

Residence Time Distribution in the Coflore[®] ATR

This technical note focuses on the plug flow performance of the Coflore ATR. The Coflore ATR is a dynamically mixed flow reactor which utilises an innovative agitation mechanism designed to promote radial mixing and prevent back mixing. It employs a series of ten 100mL reactor tubes mounted on an agitating assembly. At its core is a versatile nature in terms of reaction times and its ability to handle multi-phase processes.



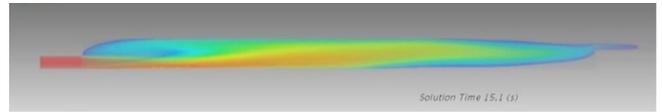
The Coflore[®] ATR continuous flow reactor

Plug flow denotes that fluid travels through the reactor in the same time order that it goes in. Aiming to get plug flow within the reactor is highly desirable, this is because it provides:

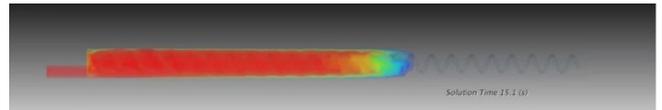
- Spatial segregation of products and reactants
- Control over residence time
- Elimination of stagnant or slow moving zones

Plug flow, however, is an ideal which is rarely accomplished by real reactors and mixing in some real reactors can be imperfect. Imperfect mixing can arise due to reasons such as the effects of axial mixing and surface friction within the tube.

These effects are highlighted in the CFD simulations below of a static tube. When the Coflore agitation technology is applied, a distinct plug flow profile develops in the tube.



CFD SIMULATION OF A STATIC TUBE



CFD SIMULATION WITH 5 HZ AGITATION

Deviation from plug flow depends on the fluid velocity, fluid characteristics (which are intrinsic of the process of interest), and of course reactor design. The use of dynamic mixing in the Coflore reactor decouples mixing and flow velocity. This allows reactions with long residence times to be run in a compact reactor volume without compromising on the quality of plug flow.

The purpose of this experiment was to evaluate the effects of various operating conditions upon plug flow in the Coflore ATR1. This was achieved with a series of step response residence time distribution (RTD) experiments. The RTD was determined by injecting a tracer, in this study NaCl salt solution, into the reactor at an initial time $t=0$ with the tracer concentration in the effluent stream measured as a function of time.

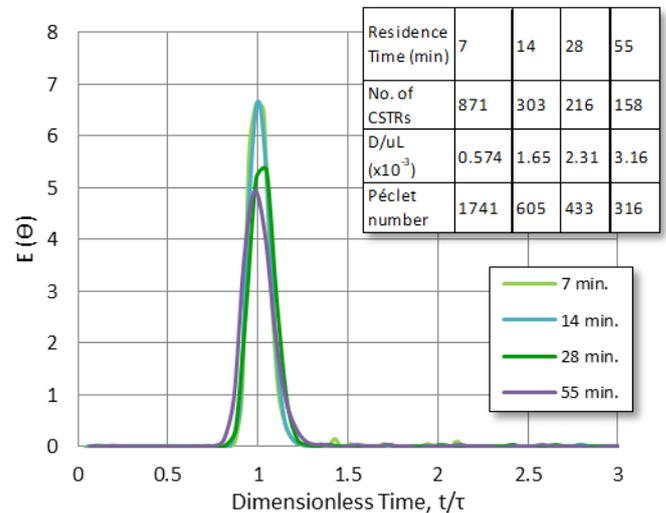
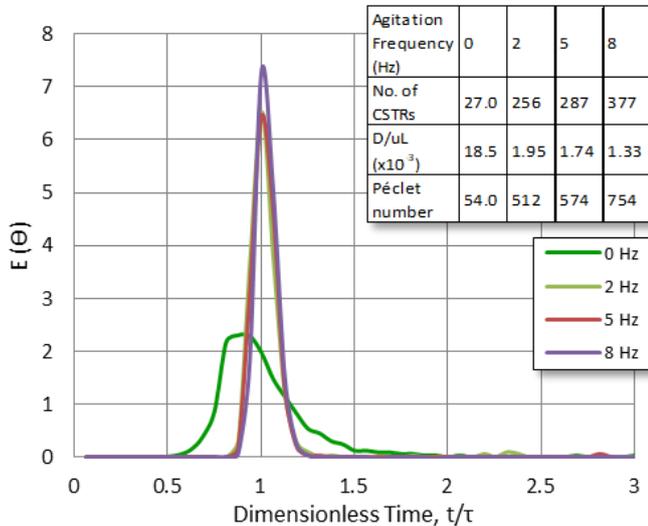
Deviation from ideal plug flow was quantified by calculating: equivalent number of CSTRs, N ; dispersion number, D/uL ; and Péclet number, Pe_L . The key variables that were investigated were agitation frequency, residence time, and scale up.

Agitation Frequency

Four agitation frequencies were investigated: 0, 2, 5, and 8 Hz. The 0 Hz (static tube) E Curve below can be seen to have a wider distribution as well as an early mean residence time and long tail. This is a sure sign of stagnant backwaters, typical of insufficient fluid velocity in static mixers. On the other hand, the three E Curves with agitation can be seen to have similar ideal plug flow 'spike' shaped curves. This is strong evidence proving that the Coflore ATR's innovative agitation technology is promoting plug flow by improving radial mixing.



Residence Time Distribution in the Coflore® ATR



Scale Up

One single Coflore ATR1 tube is equivalent to over 10 CSTRs in series. This makes the Coflore ATR1 a very simple and compact tool to carry out feasibility studies with minimum reactants requirements and reduced costs. In fact, as the process is scaled up to 10 tubes, plug flow is further improved (up to 870 CSTRs in series). This suppresses consecutive side reactions even more and guarantees a seamless scale up process.

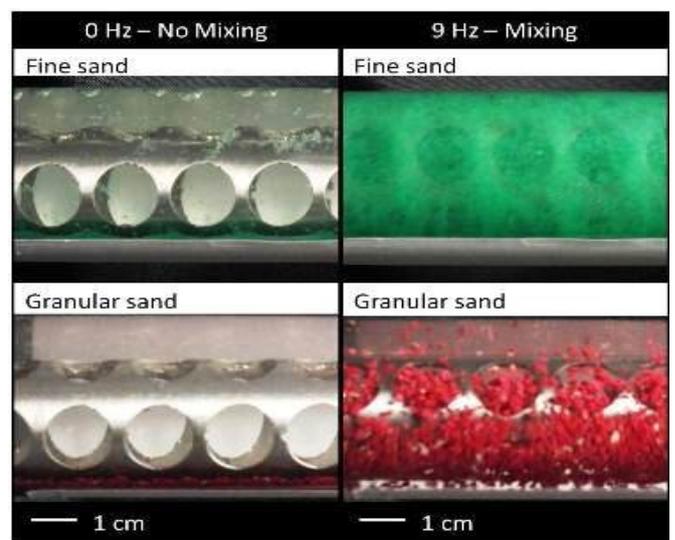
Number of tubes		1	10
Equivalent number of CSTRs	N	10.4	870.7
Dispersion number	D/uL	0.0479	0.000574
Péclet number	Pe _L	20.8	1741.4

Residence Time

Four residence times were investigated: 7, 14, 28, and 55 minutes. Each run achieved true plug flow ($D/uL < 0.01$). This proves that the use of radial mechanical agitation decouples plug flow from residence time (or fluid velocity). Additionally, in all cases steady state was reached after 1.3 reactor volumes. This increases residence time control and reduces waste upon start up and shutdown.

The residence time distributions that formed the basis of this technical note provided proof of Coflore ATR1's successful design and a step change in its characteristic understanding. The Coflore ATR1 displayed plug flow with:

- Variable agitation
- Flexible volume
- A range of residence times



Static vs dynamic mixing in the Coflore® ATR

