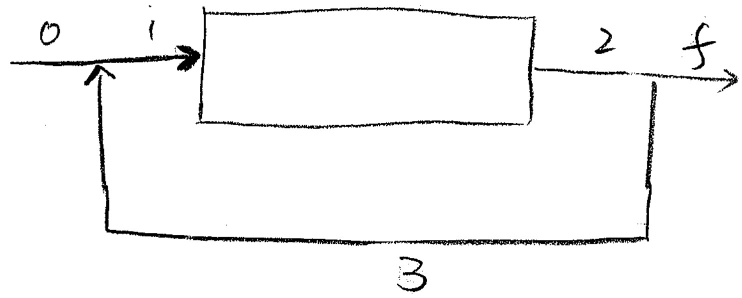
1.

#5



General reaction case

$$aA + bB \longrightarrow cC + dD$$

$$\delta = \frac{c}{a} + \frac{d}{a} - 1 - \frac{b}{a}$$

$$R = \frac{v_3}{v_f} = \frac{v_3 C_{A3}}{v_f C_{Af}} = \frac{F_{A3}}{F_{Af}} \qquad C_{i3} = C_{if}$$

$$X_{Af} = \frac{F_{A0} - F_{Af}}{F_{A0}} \Rightarrow F_{Af} = F_{A0}(1 - X_{Af})$$

$$C_{A1} = \frac{F_{A0} + F_{A3}}{v_0 + Rv_f} = \frac{F_{A0} + F_{Af}R}{v_0 + Rv_f}$$

$$= \frac{F_{A0} + RF_{A0}(1 - X_{Af})}{v_0 + Rv_0(1 + \varepsilon X_{Af})} = C_{A0}\frac{1 + R(1 - X_{Af})}{1 + R(1 + \varepsilon X_{Af})}$$

— eq A

$$C_A = C_{A0}\frac{1-X_A}{1+\varepsilon X_A} \qquad X_A = \frac{1-\frac{C_A}{C_{A0}}}{1+\varepsilon\frac{C_A}{C_{A0}}}$$

from eq A, $\boxed{\frac{C_{A1}}{C_{A0}} = \frac{1+R(1-X_{Af})}{1+R(1+\varepsilon X_{Af})}}$

at stream 1. $X_{A1} = \dfrac{1-\frac{C_{A1}}{C_{A0}}}{1+\varepsilon\frac{C_{A1}}{C_{A0}}}$

$$\Rightarrow X_{A1} = \frac{1-\frac{1+R(1-X_{Af})}{1+R(1+\varepsilon X_{Af})}}{1+\varepsilon\frac{1+R(1-X_{Af})}{1+R(1+\varepsilon X_{Af})}}$$

$$= \frac{1+R(1+\varepsilon X_{Af})-1-R(1-X_{Af})}{1+R(1+\varepsilon X_{Af})+\varepsilon+\varepsilon R(1-X_{Af})}$$

$$= \frac{RX_{Af}(1+\varepsilon)}{(1+R)(1+\varepsilon)} = \frac{R}{1+R}X_{Af} \quad \#$$

✓

at $\varepsilon = 0$

$$C_{Af} = C_{A0}(1 - X_{Af}) \qquad X_{Af} = \frac{C_{A0} - C_{Af}}{C_{A0}} = 1 - \frac{C_{Af}}{C_{A0}}$$

$$C_{A1} = C_{A0}\left(\frac{1 + R(1 - X_{Af})}{1+R}\right) \qquad 1 - X_{Af} = \frac{C_{Af}}{C_{A0}}$$

$$= C_{A0}\,\frac{1 + R\,C_{Af}/C_{A0}}{1+R}$$

$$= \frac{C_{A0} + RC_{Af}}{1+R} \qquad C_{Af} = C_{A2}$$

$$= \frac{C_{A0} + RC_{A2}}{1+R} \quad \#$$

with no volume change

1st order: $$\tau = -(R+1)\int_{\frac{C_{A0}+RC_{Af}}{R+1}}^{C_{Af}} \frac{dC_A}{kC_A}$$

$$= -\frac{R+1}{k}\ln C_A \Big|_{\frac{C_{A0}+RC_{Af}}{R+1}}^{C_{Af}} = -\frac{R+1}{k}\ln\frac{C_{Af}(R+1)}{C_{A0}+RC_{Af}}$$

$$\frac{k\tau}{R+1} \quad \ln\frac{C_{A0}+RC_{Af}}{(R+1)C_{Af}} \quad \#$$

2nd order

$$\tau = -(R+1)\int_{\frac{C_{A0}+RC_{Af}}{R+1}}^{C_{Af}} \frac{dC_A}{kC_A^2}$$

$$= \frac{R+1}{k}\left.\frac{1}{C_A}\right|_{\frac{C_{A0}+RC_{Af}}{R+1}}^{C_{Af}}$$

$$\frac{k\tau}{R+1} = \frac{1}{C_{Af}} - \frac{R+1}{C_{A0}+RC_{Af}}$$

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

1st order

recycle = $k\tau = \ln \dfrac{C_{A0} + R C_{Af}}{(R+1) C_{Af}} \cdot (R+1)$

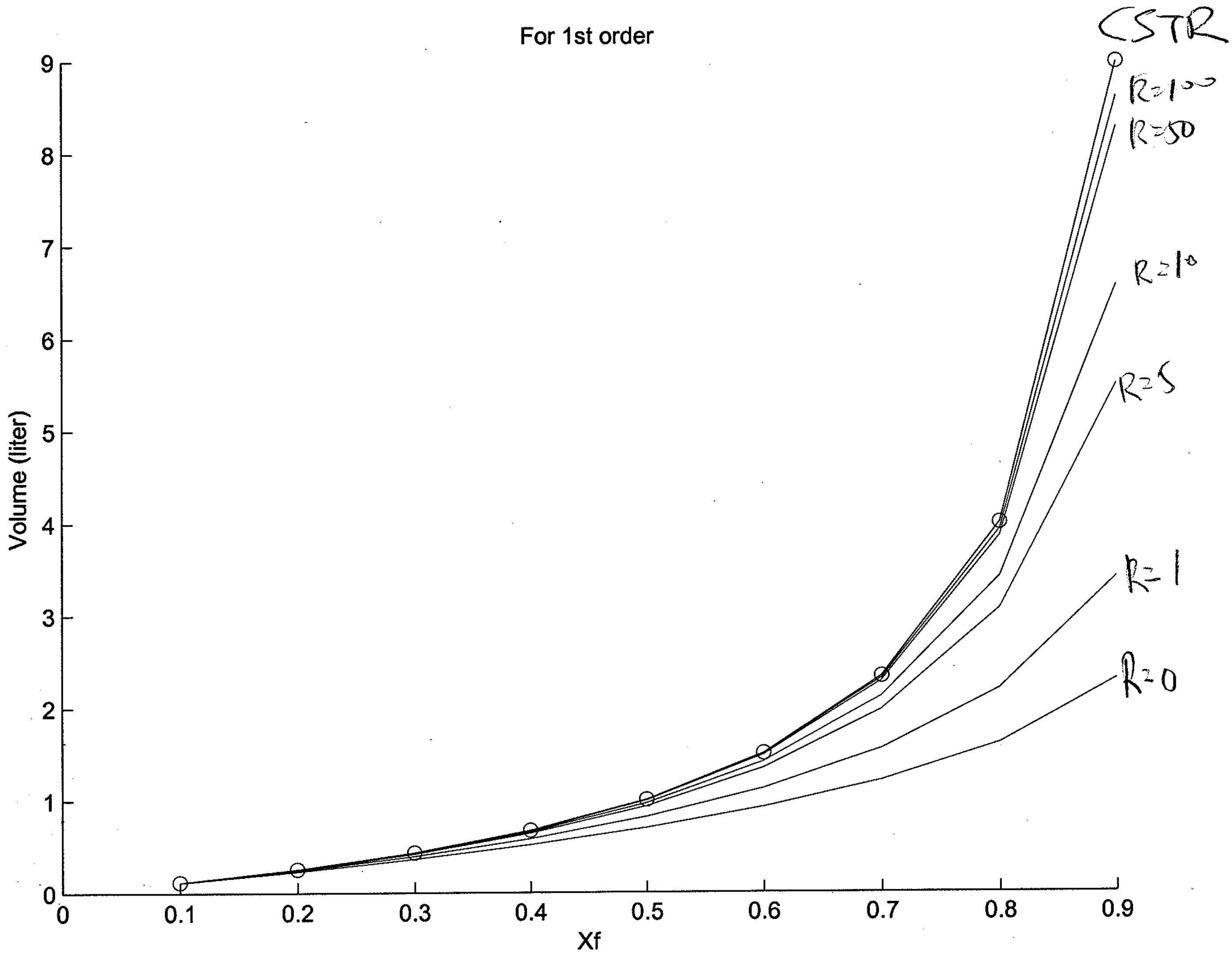
CSTR = $k\tau = \dfrac{C_{A0} - C_{Af}}{C_{Af}}$

2nd order

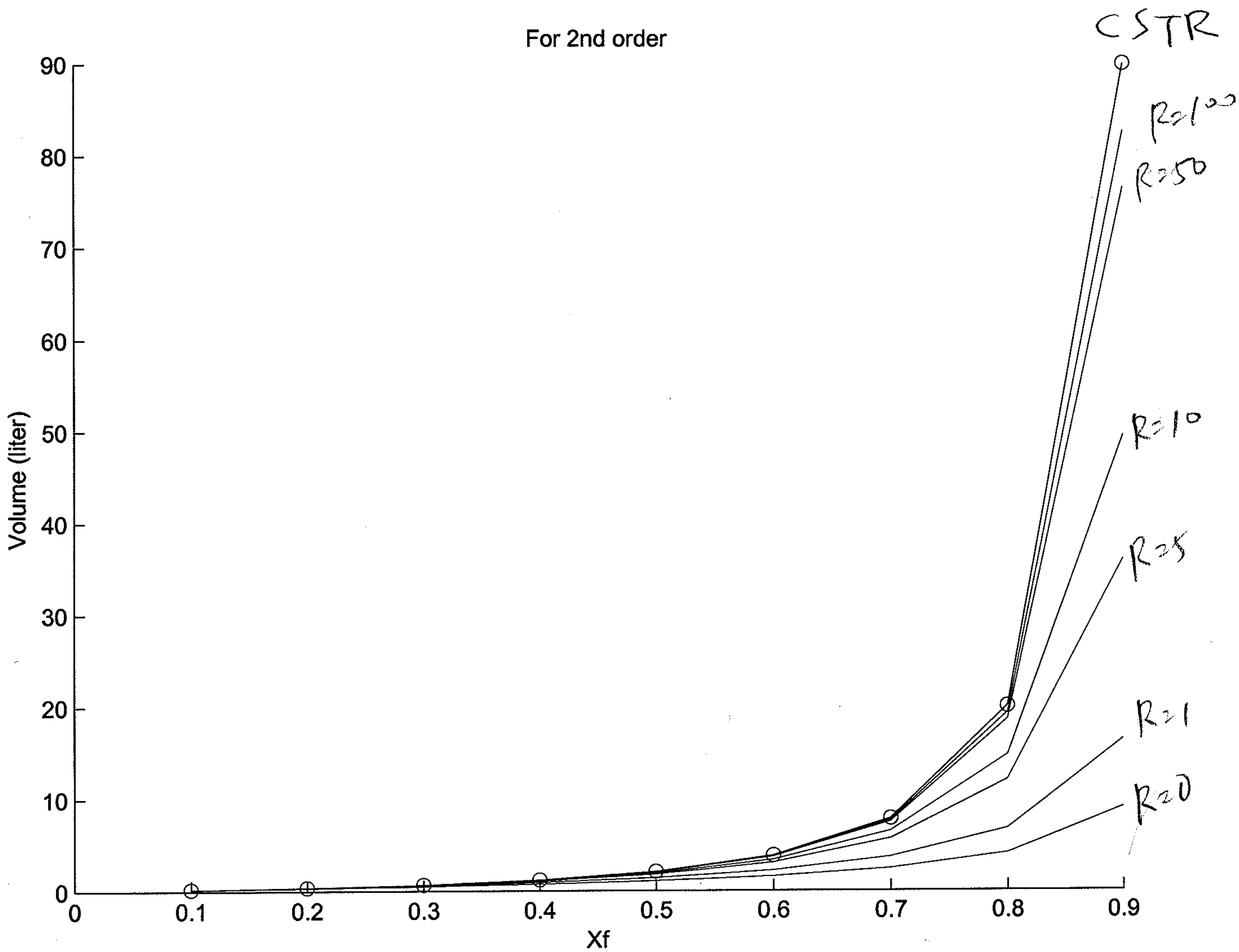
recycle = $k\tau = \dfrac{C_{A0} - C_{Af}}{C_{Af}(C_{A0} + R C_{Af})} (R+1)$

CSTR = $k\tau = \dfrac{C_{A0} - C_{Af}}{C_{Af}^2}$

As recycle ratio R increases
the performance of a recycle reactor
is going to behave like a CSTR!!



For 1st order
Volume (liter)
Xf
0
1
2
3
4
5
6
7
8
9
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
CSTR
R=100
R=50
R=10
R=5
R=1
R=0


For 2nd order
Volume (liter)
Xf
0
10
20
30
40
50
60
70
80
90
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
CSTR
R=100
R=50
R=10
R=5
R=1
R=0

2

$$2A \longrightarrow B \Rightarrow A \rightarrow \frac{1}{2}B$$

$y_{A0} = 1 \qquad F_{A0} = 2 \text{ mol/s}$

$$\varepsilon = y_{A0} \cdot \delta = 1 \cdot \left(\frac{1}{2} - 1\right) = -0.5$$

$$C_A = C_{A0} \frac{(1 - X_A)}{(1 - 0.5 X_A)} \left(\frac{P}{P_0}\right)\left(\frac{T_0}{T}\right)$$

$$\frac{V}{F_{A0}} = (R+1) \int_{\frac{R}{R+1} X_{Af}}^{X_{Af}} \frac{dX_A}{k C_A^2}$$

put C_A here.

$$= \underbrace{\frac{R+1}{k C_{A0}^2} \left(\frac{P_0}{P}\right)^2 \left(\frac{T}{T_0}\right)^2}_{\Phi} \cdot \left[\frac{X_A}{4} + \frac{0.25}{(1 - X_A)} - 0.5 \ln|1 - X_A| \right]_{\frac{R}{R+1} X_{Af}}^{X_{Af}}$$

\#

$$\frac{V}{F_{A0}\Phi} = \left[\frac{X_A}{4} + \frac{1}{4}\frac{1}{1 - X_A} - \frac{1}{2}\ln|1 - X_A|\right]_{\frac{R}{R+1}0.8}^{0.8}$$

← here for 100% credit.

a) $\frac{V}{F_{A0}\Phi} = f(R)$

\# $\qquad \frac{V}{F_{A0}\Phi} = f_1(T, P, F_{A0}, V)$ \#

b.

X_{Af} goes down as R increases

3.

$$A + B \to B + B$$

$$C_A = C_{A0}(1 - X_A)$$

$$C_B = C_{A0}\left(\frac{1}{100} + X_A\right) \quad \because C_{A0} : C_{B0} = 1 : 100$$

CSTR

$$v_0(C_{A0} - C_A) = k C_{A0}^2 (1 - X_A)(0.01 + X_A) V$$

$$\tau C_{A0} k = \frac{X_A}{(1 - X_A)(0.01 + X_A)}$$

PFR

$$C_{A0} k \tau = \int_0^{X_A} \frac{dX_A}{(1 - X_A)(0.01 + X_A)}$$

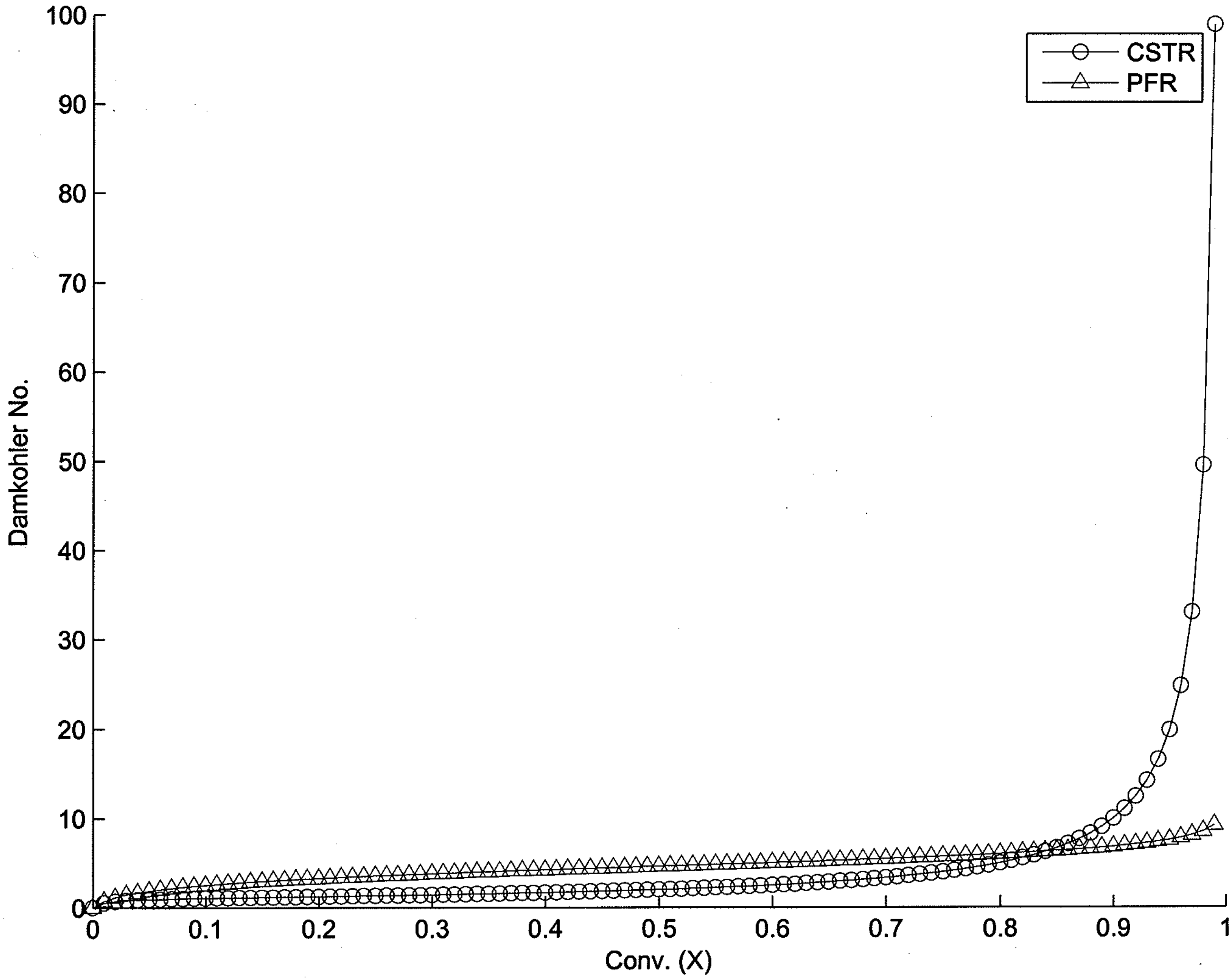
$$= \left[\frac{\ln|0.01 + X_A|}{1.01} - \frac{\ln|1 - X_A|}{1.01} \right]_0^{X_A}$$

$$= \frac{\ln|0.01 + X_A|}{1.01} - \frac{\ln|1 - X_A|}{1.01} - \frac{\ln 0.01}{1.01}$$

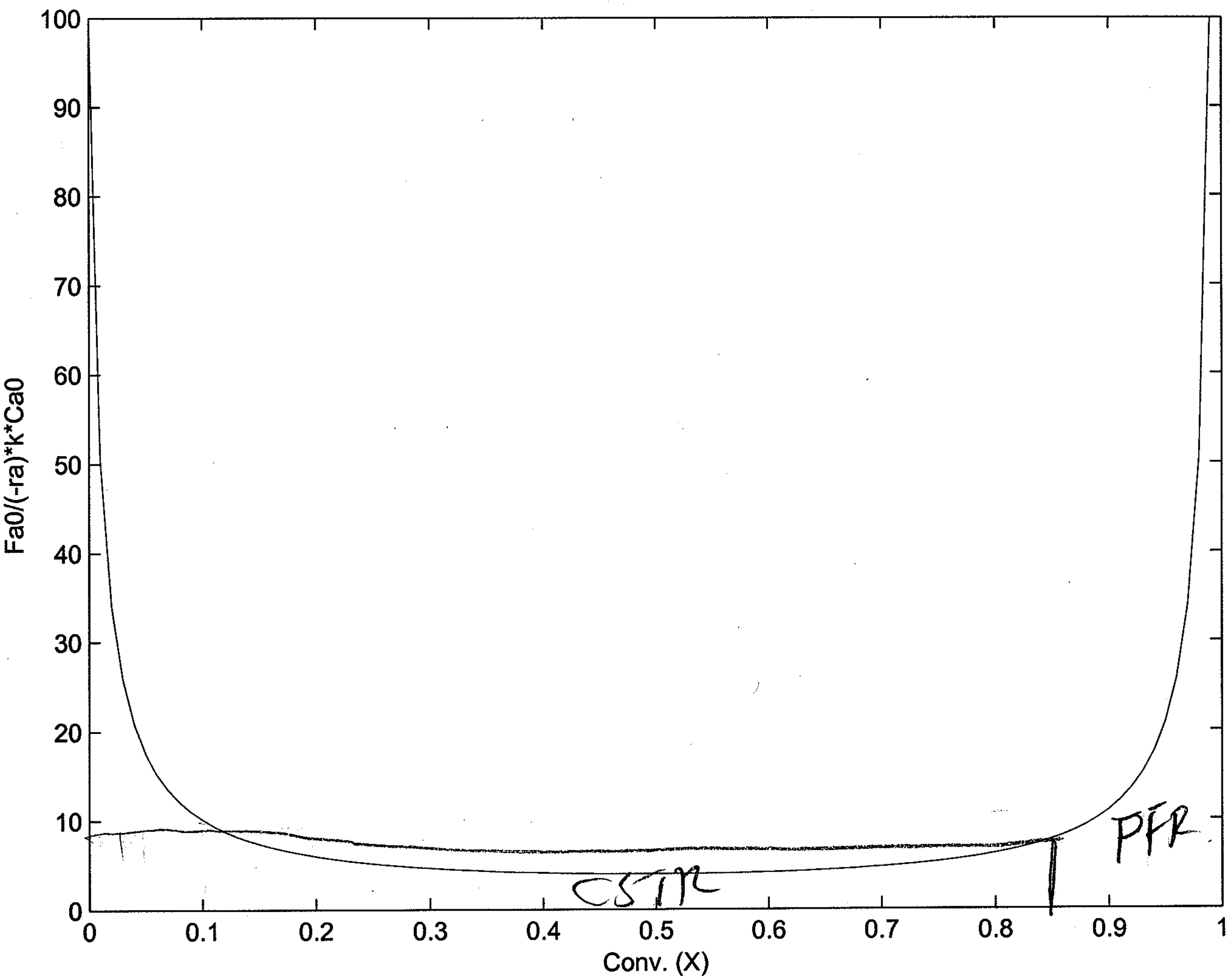
at $X \overset{u}{=} 0.85$, the volume of a CSTR is equal to that of a PFR.

Before 0.85, the volume of PFR is larger than CSTR, after 0.88 the volume of CSTR is larger than PFR.

from this plot, the best reactor arrangement should put CSTR first and let its exit conversion reach 0.85 and followed by a PFR. to a



100
90
80
70
60
50
40
30
20
10
0
Damkohler No.
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Conv. (X)
CSTR
PFR



Best arrangement is that CSTR goes first till $X_A = 0.85$ Then followed by a PFR.