



## Coflore™ ACR Technical Note Series

### Flow Reactor Tackles Mixing Problems

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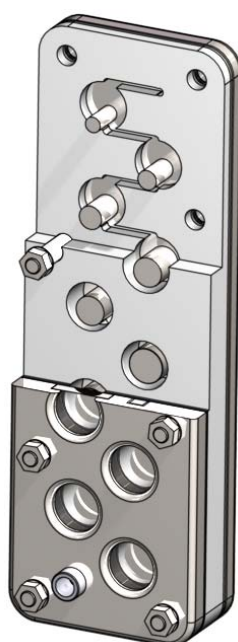


# Mixing Efficiency

**Process characteristics at a glance:**

**Reaction:** 3<sup>rd</sup> and 4<sup>th</sup> Bourne Reaction  
**Temperature:** Ambient  
**Pressure:** 1 bar A  
**Phases:** homogeneous

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

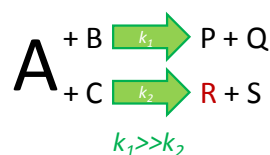


**Figure 1.** Coflore ACR reactor

*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 duties. By separating the flow channel into a series of discrete cells with independent dynamic mixers, it offers plug flow, low pressure drop and good mixing over a much wider range of operating conditions than PFRs or static mixers. It can also handle materials that would block a micro reactor.

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



The 3<sup>rd</sup> Bourne reaction is comparatively slow and this was performed in a 2 litre batch reactor (with variable speed agitator), a Kenics HEM static mixer (72 mm long and ¼ inch diameter) and a 10 stage Coflore ACR (maximum capacity of 100 ml). The 4<sup>th</sup> Bourne reaction was also performed, however, being much faster than the 3<sup>rd</sup> Bourne; this experiment was limited to the Kenics HEM and the ACR.

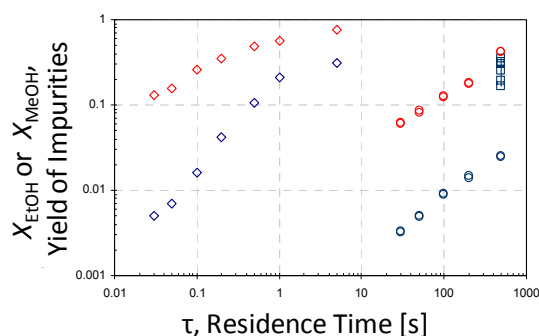
Chemical A is added as a limiting reagent. If the system is well mixed, A is quickly consumed by B (the reaction  $\text{A} + \text{B} \rightarrow \text{P} + \text{Q}$  is much faster than  $\text{A} + \text{C} \rightarrow \text{R} + \text{S}$ ). If areas of segregation are present however, A and C can interact, giving the unwanted product R. By measuring the concentration of R it is possible to quantify the mixing, (and in particular micromixing).

The unwanted component R in the 3<sup>rd</sup> Bourne reaction is Ethanol (EtOH) while for the 4<sup>th</sup> Bourne reaction it is Methanol (MeOH). The value of  $X_R$  is the yield of R and it varies from 0 to 1. This value is expressed in relation to the initial concentration of the limiting reagent A as follows.

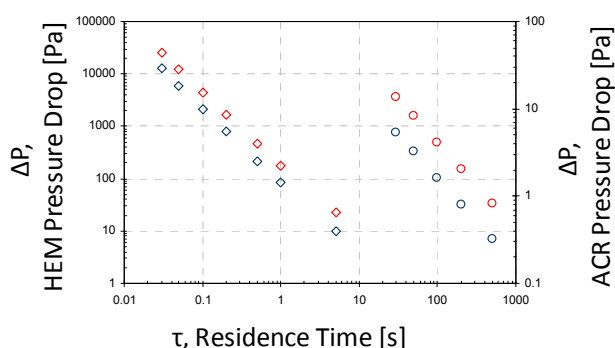
$$X_R = \frac{c_R \cdot V_{reactor}}{mol_{A,0}}$$

The 3<sup>rd</sup> and 4<sup>th</sup> Bourne reactions are competitive reactions which are sensitive to mixing. This makes them ideal for this kind of study:

## Results



**Figure 2. Impurity formation versus residence time**  
 Legend: ACR (EtOH =  $\circ$ ; MeOH =  $\circ$ ), Kenics HEM static-mixer (EtOH =  $\diamond$ ; MeOH =  $\diamond$ ), batch vessel (EtOH =  $\square$ ).



**Figure 3. Pressure drop versus time**  
 Legend: ACR (EtOH =  $\circ$ ; MeOH =  $\circ$ ), Kenics HEM static-mixer (EtOH =  $\diamond$ ; MeOH =  $\diamond$ ).

## Discussion

Both the 3<sup>rd</sup> and 4<sup>th</sup> Bourne reactions gave higher levels of the unwanted component R under conditions of poor mixing. Being a much faster reaction, the 4<sup>th</sup> Bourne tended to generate significantly higher levels of R (than the 3<sup>rd</sup> Bourne) under comparable conditions.

All experiments indicated a clear correlation between longer reaction times and higher impurity levels. This can be attributed to better mixing associated with short reaction times (due to higher fluid velocities). Because the ACR uses dynamic mixing however, its sensitivity to reaction time is dramatically lower than that of the Kenics mixer.

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In the 3<sup>rd</sup> Bourne reaction for example (figure 2) the Kenics HEM generated levels of R in excess of 20% for reaction times of as little as 1 second. This compares to <0.3% for the ACR at 20 seconds. With very short residence times (<0.1 seconds) the Kenics HEM provided good mixing. This however equates to a throughput in excess of 70 kg/hr.

For the same residence time the mixing performance of the ACR was significantly better than that of the stirred tank

At a residence time of 0.1 seconds, the Kenics HEM gave good mixing (3<sup>rd</sup> Bourne) and a pressure drop of 0.03 bar (figure 3). To sustain this level of mixing for a reaction time of 100 seconds however requires a Kenics mixer 72 metres long giving a total pressure drop of 30 bar. The pressure drop in the ACR (for efficient mixing at 100 seconds) was 0.0001 bar.

## Conclusions

The Agitated Cell reactor (ACR) is designed for throughputs of 10 – 2000 g/hr. By using multiple stirred cells it is able to maintain good mixing and plug flow independently of throughput. The comparatively large flow channels also give the ACR good tolerance to solids. The results demonstrate:

- Good micromixing was achieved in the ACR for residence times of up to 500 seconds. Mixing performance in the 72 mm Kenics HEM was limited to short residence times (<0.5 seconds) and high throughputs.
- For a 100 second reaction (under well mixed conditions) the pressure drop in the ACR was orders of magnitude lower than that of the Kenics HEM.