CHEN 416: CHEMICAL REACTION ENGINEERING II

DESIGN OF RECYCLE REACTORS

LEARNING OBJECTIVES

- At the end of this week's lecture, students should be able to:
  - Define and illustrate what recycle reactors are.
  - Develop performance equation for recycle reactors.
  - Evaluate performance of recycle reactors

RECYCLE REACTORS

- WHAT IS A RECYCLE REACTOR?

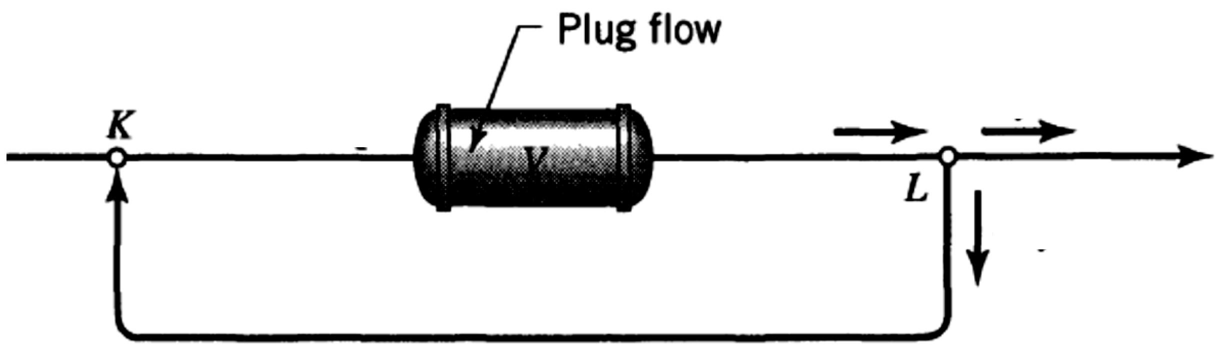
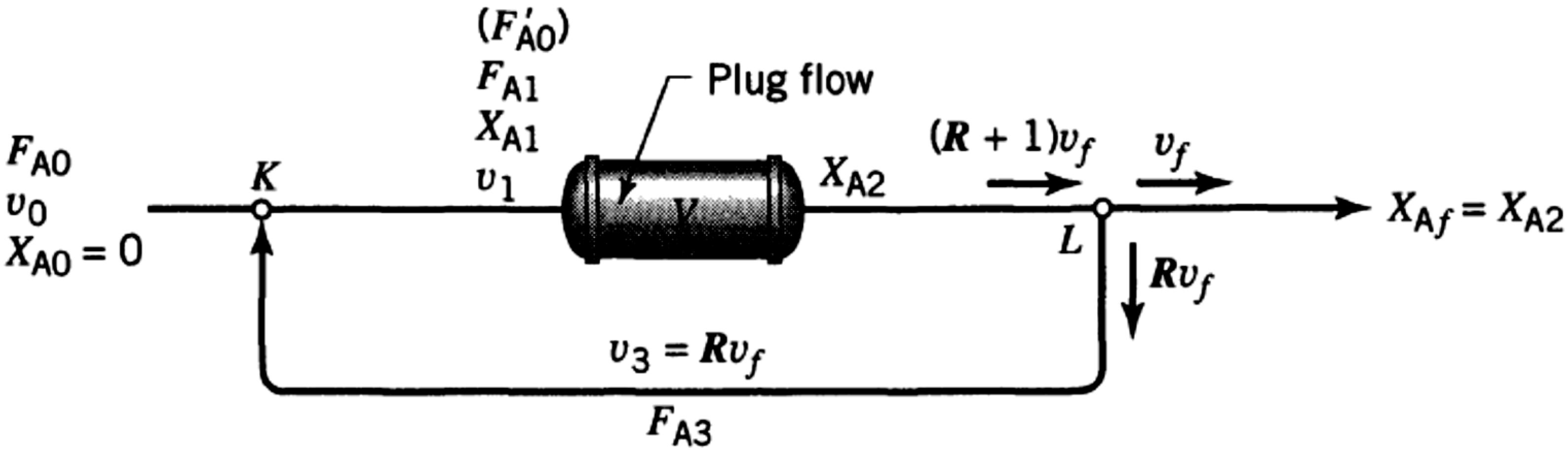


Figure 6-1 Nomenclature for the recycle reactor

- This represents when the product stream from a plug flow reactor is divided and a portion of it is returned to the entrance of the reactor.
- The *recycle ratio* R can be defined as
- $$R = \frac{\text{volume of fluid returned to the reactor entrance}}{\text{volume leaving the system}} \qquad 6\text{-}1$$
- The recycle ratio can be made to vary from zero to infinity.
- As ***R*** is raised the behavior shifts from PFR (R = 0) to MFR (R = ∞).

PERFORMANCE EQUATION OF RECYCLE REACTOR

- Thus, recycling provides a means for obtaining various degrees of back-mixing with a plug flow reactor.
- Developing the performance equation for the recycle reactor is as shown below,



- Taking a balance across the reactor itself i.e. for plug flow gives
- $$\frac{V}{F'_{A0}} = \int_{X_{A1}}^{X_{A2}=X_{Af}} \frac{dX_A}{-r_A} \qquad 6\text{-}2$$
  - where F'_{A0} would be the feed rate of A if the stream entering the reactor (fresh feed plus recycle) were unconverted.
- Since F'_{A0} and X_{A1} are not known directly, they must be written in terms of known quantities before Eq. 6-2 can be used.

PERFORMANCE EQUATION OF RECYCLE REACTOR

- The flow entering the reactor includes both fresh feed and the recycle stream. Measuring the flow split at point L we then have

$$F'_{A0} = \begin{pmatrix} \text{A which would enter in an} \\ \text{unconverted recycle stream} \end{pmatrix} + \begin{pmatrix} \text{A entering in} \\ \text{fresh feed} \end{pmatrix}$$

- $$= \boldsymbol{R}F_{A0} + F_{A0} = (\boldsymbol{R}+1)F_{A0} \qquad 6\text{-}3$$

- Also, X_{A1} could be evaluated as

  - $$X_{A1} = \frac{1 - C_{A1}/C_{A0}}{1 + \varepsilon_A C_{A1}/C_{A0}} \qquad 6\text{-}4$$

- At constant pressure, the streams meeting at point ***K*** may be added directly giving,

$$C_{A1} = \frac{F_{A1}}{v_1} = \frac{F_{A0} + F_{A3}}{v_0 + \boldsymbol{R}v_f} = \frac{F_{A0} + \boldsymbol{R}F_{A0}(1 - X_{Af})}{v_0 + \boldsymbol{R}v_0(1 + \varepsilon_A X_{Af})}$$

  - $$= C_{A0}\left(\frac{1 + \boldsymbol{R} - \boldsymbol{R}X_{Af}}{1 + \boldsymbol{R} + \boldsymbol{R}\varepsilon_A X_{Af}}\right) \qquad 6\text{-}5$$

PERFORMANCE EQUATION OF RECYCLE REACTOR

- Combining Eqs. 6-4 and 6-5 gives X_{A1} in terms of measured quantities, or
- $$X_{A1} = \left(\frac{R}{R+1}\right) X_{Af} \qquad 6\text{-}6$$
- Finally, on replacing Eqs. 6-3 and 6-6 in Eq. 6-2 we obtain the useful form for the performance equation for recycle reactors, good for any kinetics, any ε value and for $X_{A0} = 0$.
- $$\frac{V}{F_{A0}} = (R+1) \int_{\left(\frac{R}{R+1}\right) X_{Af}}^{X_{Af}} \frac{dX_A}{-r_A} \quad \ldots \text{any } \varepsilon_A \qquad 6\text{-}7$$
- For the special case where density changes are negligible we may write this equation in terms of concentrations, or
- $$\tau = \frac{C_{A0}V}{F_{A0}} = -(R+1) \int_{\frac{C_{A0}+RC_{Af}}{R+1}}^{C_{Af}} \frac{dC_A}{-r_A} \quad \ldots \varepsilon_A = 0 \qquad 6\text{-}8$$
- These expressions are represented graphically in Fig. 6.2.

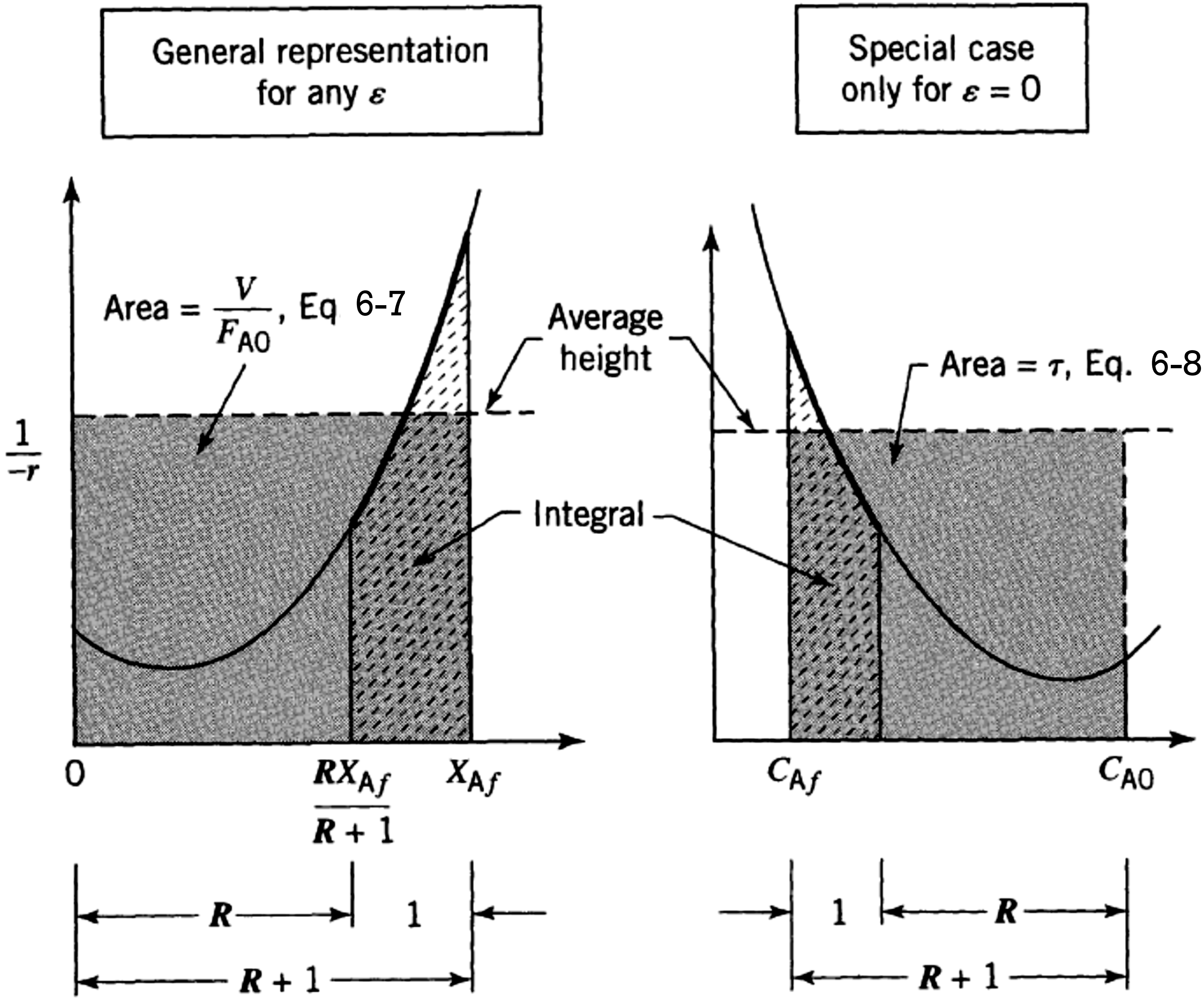


Figure 6-2 Representation of the performance equation for recycle reactors

PERFORMANCE EQUATION OF RECYCLE REACTOR

- For the extremes of negligible and infinite recycle, the system approaches plug flow and mixed flow, or

$$\frac{V}{F_{A0}} = (R+1)\int_{\left(\frac{R}{R+1}\right)X_{Af}}^{X_{Af}} \frac{dX_A}{-r_A} \quad \ldots \text{any } \varepsilon_A$$

$R = 0$ ↓

$$\frac{V}{F_{A0}} = \int_{A}^{X_{Af}} \frac{dX_A}{-r_A}$$

plug flow

$R = \infty$ ↓

$$\frac{V}{F_{A0}} = \frac{X_{Af}}{-r_{Af}}$$

mixed flow

- The approach to these extremes is shown in Fig. 6-3.

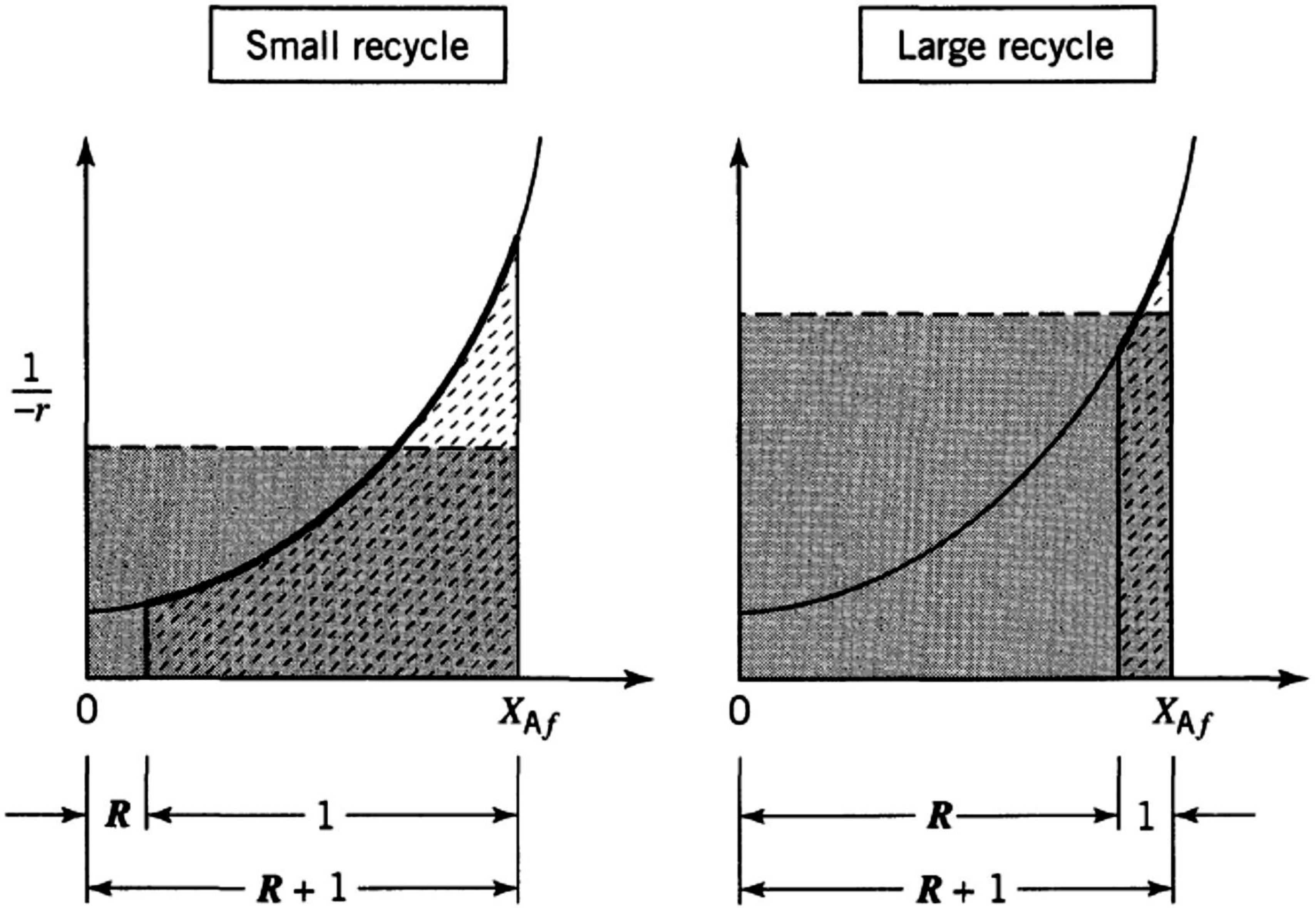


Figure 6-3 The recycle extremes approach PFR (R +0) and MFR (R → ∞).

PERFORMANCE EQUATION OF RECYCLE REACTOR

- For *first-order reaction,* and $\varepsilon_A = 0$, the integration of the recycle equation gives,

$$\frac{k\tau}{R+1} = \ln\left[\frac{C_{A0} + RC_{Af}}{(R+1)C_{Af}}\right]$$

- and for *second-order reaction,* **2A** → products, $-r_A = kC_A^2$ and $\varepsilon_A = 0$,

$$\frac{kC_{A0}\tau}{R+1} = \frac{C_{A0}(C_{A0} - C_{Af})}{C_{Af}(C_{A0} + RC_{Af})}$$

- The expressions for $\varepsilon_A \neq 0$ and for other reaction orders can be evaluated, but are more cumbersome.
- Figures 6-4 and 6-5 show the transition from plug to mixed flow as R increases

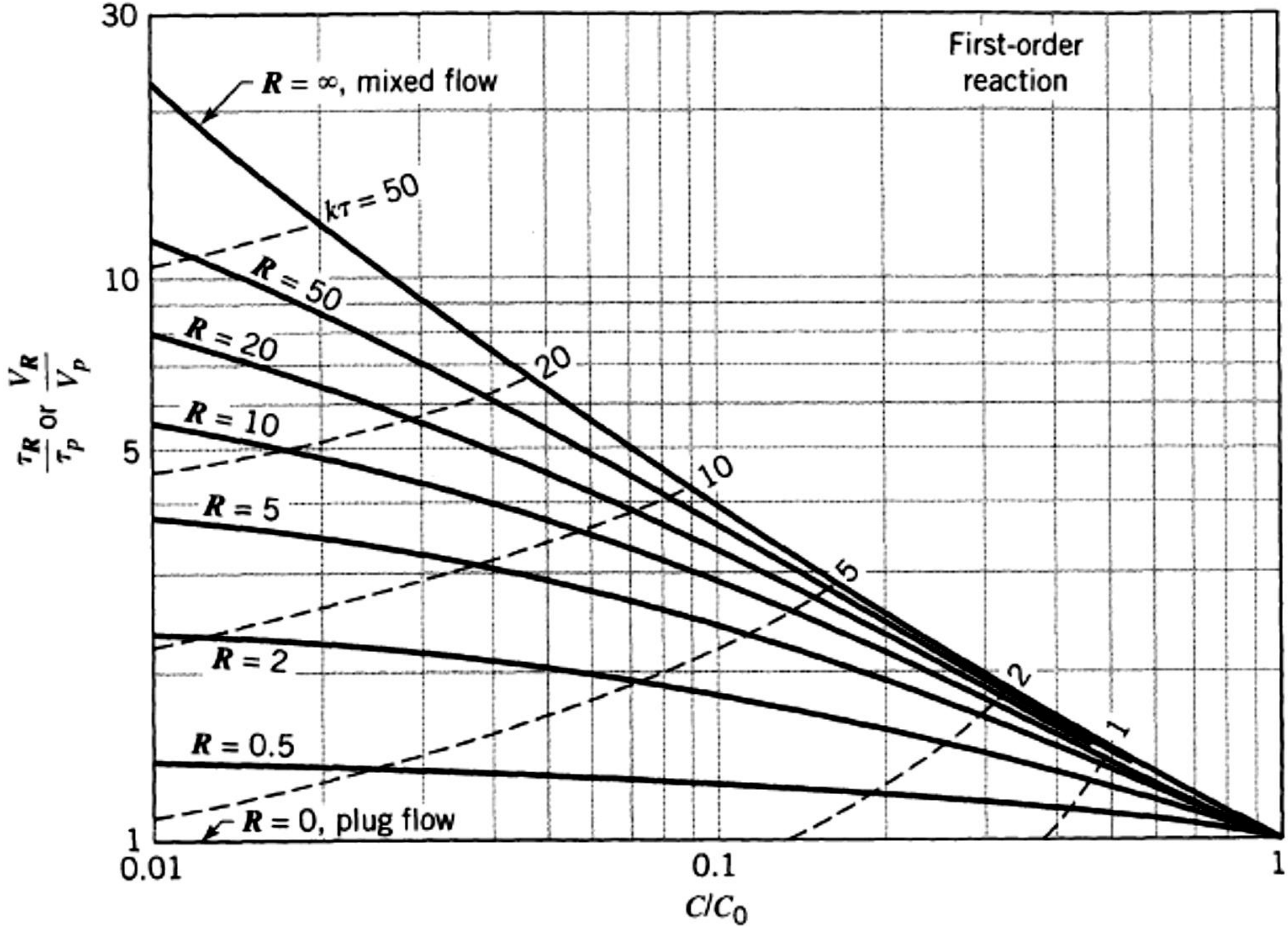
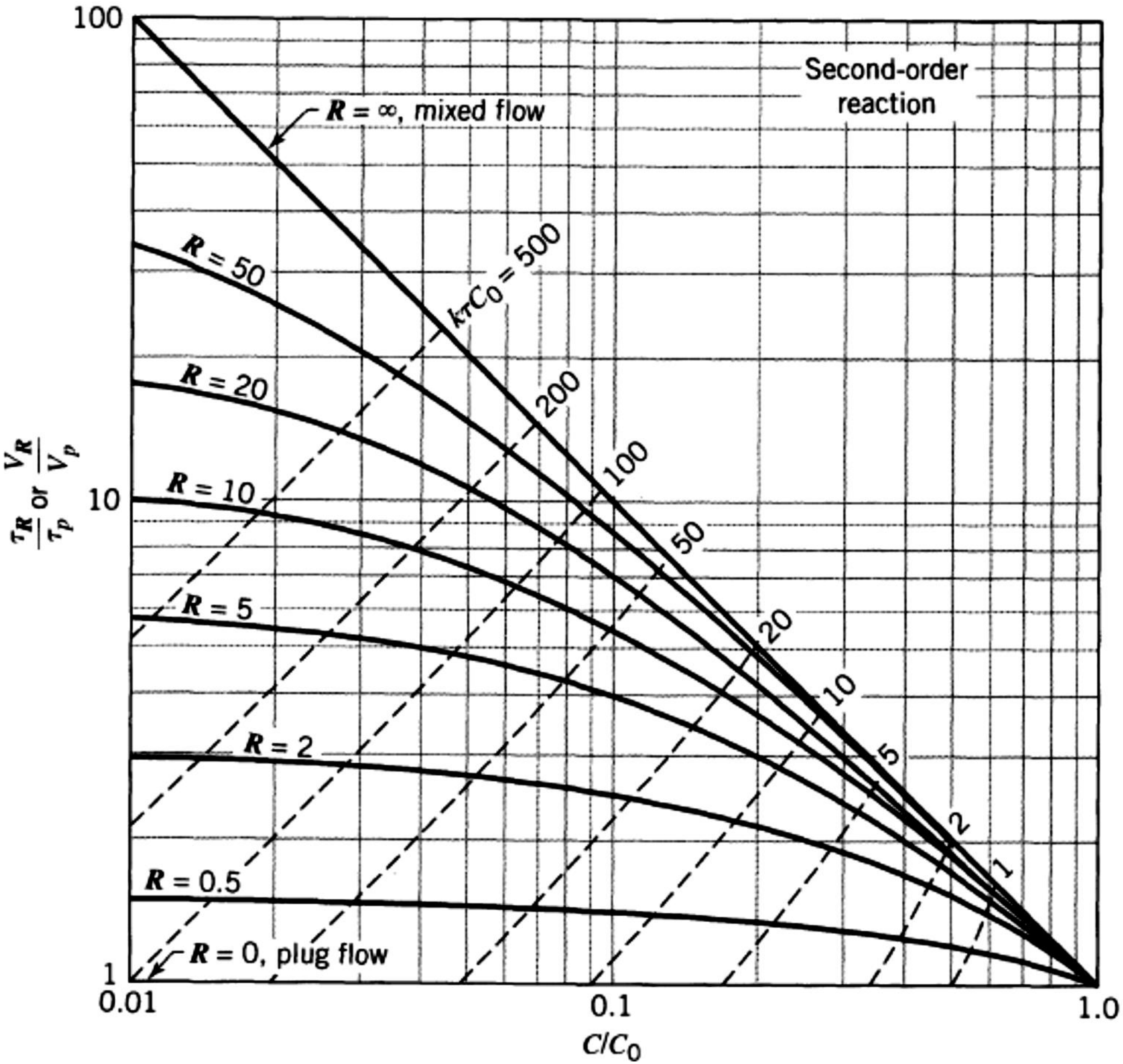


Figure 6.4 Comparison of performance of recycle reactors with PFRs for elementary first-order reactions



2A → products,

A + B → products,

$\varepsilon = 0$

$C_{A0} = C_{B0}$ with $\varepsilon = 0$

Figure 6.5 Comparison of performance of recycle reactors with PFRs for elementary second-order reactions

PERFORMANCE EQUATION OF RECYCLE REACTOR

- A match of these curves with those for N tanks in series gives the following rough comparison for equal performance:

No. of tanks	R for first-order reaction at X_A = 0.5	0.90	0.99	R for second-order reaction at X_A = 0.5	0.90	0.99
1	∞	∞	∞	∞	∞	∞
2	1.0	2.2	5.4	1.0	2.8	7.5
3	0.5	1.1	2.1	0.5	1.4	2.9
4	0.33	0.68	1.3	0.33	0.90	1.7
10	0.11	0.22	0.36	0.11	0.29	0.5
∞	0	0	0	0	0	0

- The recycle reactor is a convenient way for approaching mixed flow with what is essentially a plug flow device. Its particular usefulness is with solid catalyzed reactions with their fixed bed contactors

THANK YOU
FOR
YOUR
ATTENTION!
ANY QUESTIONS?