



Mixing

Process characteristics at a glance:

Reaction: 3rd and 4th Bourne Reaction
Temperature: Ambient
Pressure: 1 bar A
Phases: homogeneous

Keywords: Flow reactor, pressure drop, micromixing, plug flow reactor

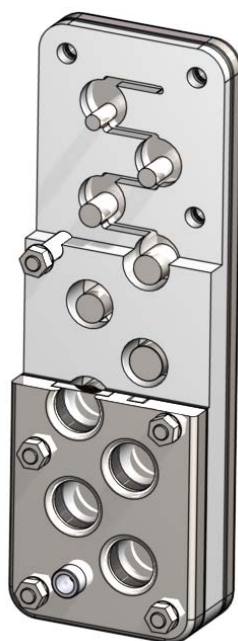


Figure 1. Coflore ACR reactor. Product flows through a series of ten stirred cells under temperature controlled conditions

The Coflore™ Agitated Cell Reactor (ACR) is a multi-purpose flow reactor designed for laboratory and small scale manufacturing. By separating the flow channel into a series of discrete cells with independent dynamic mixers, it offers good plug flow, low pressure drop and good mixing over a much wider range of operating conditions than can be achieved in static mixers or tubular reactors. The ACR is also good with slurries, immiscible fluids and gas/liquid mixtures.

In this study, mixing and pressure drop in the ACR were compared to a static mixer (Kenics HEM).

The Bourne reactions were used to compare the mixing performance of a 10 cell 100 ml Coflore ACR (figure1) with a Kenics HEM static mixer (72 mm long and ¼ inch diameter). The ACR also used an injection nozzle (figure 2)

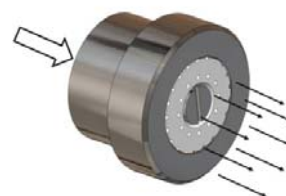
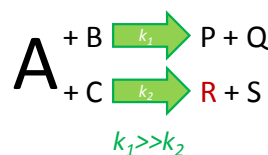


Figure 2. Injection nozzle used by the ACR

Although the 3rd and 4th Bourne reactions are different, both are sensitive to poor mixing. Chemical A is added as a limiting reagent. Under well mixed condition, A is consumed by B as the reaction $A + B \rightarrow P + Q$ is much faster than $A + C \rightarrow R + S$. If areas of segregation are present however, A and C can interact to produce unwanted product R. By measuring the concentration of R it is possible to quantify mixing, and in particular micromixing.



Experimental Set Up

The 3rd and 4th Bourne reactions are competitive/consecutive reactions which are sensitive to mixing. This makes them well suited to this kind of study.

Component R in the 3rd Bourne reaction is Ethanol (EtOH) and in the 4th Bourne reaction, methanol (MeOH). The yield of R (X_R) is expressed in relation to initial concentration of the limiting reagent A and varies from 0 to 1.

Results

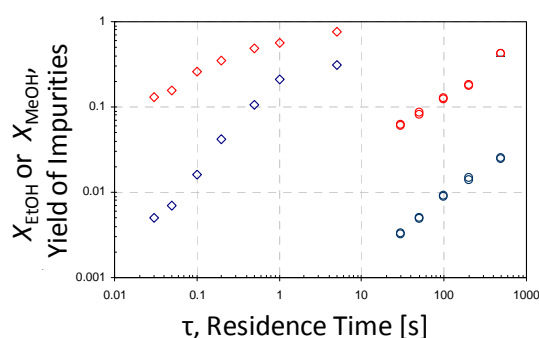


Figure 3. Impurity formation versus residence time
 Legend: ACR (EtOH = \circ ; MeOH = \circ), Kenics HEM static-mixer (EtOH = \diamond ; MeOH = \diamond),

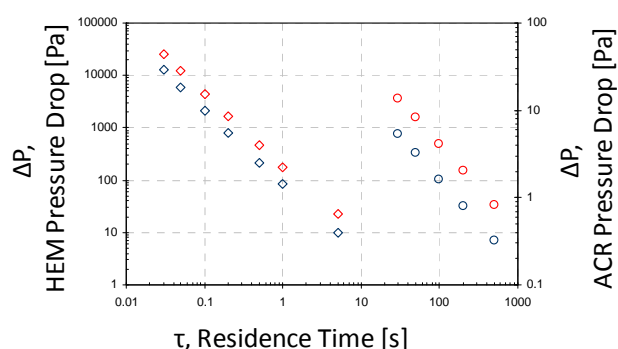


Figure 4. Pressure drop versus time
 Legend: ACR (EtOH = \circ ; MeOH = \circ), Kenics HEM static-mixer (EtOH = \diamond ; MeOH = \diamond).

The Bourne reaction provides a means of comparing mixing efficiency in different types of process equipment. Higher levels of unwanted component R are formed under conditions of poor mixing. The 4th Bourne reaction is faster than the 3rd Bourne reaction and therefore generates higher levels of R under comparable mixing conditions.

At 30 seconds residence time, the ACR delivered better mixing than the Kenics mixer at any residence time with both Bourne reactions. Had the ACR been tested at shorter residence times, the results point to further improvements in mixing efficiency.

The Kenics mixer had a very narrow operating range and residence times of over 1 second resulted in very poor mixing efficiencies. This is due to the fact that it relies on static mixing.

In terms of residence time, the ACR had an operating range which was orders of magnitude greater than the Kenics HEM. The moderate reduction in mixing performance with longer reaction times can be attributed to lower injection velocities through the feed nozzle for component A. This can be corrected for by using smaller injection nozzles.

The pressure drop in the Kenics mixer was also seen to be substantially greater than the ACR. Based on the results from Figures 3 and 4, a 100 second reaction in the Kenics mixer (with mixing conditions equivalent to <2% R in the 3rd Bourne reaction) would result in a pressure drop of >30 bar. The equivalent pressure drop in the ACR would be less than 0.001 bar.

Discussion

Mixing brings reactants together, promotes good temperature control and prevents bypassing. For many flow processes, efficient mixing is the key to optimum quality, yield and cycle time.

The ACR delivered better mixing than the Kenics static mixer. It also gave a residence time range (for efficient mixing) that was orders of magnitude greater than the Kenics device. This can be attributed to the ACR's use of dynamic mixing. The ability to vary reaction time without compromising mixing efficiency is a valuable feature for any flow reactor and particularly so for process development

The results also indicate that good design of the injection nozzle can make a useful contribution to mixing efficiency at the point where two chemicals are mixed.

Pressure drop through the ACR was orders of magnitude lower than the Kenics HEM. This again demonstrates the advantages of dynamic mixing. Low pressure drops are particularly desirable as they reduce the problem of pump selection and wear.

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