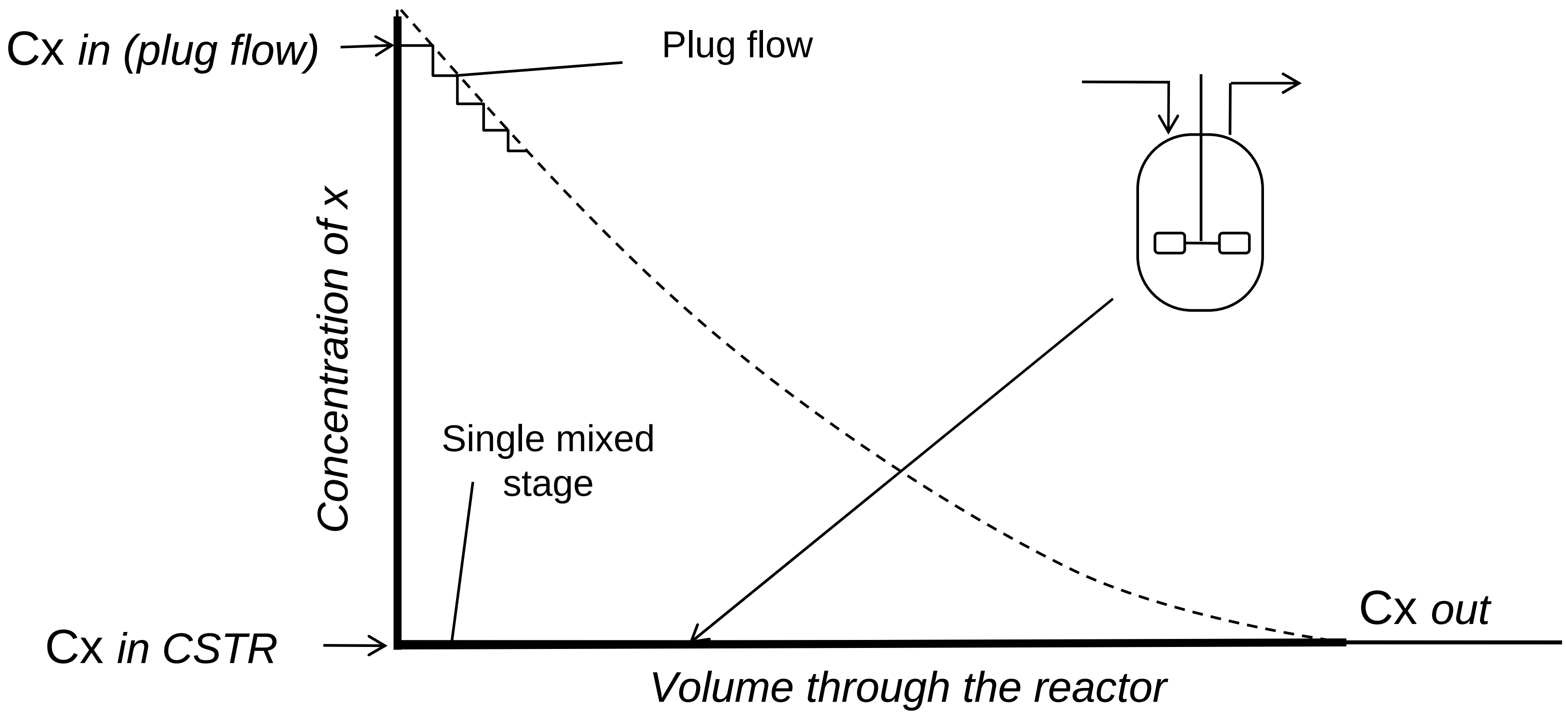
The continuously stirred tank reactor (CSTR) has significant advantages over PFRs.



- Very wide flow capacity range
- Low pressure drop
- Low tendency to block
- Good at handling solids and gases
- Compact size
- Low fouling problems
- Good mixing at high or low throughputs
- Turbulent flow at high or low throughputs

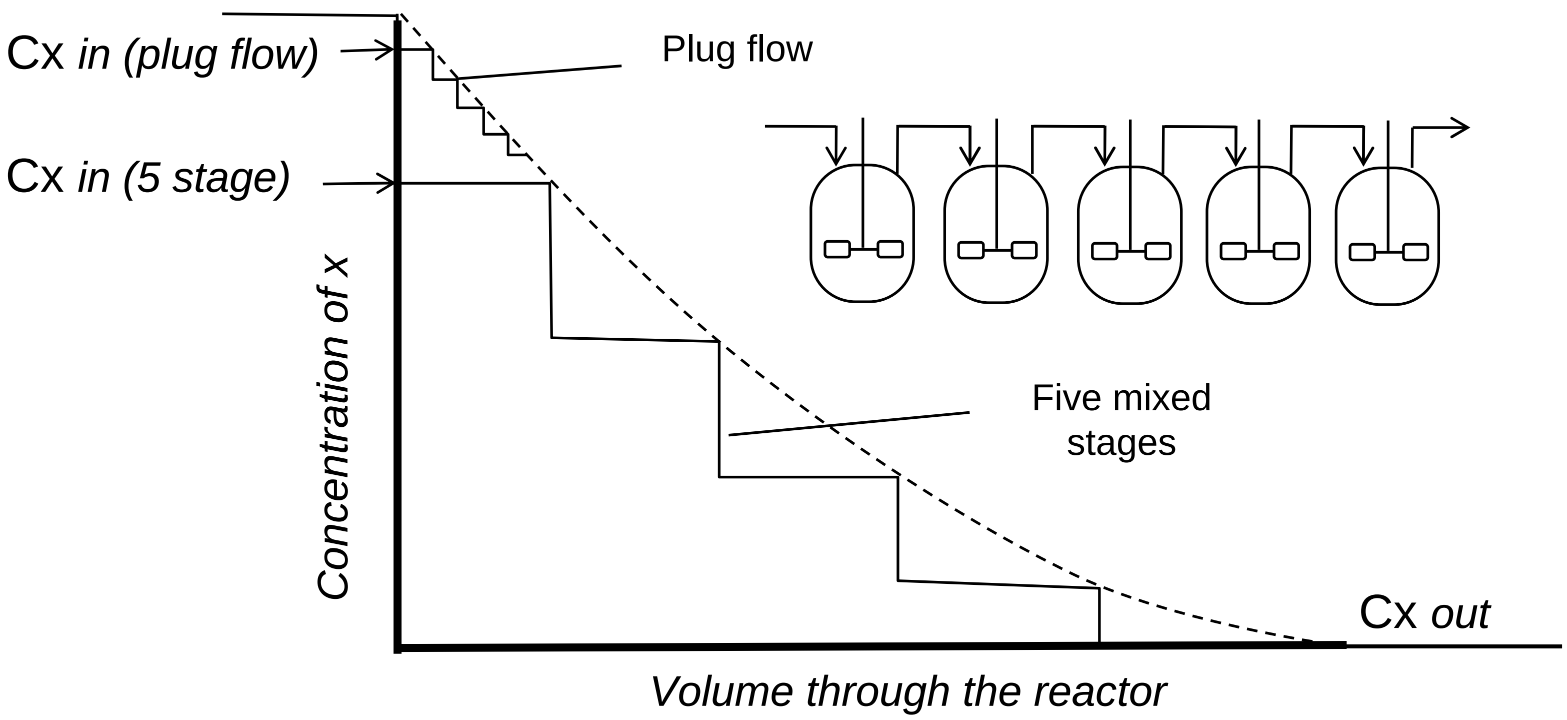
Plug flow reactors and CSTRs

The disadvantage with the CSTR is that the reactants are diluted and precise control of reaction time is not possible.



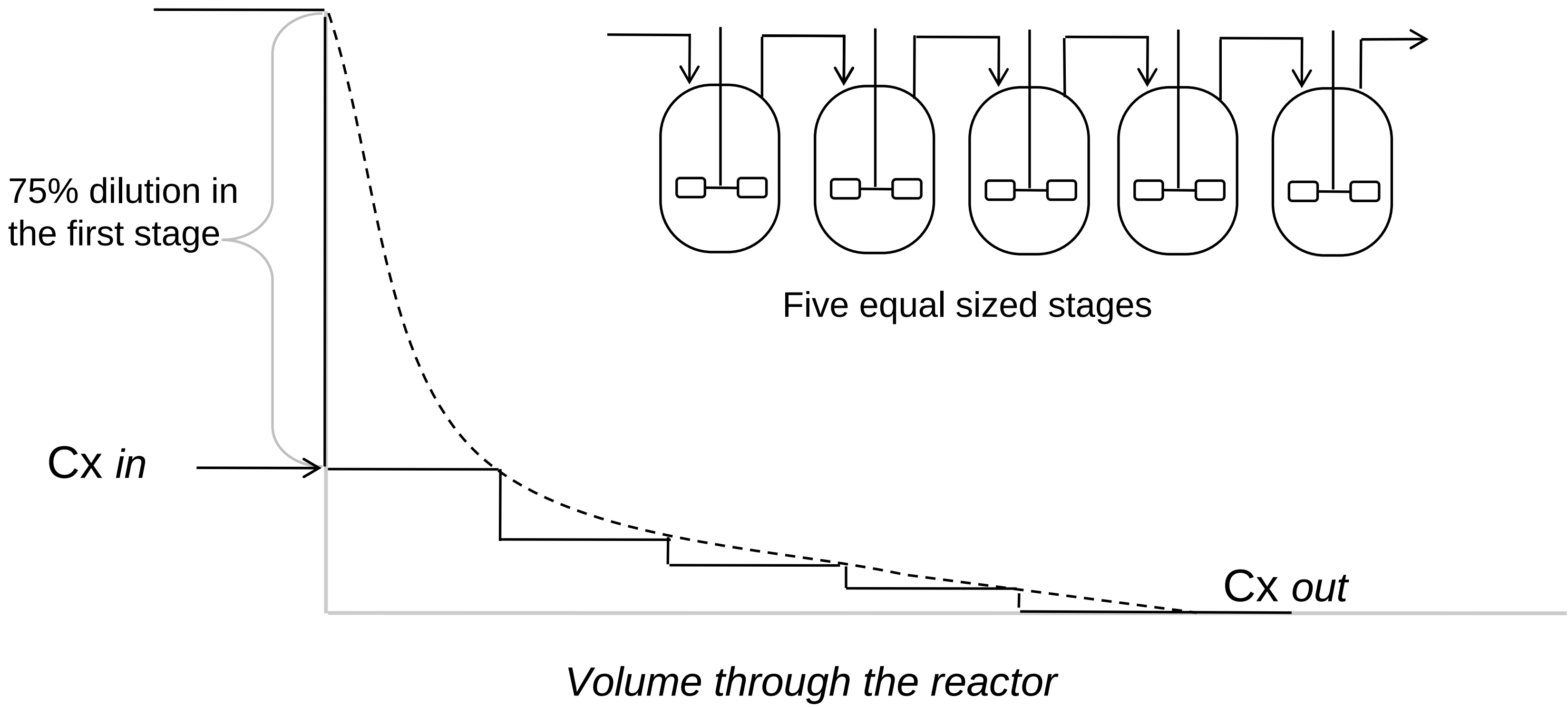
Plug flow reactors and CSTRs

These problems can be overcome by using multi stage CSTRs



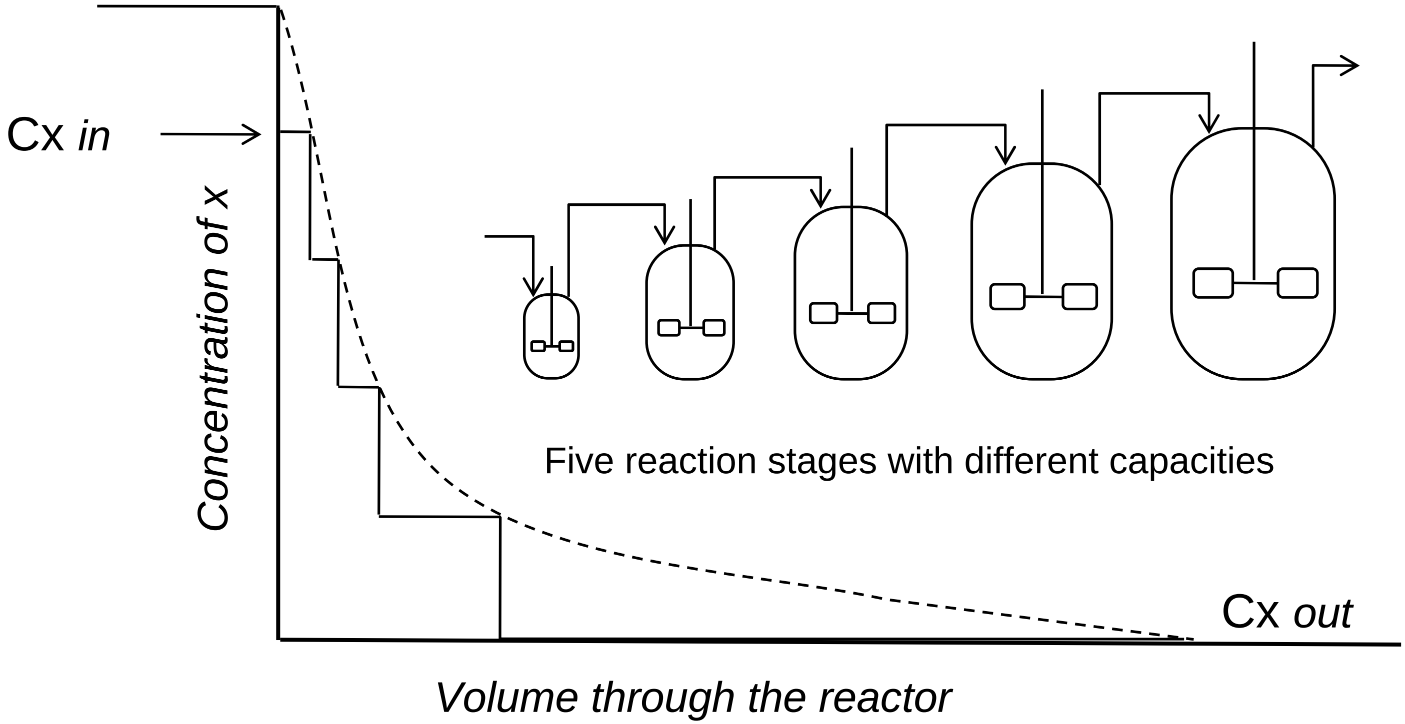
Multi stage CSTRs

Equal stage sizes however do not give optimum performance.



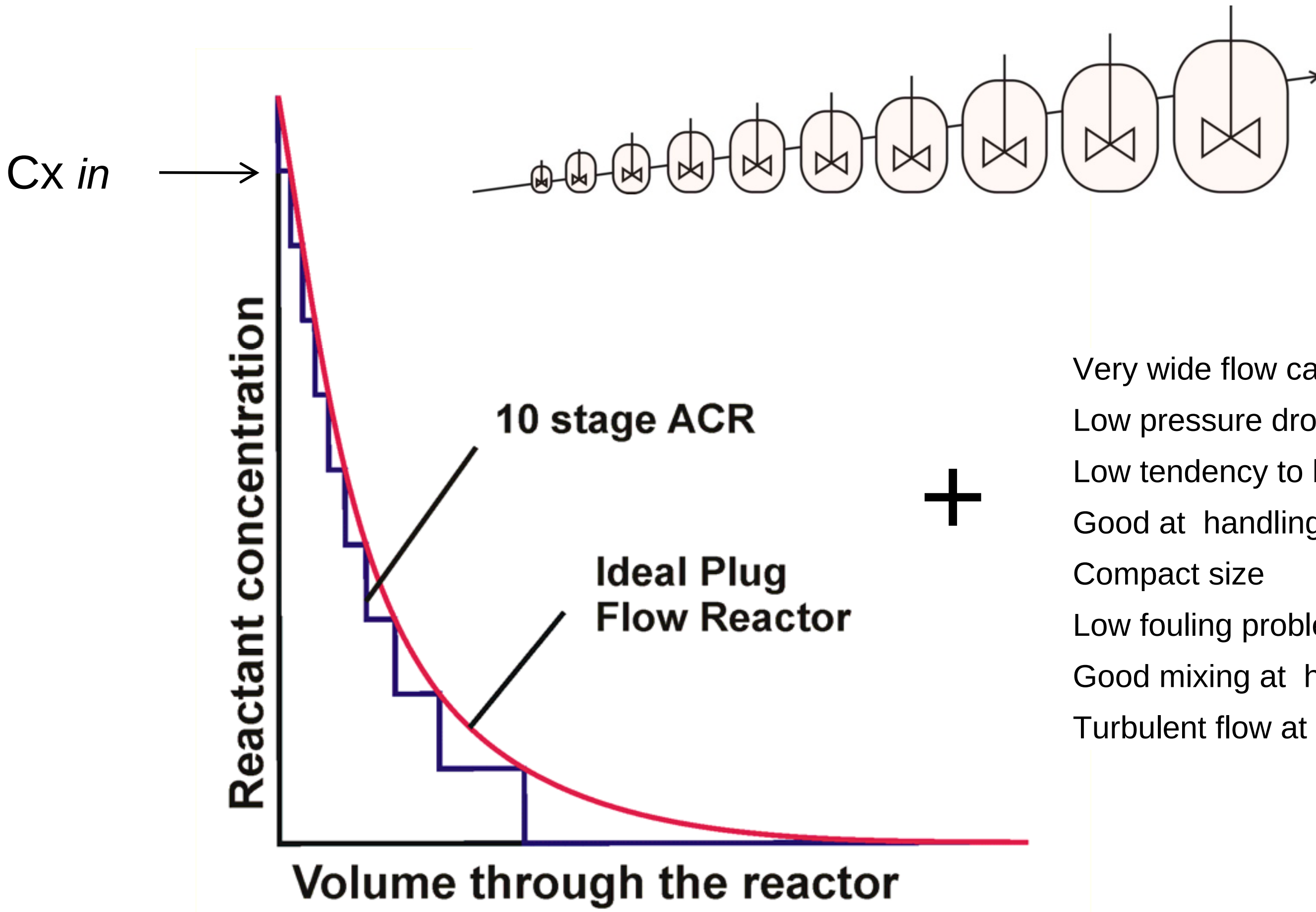
Multi stage CSTRs

Varying the stage size takes the system closer to an efficient PFR.



Multi stage CSTRs

Combining the best qualities of plug flow and stirred tank systems



\+

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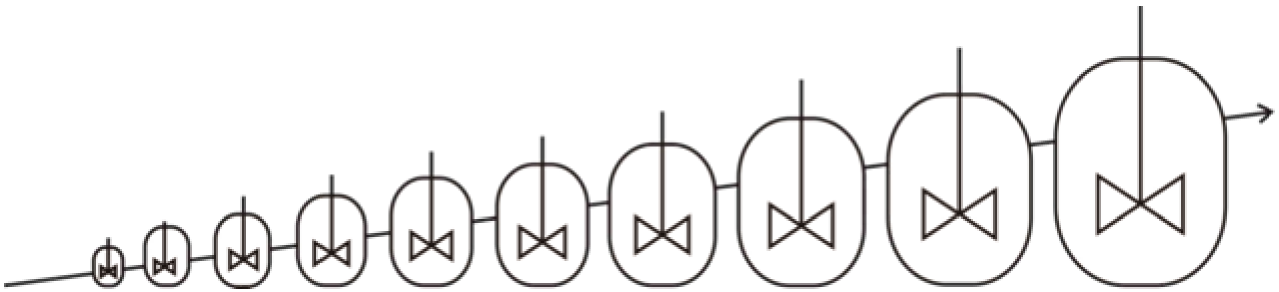
Multi stage CSTRs

Limitations of this design



- Build cost and complexity
- Vessels have to be replaced to modify the volumetric profile
- The heat transfer areas on each stage are different
- Product is wasted during start up or shut down

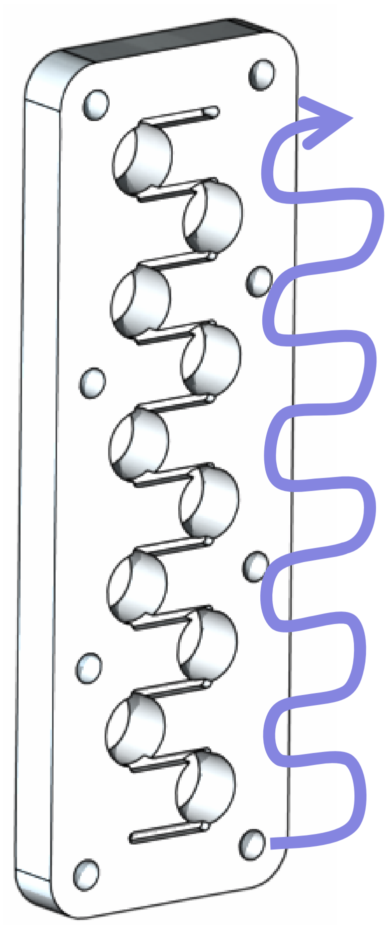
Agitated cell reactor (ACR)

Simplifying the design of multi stage CSTRs

Agitated cell reactor (ACR)

Designing a multistage reactor

A series of 10 stirred reaction cells linked by plug flow inter-stage channels.



Patents pending

Agitated cell reactor (ACR)

The core of the agitated cell reactor is the cell block with a series of 10 reaction cells

The front face is used for sight glasses, chemical addition, sampling and

The back face is used for temperature control

Agitated cell reactor (ACR)

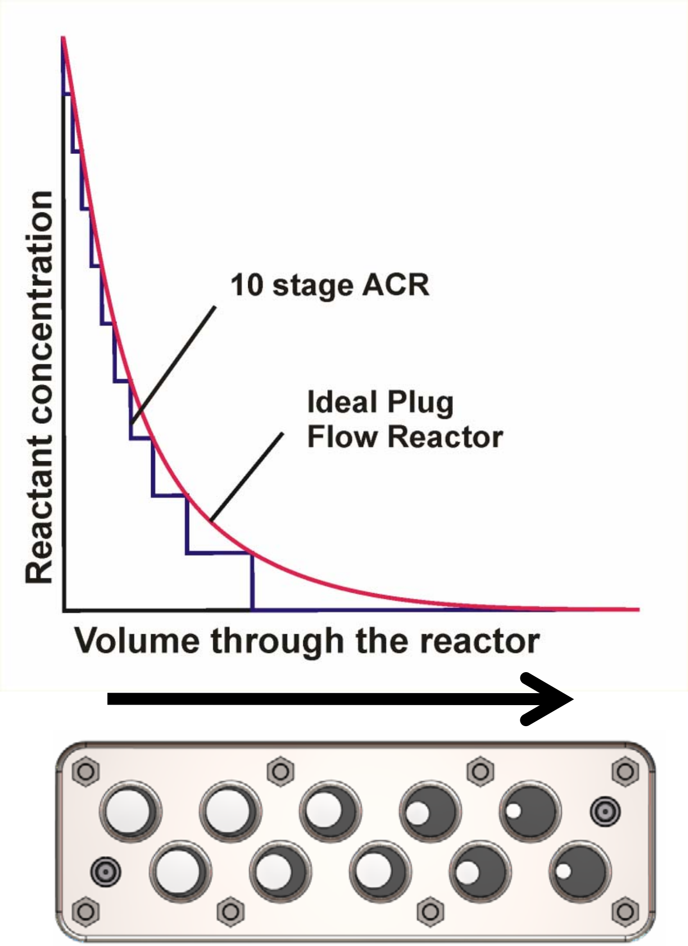
For agitation, loose elements are used

Agitated cell reactor (ACR)

The reactor block is mounted in an enclosure on an agitating platform

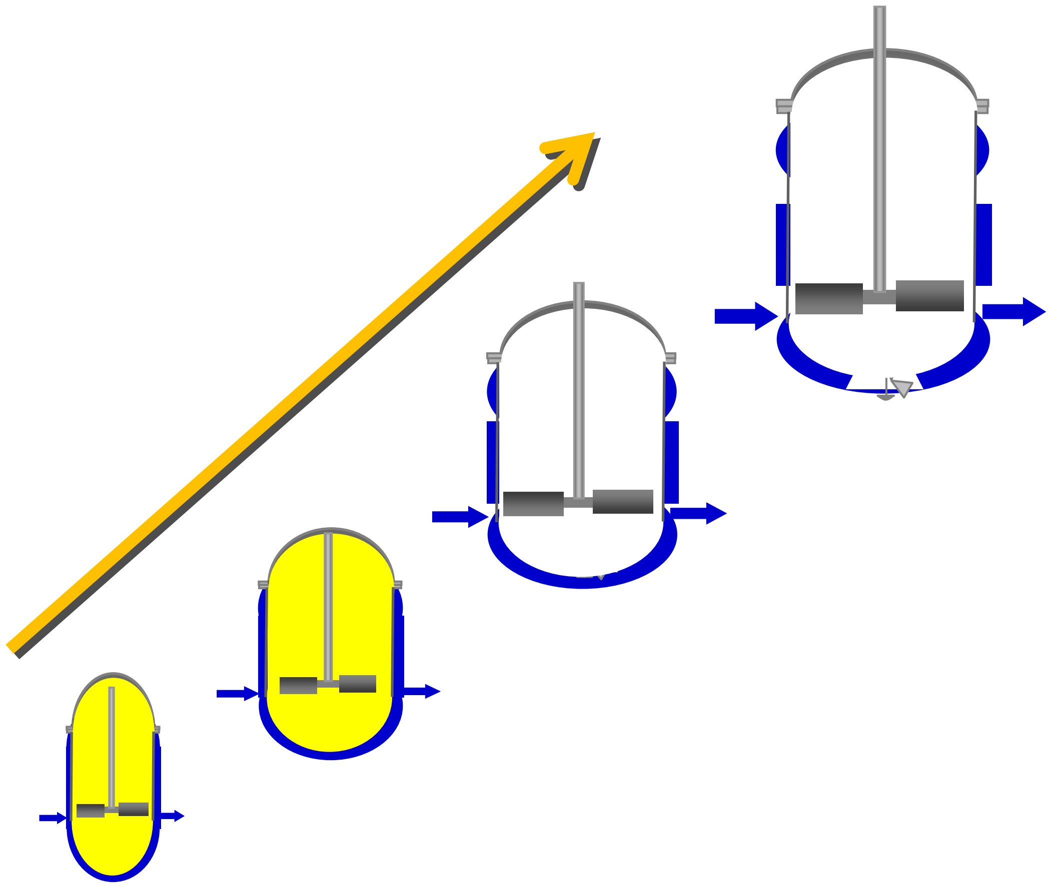
Agitated cell reactor (ACR)

Cell size is modified by altering the agitator/insert size



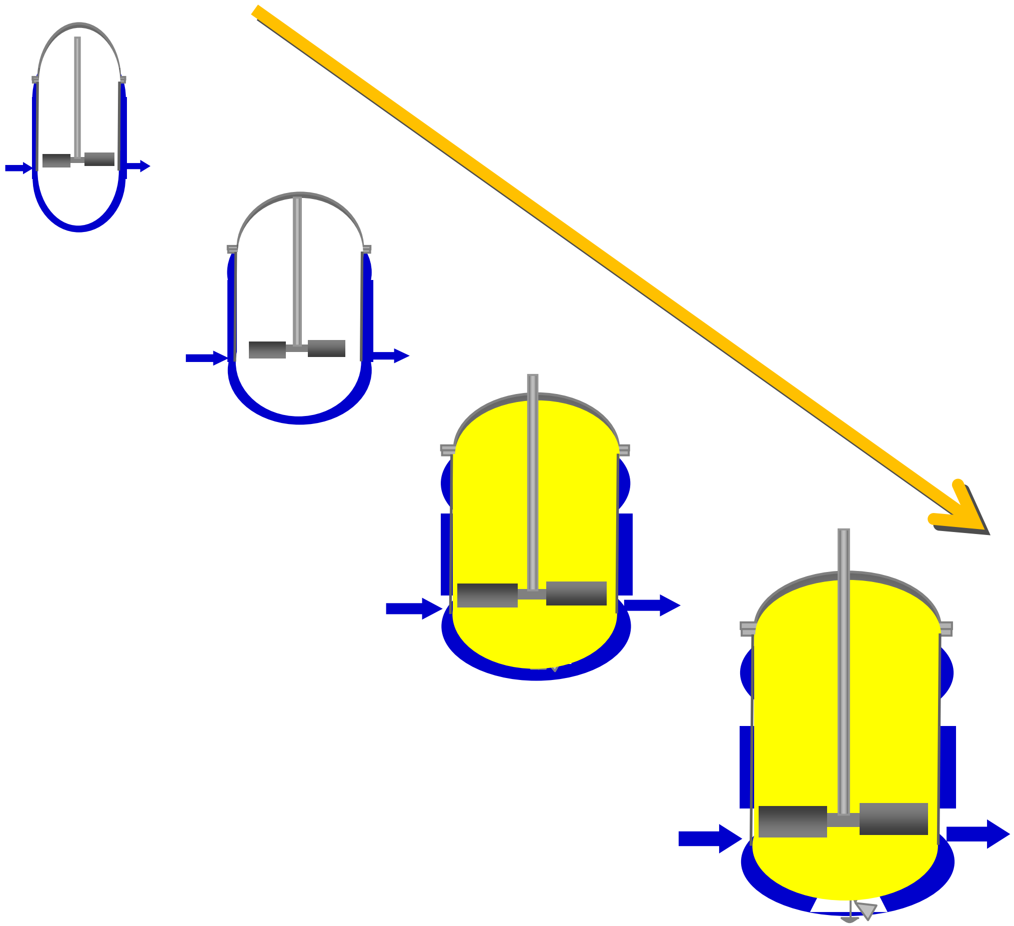
Agitated cell reactor (ACR)

Fill upwards to displace gas



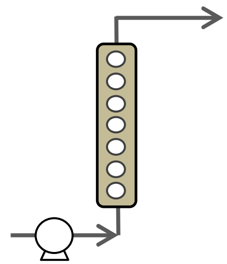
Agitated cell reactor (ACR)

Drain downwards to maintain direction of flow and avoid the need for buffer fluids

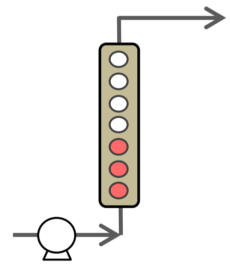


Agitated cell reactor (ACR)

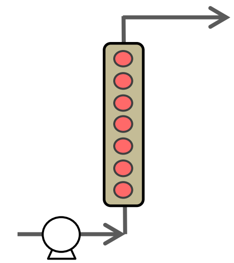
Inverting the reactor permits filling and emptying without buffer fluids and without changing the direction of flow or residence time.



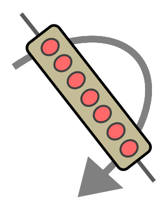
1. System empty at start up



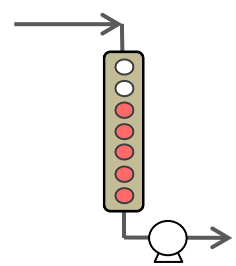
2. Cells fill from bottom up



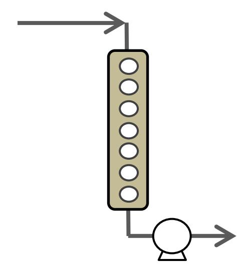
3. Normal running mode with cells full



4. At the end of the normal running cycle, the reactor is flipped over for discharge and drain down



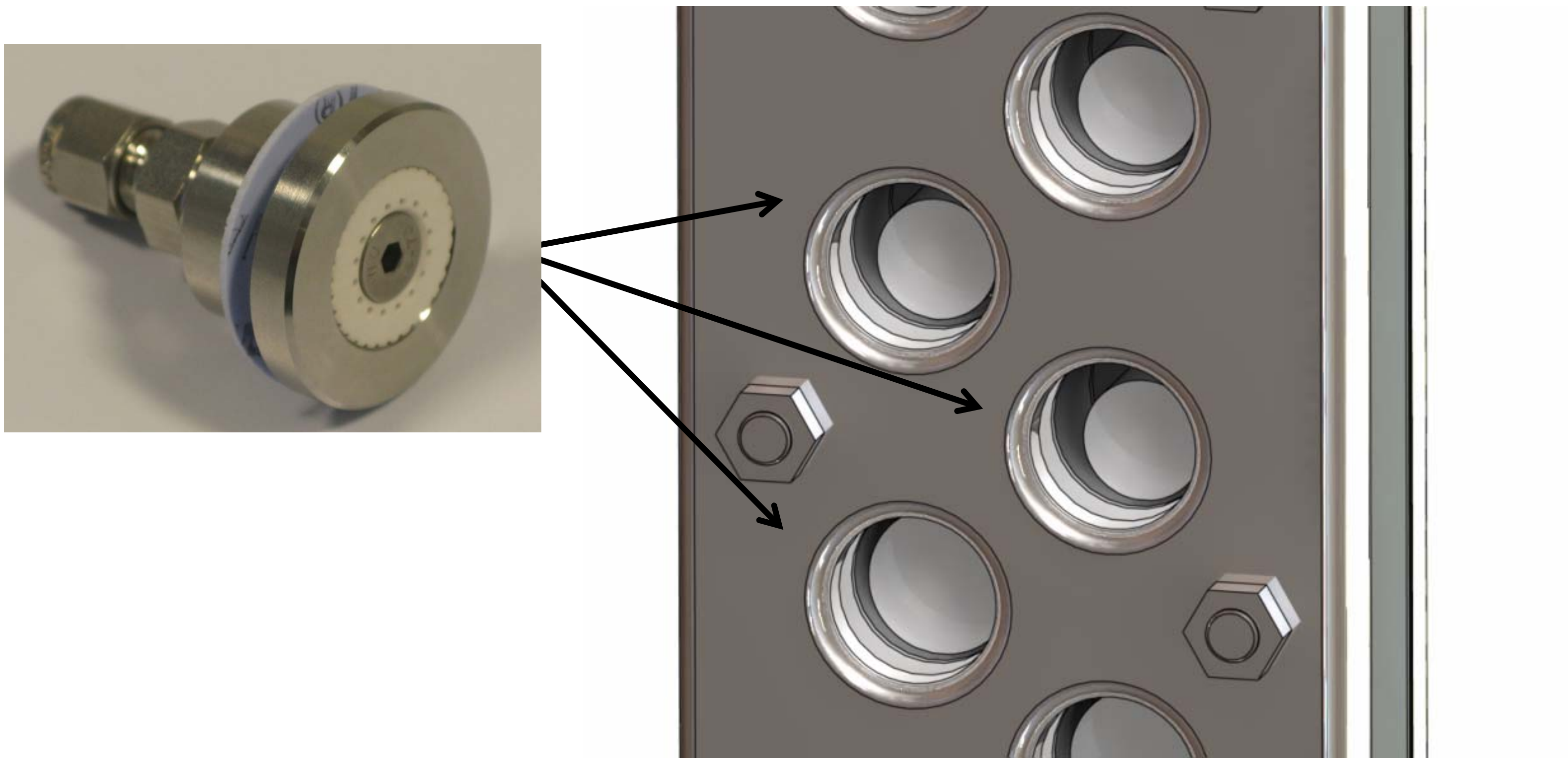
5. A discharge pump ensures constant flow rate is maintained during drain down



6. The product drains down maintaining the slug flow profile without the need for a buffer fluid to displace the product.

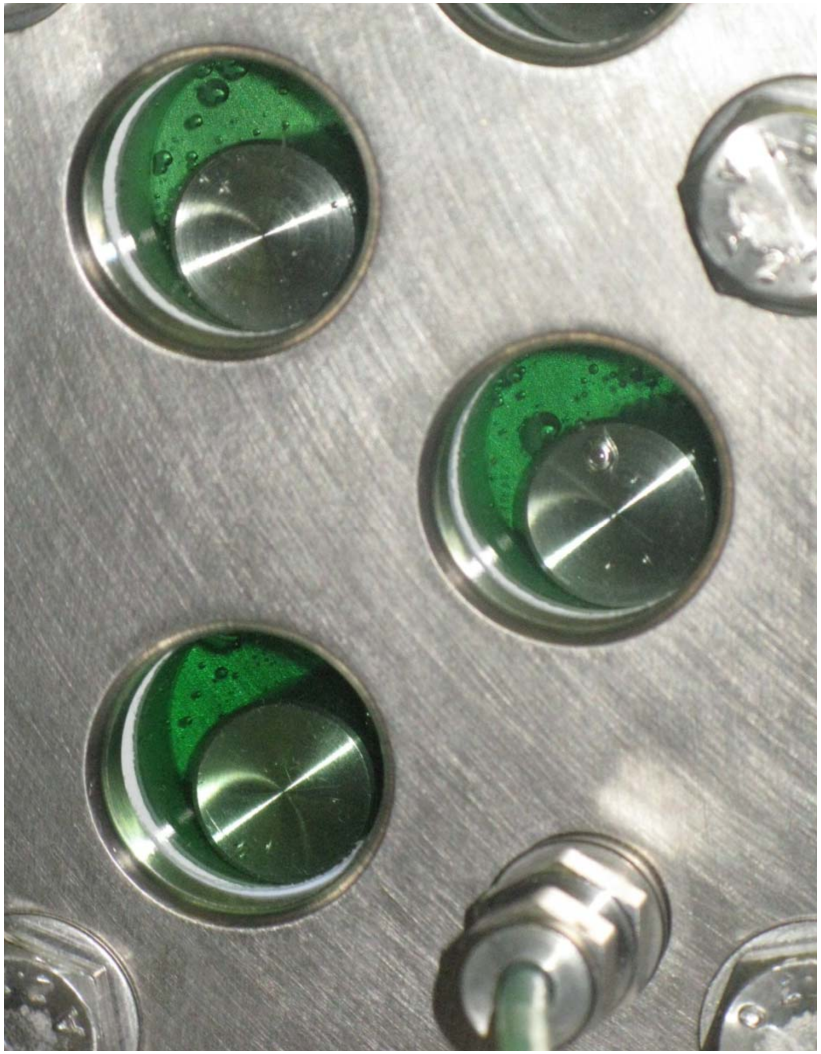
Agitated cell reactor (ACR)

Chemical addition can be made at any stage



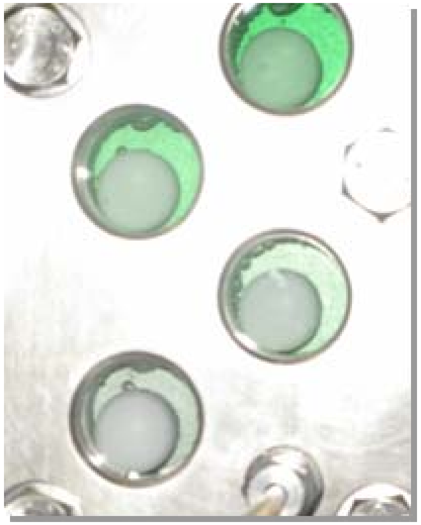
Agitated cell reactor (ACR)

Testing and evaluation



Agitated cell reactor (ACR)

Dye injection



Mixing

Agitated cell reactor (ACR)

Variable channel and agitated cell reactors

Combining ACR and VCR

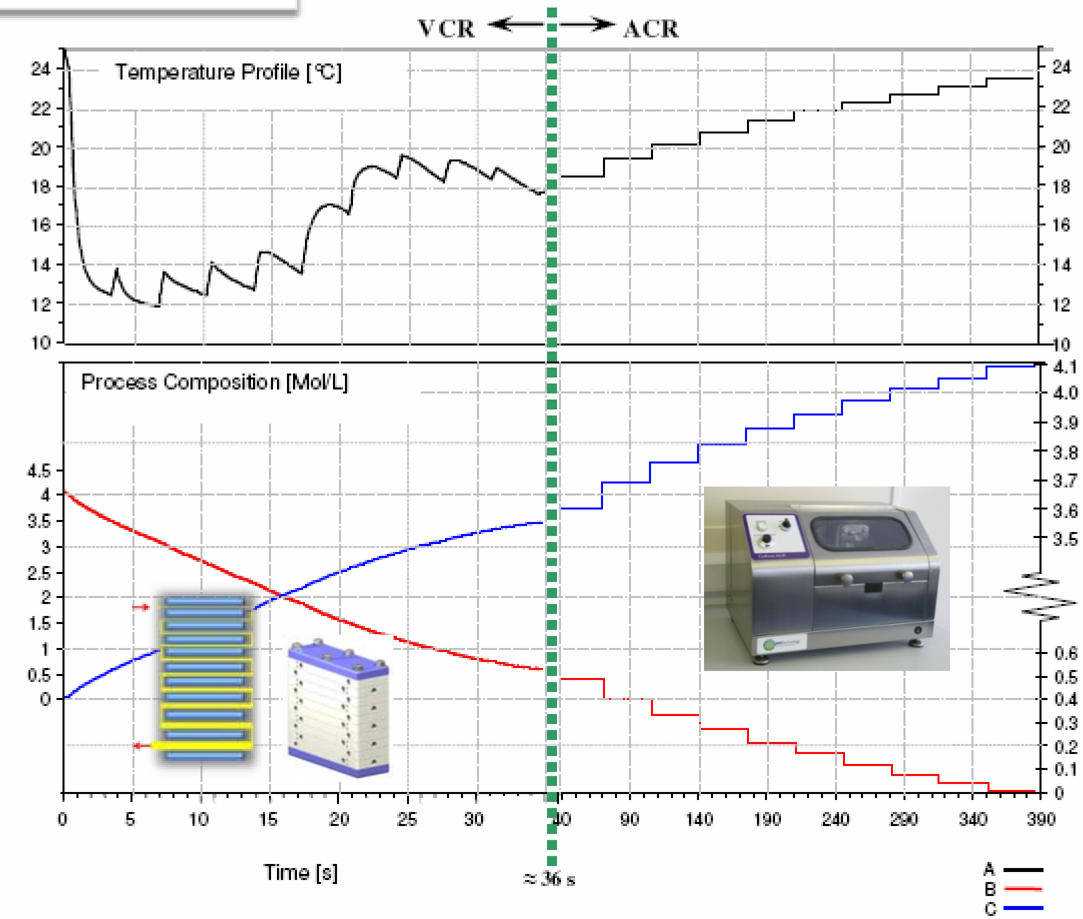


Figure 5.11. Process composition and temperature profile of material within the VCR and ACR through 1st principles models shows a near complete conversion of ≈99.6 %.

__NB:__ The cells of the ACR have uniform RTDs as the cells are devoid of agitation elements.

By permission of Imperial College

Thanks to:

Mayank Patel , Imperial College

Coflore™ ACR

Thank you

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Batch Reactors

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Process Intensification using Rotor Stator Devices