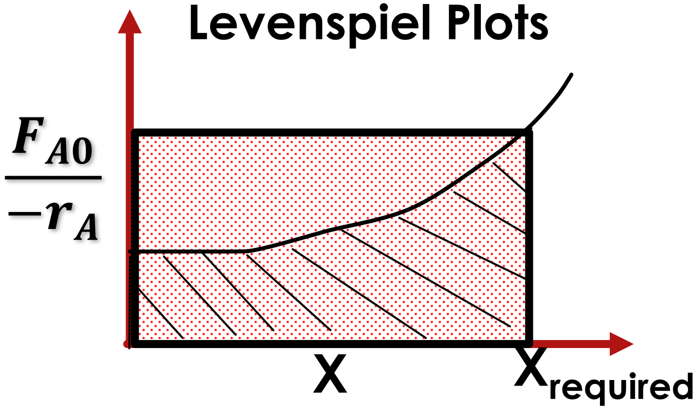
Lecture # 3.2

- Define conversion, X, for BR and flow reactors
- Design equation in terms of X
- Levenspiel plots
- Next Multiple reactors

$$X = \frac{N_{A0} - N_A}{N_{A0}} \qquad X = \frac{F_{A0} - F_A}{F_{A0}}$$

Reactor	Conversion
BR	$t = N_{A0} \int_{X\ at\ t=0}^{X} \frac{dX}{-r_A . V}$
CSTR	$V = \left(\frac{F_{A0}}{-r_A}\right) X$
PFR	$V = \int_{X\ at\ V=0}^{X} \left(\frac{F_{A0}}{-r_A}\right) dX$
PBR	$W = \int_{X\ at\ W=0}^{X} \left(\frac{F_{A0}}{-r'_A}\right) dX$

Levenspiel Plots



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Multiple reactors are often used in the Chemical Industry

- Two main possibilities: Reactors in series and Reactors in parallel
  - Combinations of series and parallel also possible

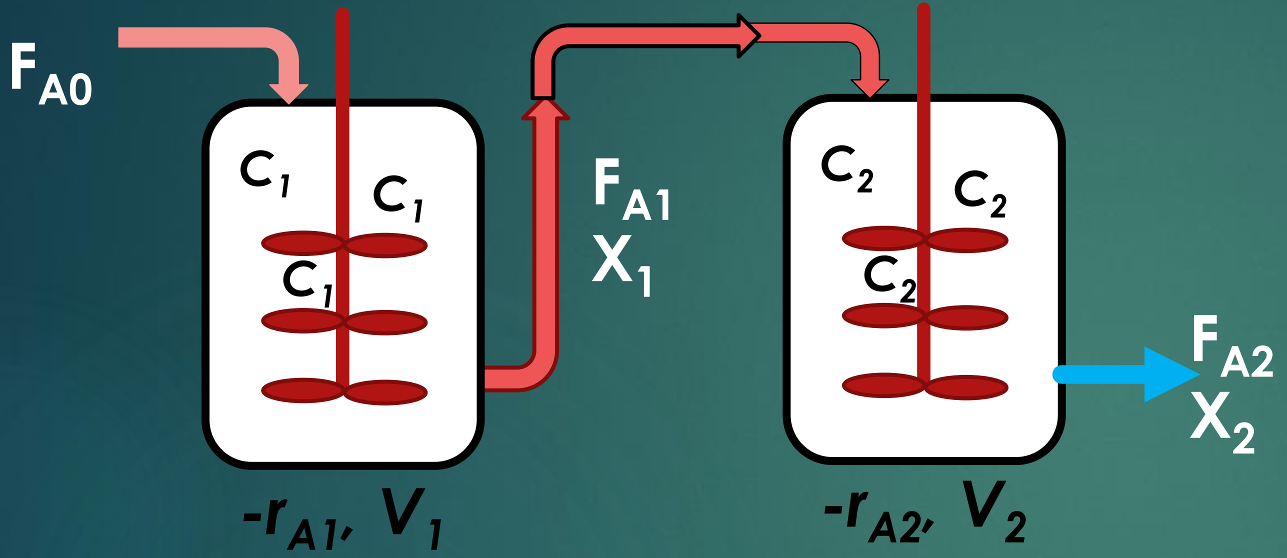
- Conversion for multiple reactors are defined based on the inlet to the first reactor (no side streams!)

- Conversion after the *i*th reactor, X_i, is: $X_i = \dfrac{total\ A\ converted\ after\ \boldsymbol{reactor\ i}}{molar\ flowrate\ of\ A\ to\ first\ reactor}$

- Thus, $X_i = \frac{F_{A0} - F_{Ai}}{F_{A0}}$ where F_{Ai} is the molar flowrate of A after reactor ***i***
- And, $F_{Ai} = F_{A0}(1 - X_i)$

Design equations applied to CSTR in series

- Two CSTRs in series → The outlet of the first is the feed to the second



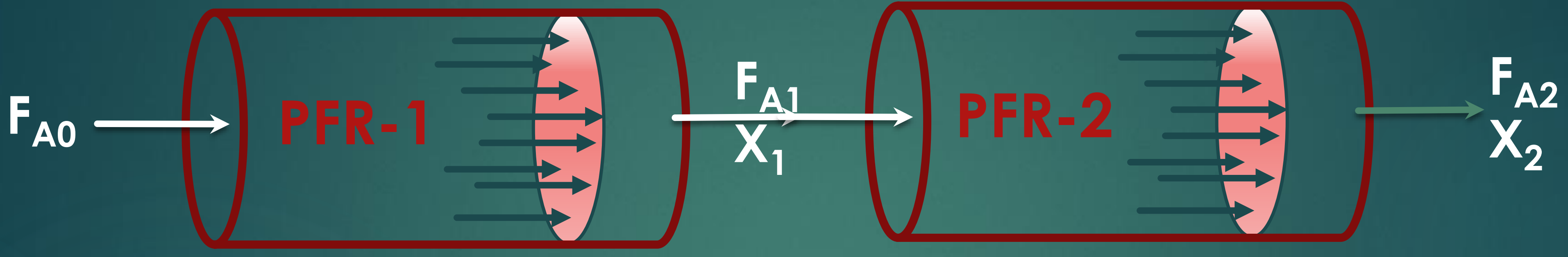
$X_1 = \frac{F_{A0}-F_{A1}}{F_{A0}}$ and $X_2 = \frac{F_{A0}-F_{A2}}{F_{A0}}$

$F_{A1} = F_{A0}(1-X_1)$ and $F_{A2} = F_{A0}(1-X_2)$

$$F_{A1} - F_{A2} + r_{A2}.V = 0$$

- $V_1 = \left(\frac{F_{A0}}{-r_{A1}}\right) X_1$ and $V_2 = \left(\frac{F_{A1}-F_{A2}}{-r_{A2}}\right) = \frac{F_{A0}(1-X_1)-F_{A0}(1-X_2)}{-r_{A2}}$
- $V_2 = \left(\frac{F_{A0}}{-r_{A2}}\right)(X_2 - X_1)$ total vol. required to achieve X_2: $V_T = V_1 + V_2$
- For a single CSTR to achieve X_2: $V = \left(\frac{F_{A0}}{-r_A}\right) X_2$

For PFR/PBR in series there is no saving in volume



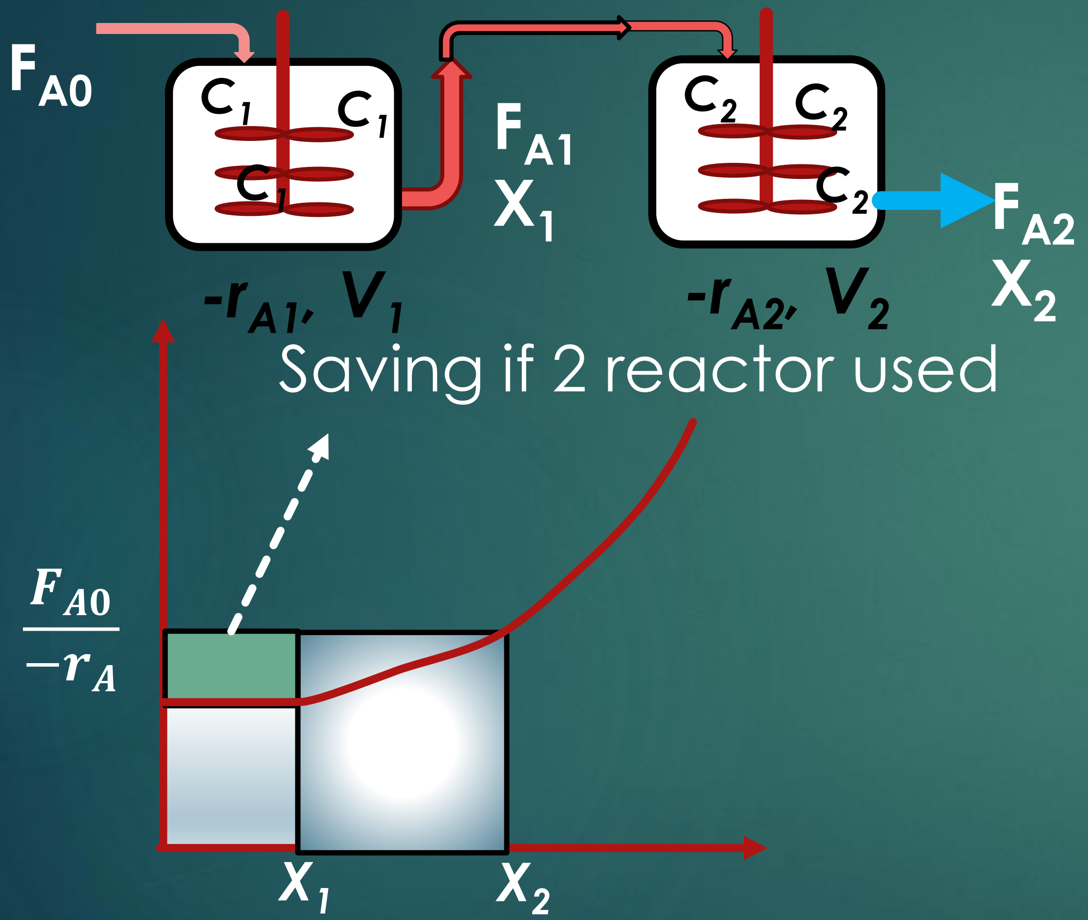
- For 1st PFR reactor: $V_1 = \int_0^{X_1} \left(\frac{F_{A0}}{-r_A}\right) dX$ and

- For 2nd PFR reactor: $V_2 = \int_{X_1}^{X_2} \left(\frac{F_{A0}}{-r_A}\right) dX$

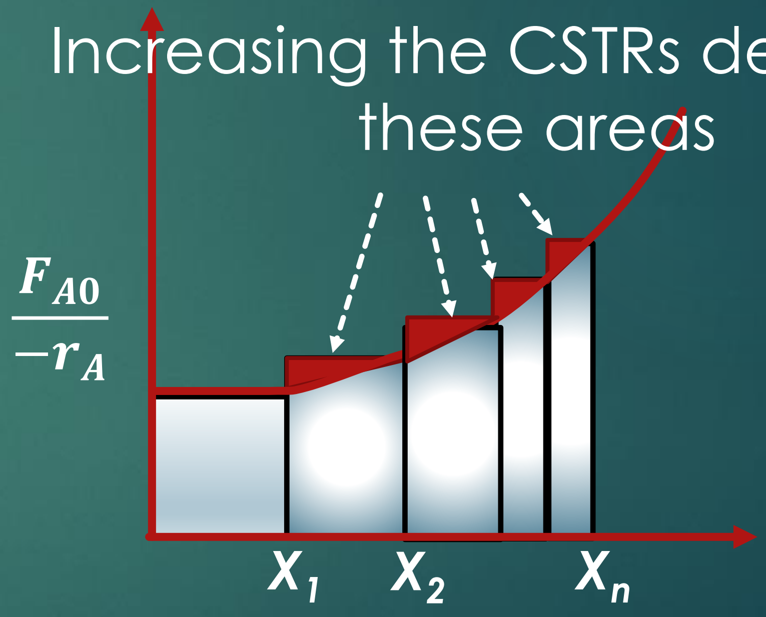
- And, $V = V_1 + V_2 = F_{A0} \int_0^{X_2} \frac{dX}{-r_A}$ same for a single reactor of vol. V

Corresponding Levenspiel plots are useful

Two CSTRs in series

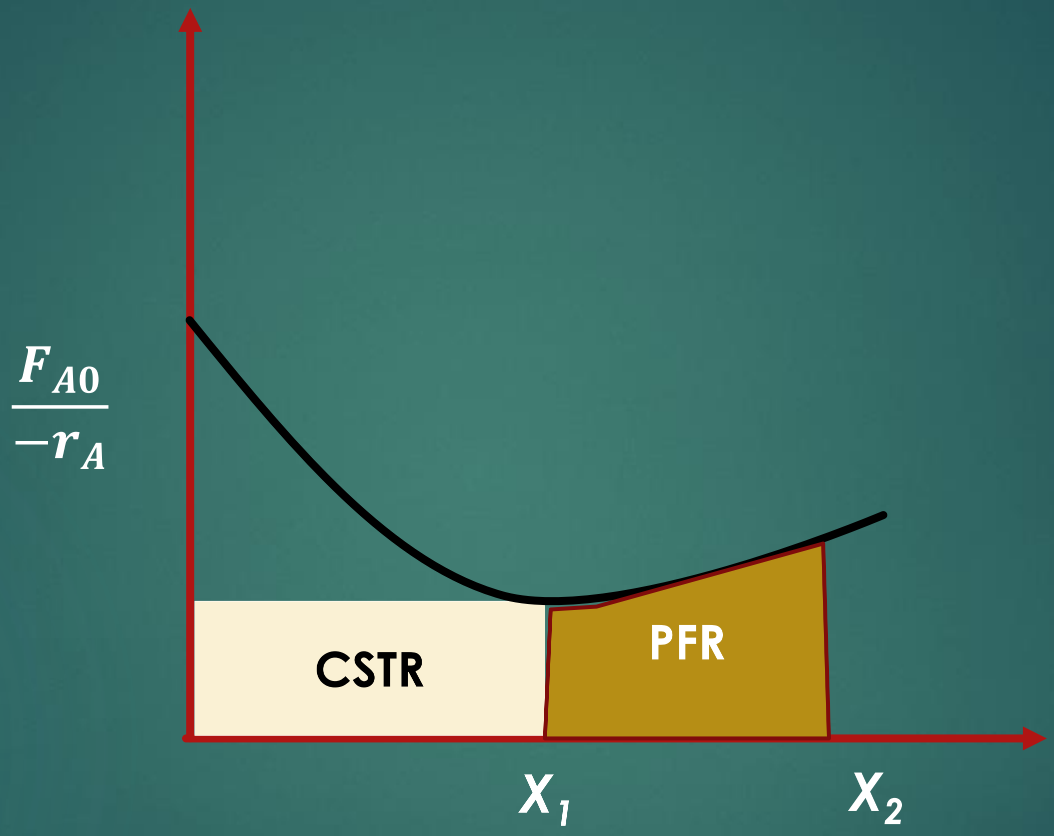


Multiple CSTRs in series



- **For achieving same conversion X_2 two CSTRs are beneficial!**
- **A PFR/PBR can be modelled as a series of CSTRs**

Combination of CSTR and PFR/PBR reactors



- A CSTR + PFR is better than (2 PFRs) or (2CSTRs) or (PFR+CSTR)

Miscellaneous information about flow reactors

- Space time: $\tau = \frac{V}{v_0} (\equiv \frac{m^3}{m^3/s})$ which has the unit of time
- It is the time required to process one reactor volume of fluid based on the inlet conditions
- For ideal flow reactors the space time is the mean residence time, which is the average time the molecules spend in the reactor
- Related to space time is the space velocity (SV) = $\frac{v_o}{V}$
- SV is referred to as LHSV or GHSV. For LHSV v_0 is measured as that of a liquid at 60°F or 75°F, even though the actual feed may be a vapor at some high temperature. For GHSV v_0 is measured at STP.

Some typical space time for Industrial Reactors

Reactor Type	Mean Residence Time Range	Production Capacity
Batch	15 min to 20 h	Few kg/day to 1,00,000 tons/day
CSTR	10 min to 4 h	10 t0 30,00,000 tons/day
Tubular (PFR/PBR)	0.5 s to 1 h	50 to 50,00,000 tons /day

Trambouze, Landeghem and Wauquier, Chemical Reactors, p. 154
(Paris: Editions Technip, 1988; Houston: Gulf Publishing Company, 1988)