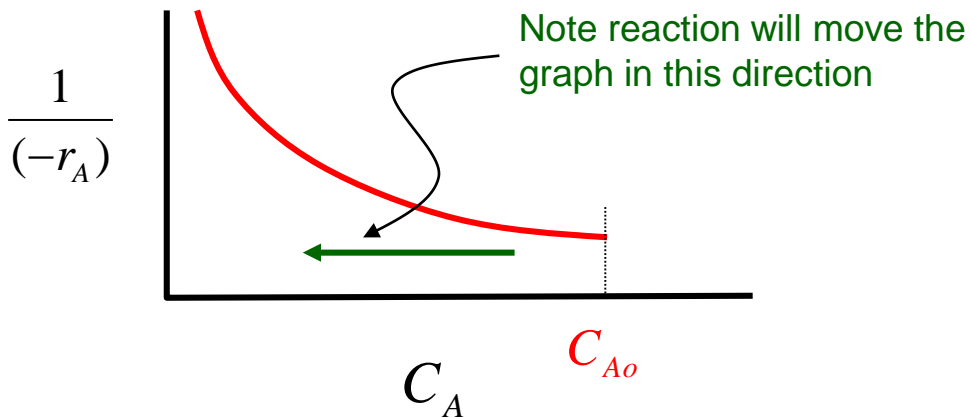
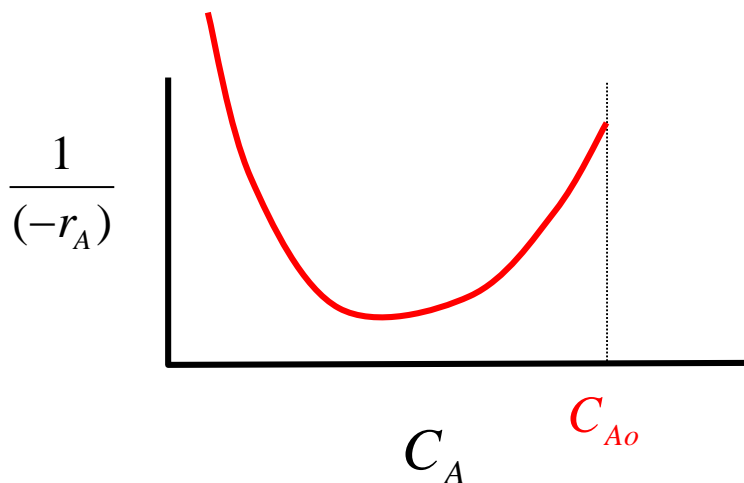


# THE LEVENSPIEL PLOT

Levenspiel developed a method to visualise the difference between mixing and non-mixing in reactors. We start by representing the reaction kinetics on the following graph:

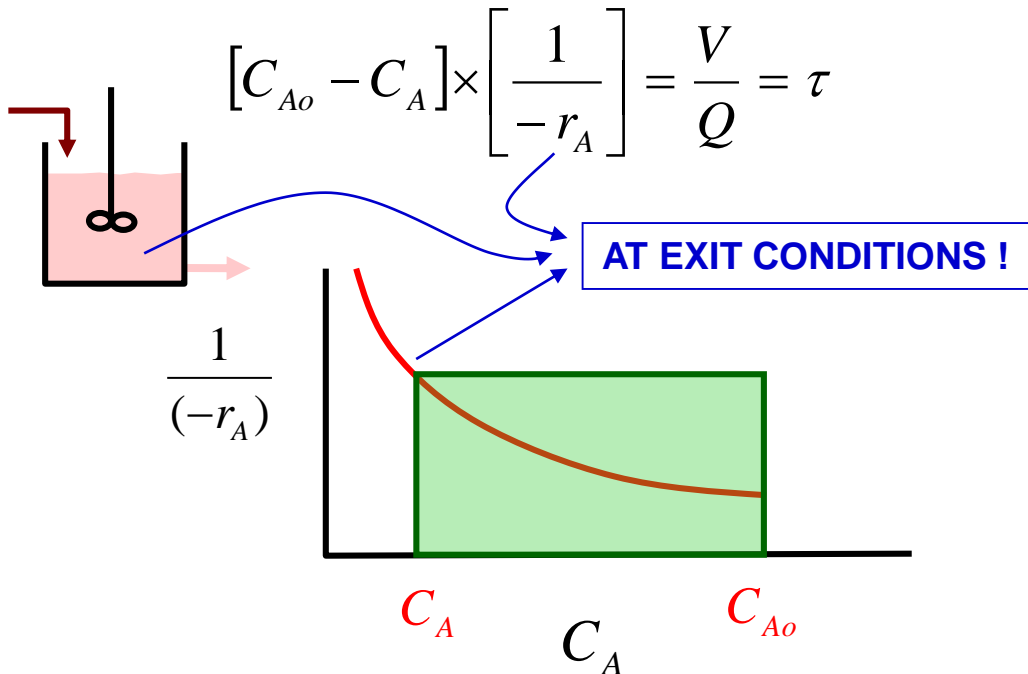


The graph above represents a first order reaction. Note that the inverse of rate increases with decreasing concentration (reaction progression). An autocatalytic reaction will have the following plot:



# THE LEVENSPIEL PLOT

For a liquid phase reaction (or a gas phase with  $\varepsilon=0$ ), we can visualise the CSTR and PFR mole balance on the Levenspiel plot. For the homogeneous CSTR you should be able to prove to yourself that:



Note the area (residence time) is given by width times height. We always use the exit concentration since this the concentration at which the rate operates!

For catalysed reactions we use mass time:

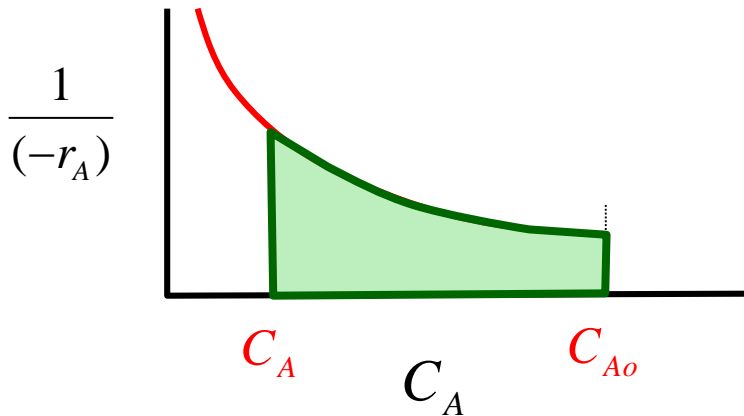
$$[C_{Ao} - C_A] \times \left[ \frac{1}{-r_A'} \right] = \frac{W}{Q} = \tau_m$$

# THE LEVENSPIEL PLOT

For a liquid phase PFR we have:

$$\tau = \int_{C_A}^{C_{Ao}} \left( \frac{1}{-r_A} \right) dC_A$$

*Note the sign change due to the boundary switch*

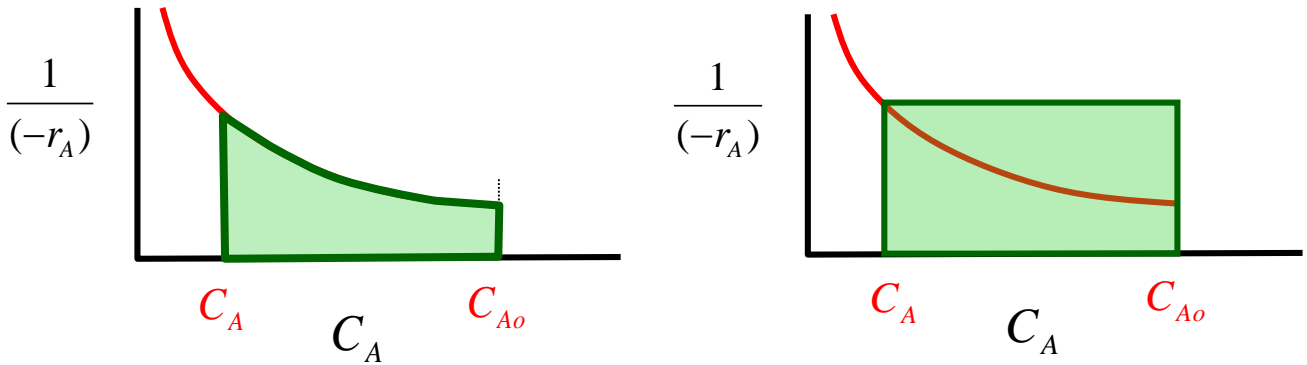


Note that the rate changes as concentration change and therefore the rate curve is followed.

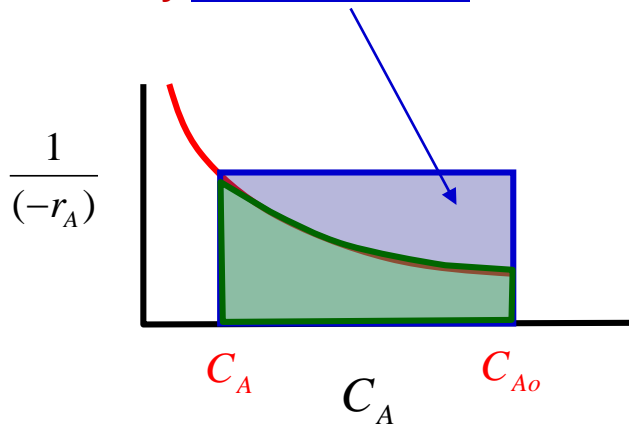


# THE LEVENSPIEL PLOT

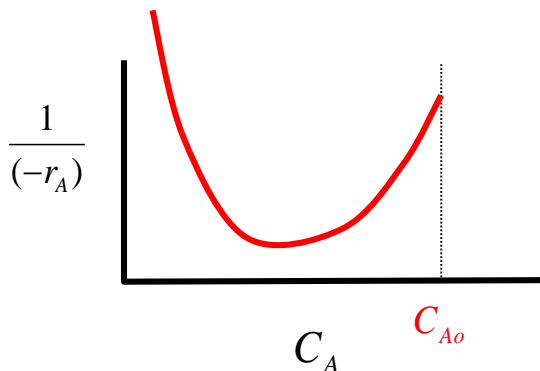
To achieve a certain conversion for a first order reaction, would you rather use a CSTR or a PFR?



See the unnecessary space (catalyst) used.



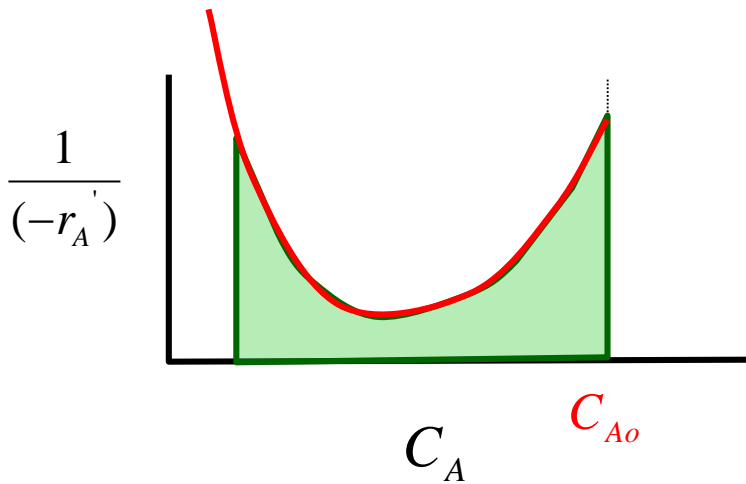
What about this one?



# THE LEVENSPIEL PLOT

The objective for most reactor designs is to minimize  $\tau$  or  $\tau_m$ . This implies smaller volume (less catalyst) for a given feed.

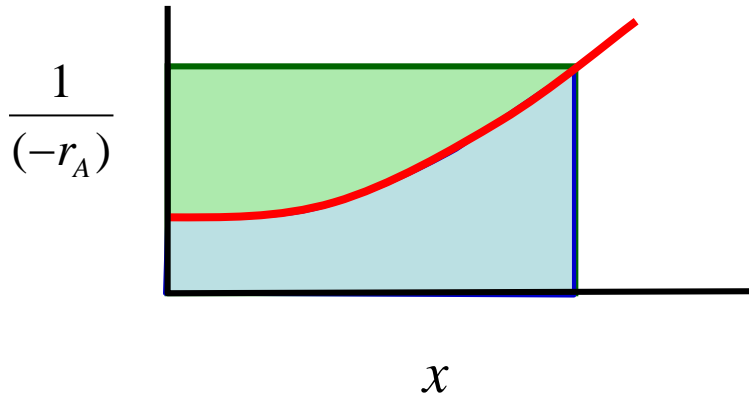
We can now use the Levenspiel plot to find the smallest area. We can even use different reactors in series.



How will you decrease the amount of catalyst required? Is the single PFR the optimum choice?

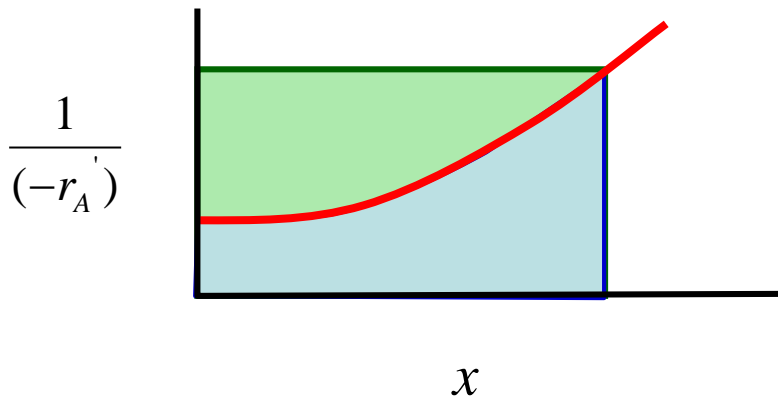
# THE LEVENSPIEL PLOT

We can also use conversion for Levenspiel plots.



$$[x_A] \times \left[ \frac{1}{-r_A} \right] = \frac{V}{F_{Ao}}$$

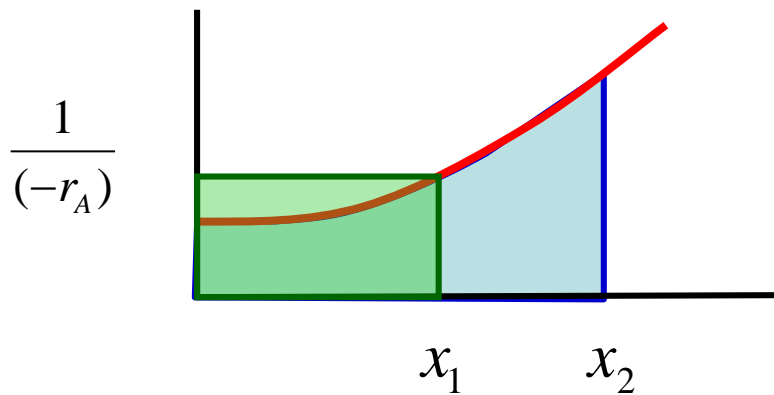
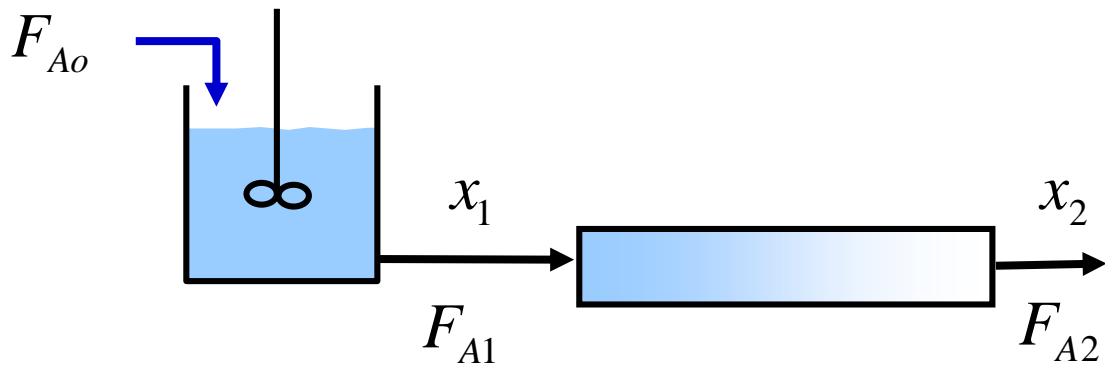
$$\int_0^x \left( \frac{1}{-r_A} \right) dx_A = \frac{V}{F_{Ao}}$$



$$[x_A] \times \left[ \frac{1}{-r_A'} \right] = \frac{W}{F_{Ao}}$$

$$\int_0^x \left( \frac{1}{-r_A'} \right) dx_A = \frac{W}{F_{Ao}}$$

# SERIAL REACTORS AND CONVERSION



$$x_1 = \frac{F_{Ao} - F_{A1}}{\underline{F_{Ao}}}$$

$$x_2 = \frac{F_{Ao} - F_{A2}}{\underline{F_{Ao}}}$$

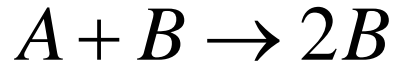
Be careful, conversion is relative and always defined with respect to a basis. For serial reactor combinations you need a single basis.

$$x_2 \neq \frac{F_{A1} - F_{A2}}{F_{A1}}$$

**Don't make this mistake !**

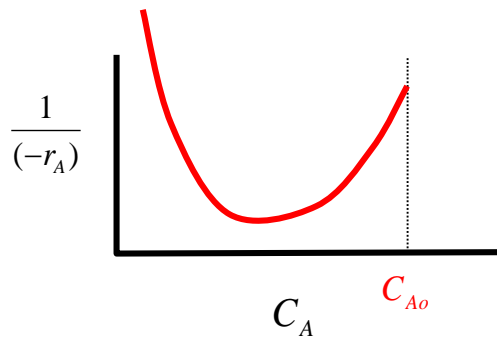
## TRICK QUESTION

Elementary spontaneous autocatalytic reaction:



$$k_{(300K)} = 2 \frac{l}{mol \cdot min}$$

$$C_{Ao} = 1 \frac{mol}{l}, \quad C_{Bo} = 0.1 \frac{mol}{l}$$



A 30% conversion at 300K is required. What reactor configuration will give the smallest residence time? What is the residence time?

Hint:  $\tau < 0.53$

First person with correct answer gets 100% for tut-class test mark