BT209

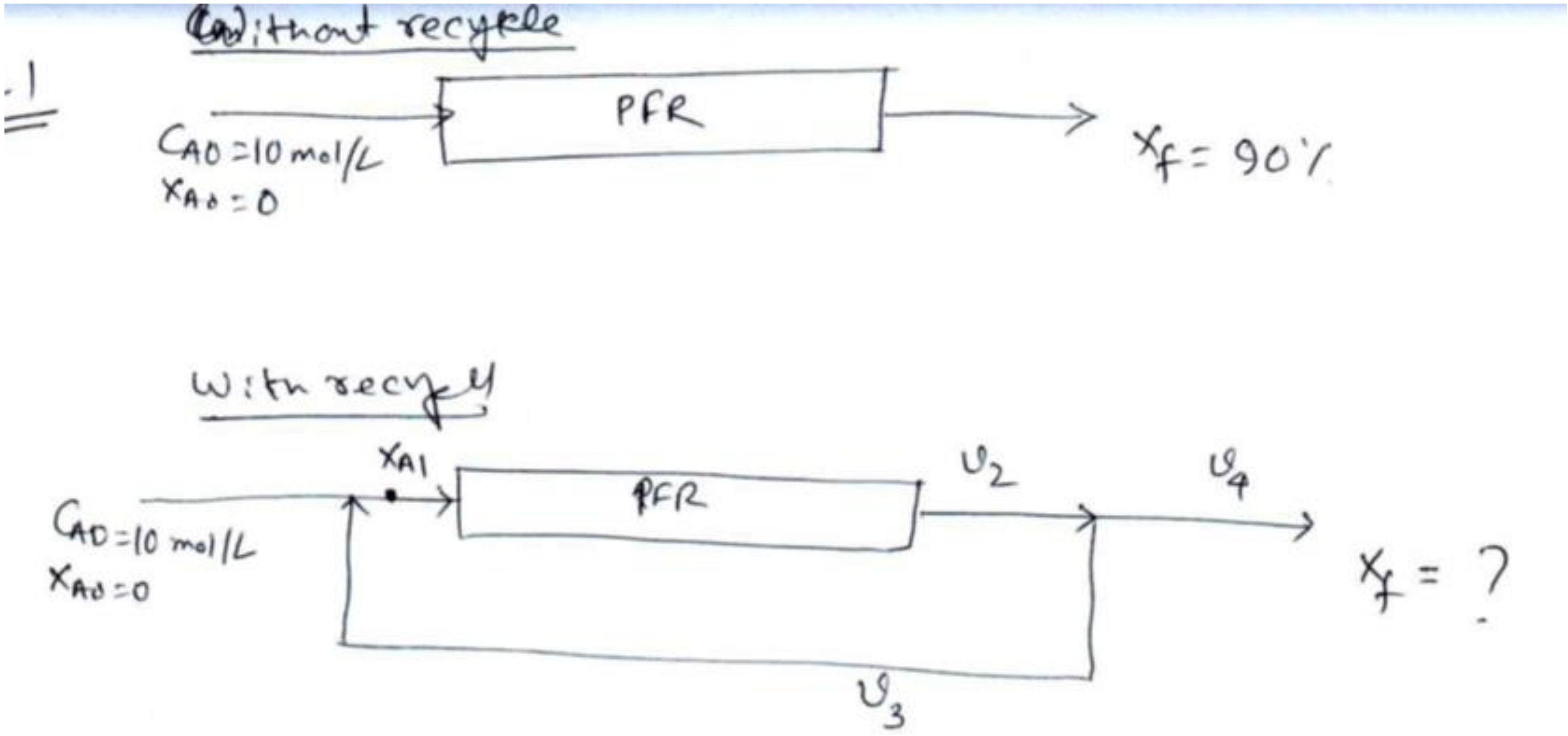
Bioreaction Engineering

23/03/2023

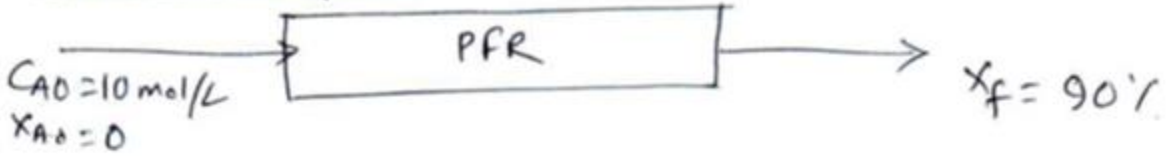
Problem 1

For an irreversible first-order liquid-phase reaction (C_{AO}= 10 mol/liter) conversion is 90% in a plug flow reactor. If two-thirds of the stream leaving the reactor is recycled to the reactor entrance, and if the throughput to the whole reactor-recycle system is kept unchanged, what does this do to the concentration of reactant leaving the system?

solution


Without recycle
PFR
CAO = 10 mol/L
XAo = 0
Xf = 90%
With recycle
XA1
PFR
υ2
υ4
CAO = 10 mol/L
XAo = 0
Xf = ?
υ3

Without recycle



From without recycle

$$\frac{V}{F_{A0}} = \int_0^{0.9} \frac{dX_A}{-r_A} = \int_0^{0.9} \frac{dX_A}{kC_{A0}(1-X_A)}$$

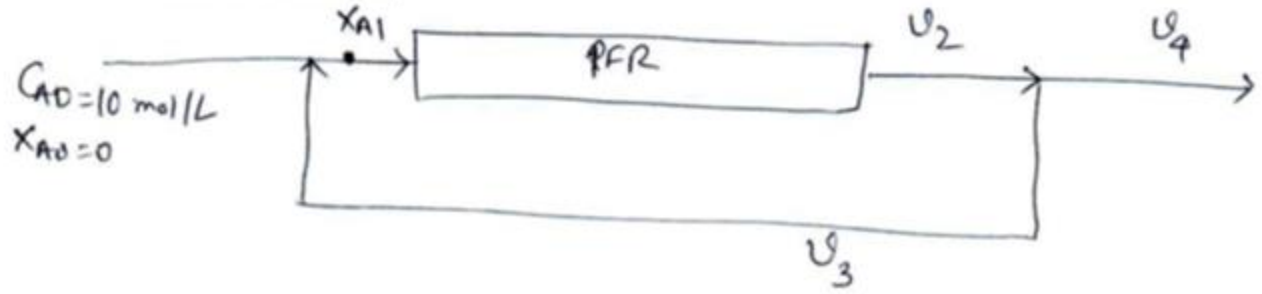
[as first order liquid phase rxn]

$$= \frac{1}{kC_{A0}}\left[-\ln(1-X_A)\right]\Big|_0^{0.9}$$

$$= \frac{1}{kC_{A0}} \ln\left[-\ln(0.1) + \ln(1)\right]$$

$$= \frac{1}{kC_{A0}} \ln 10$$

With recycle



$x_f = ?$

With recycle

$$\frac{V}{F_{A0}} = (R+1)\int_{x_{A1} = \frac{R}{R+1}x_f}^{x_f} \frac{dx_A}{k\,C_{A0}(1-x_A)}$$

$$= \frac{3}{kC_{A0}}\int_{\frac{2}{3}x_f}^{x_f} \frac{dx_A}{1-x_A}$$

$$= \frac{3}{kC_{A0}}\left[-\ln(1-x_A)\right]\Big|_{\frac{2}{3}x_f}^{x_f}$$

$$= \frac{3}{kC_{A0}} \ln \frac{1-\frac{2}{3}x_f}{1-x_f}$$

$$v_3 = \frac{2}{3}v_2$$

$$v_4 = \frac{1}{3}v_2$$

$$\therefore R = \frac{v_3}{v_4} = 2$$

$$\frac{1}{KC_{A0}} \ln 10 = \frac{3}{KC_{A0}} \ln \frac{1-\frac{2}{3}X_f}{1-X_f}$$

$$\Rightarrow \quad \frac{1-\frac{2}{3}X_f}{1-X_f} = \exp\left(\frac{\ln 10}{3}\right) = 2.154$$

$$\Rightarrow \quad 1.49 X_f = 1.154$$

$$\Rightarrow \quad X_f = 0.776$$

Problem 2

In the presence of a specific enzyme E, which acts as a homogeneous catalyst, a harmful organic A present in industrial waste water degrades into harmless chemicals. At a given enzyme concentration C_E tests in a laboratory mixed flow reactor give the following results:

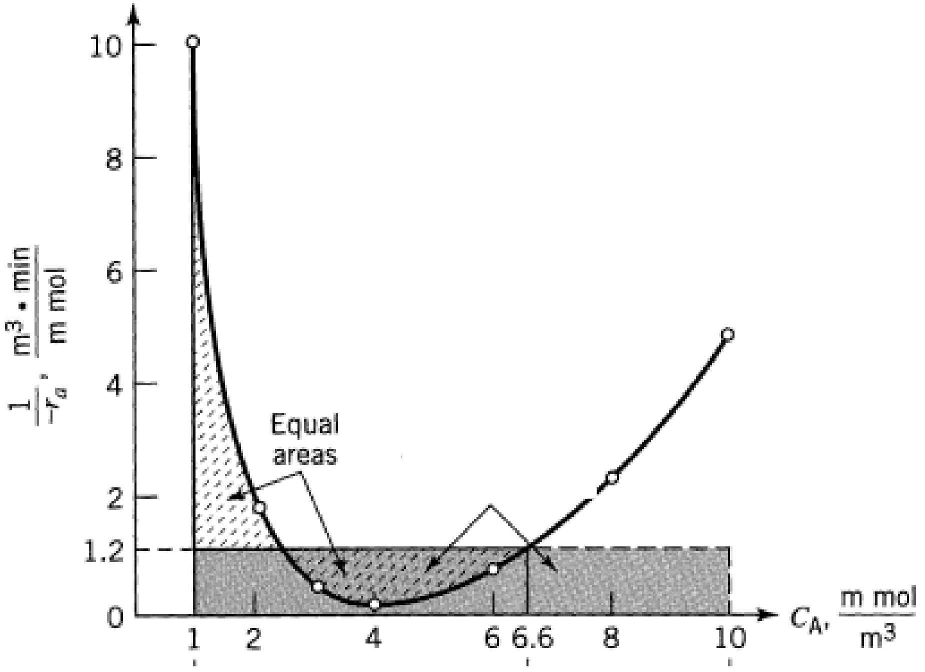
C_{A0}, mmol/m^3	2	5	6	6	11	14	16	24
C_A, mmol/m^3	0.5	3	1	2	6	10	8	4
τ, min	30	1	50	8	4	20	20	4

We wish to treat 0.1 m^3/min of this waste water having $C_{A0} = 10$ mmol/m^3 to 90% conversion with this enzyme at concentration C_E.

One possibility is to use a long tubular reactor (assume plug flow) with possible recycle of exit fluid. What design do you recommend? Give the size of the reactor, tell if it should be used with recycle, and if so determine the recycle ratio

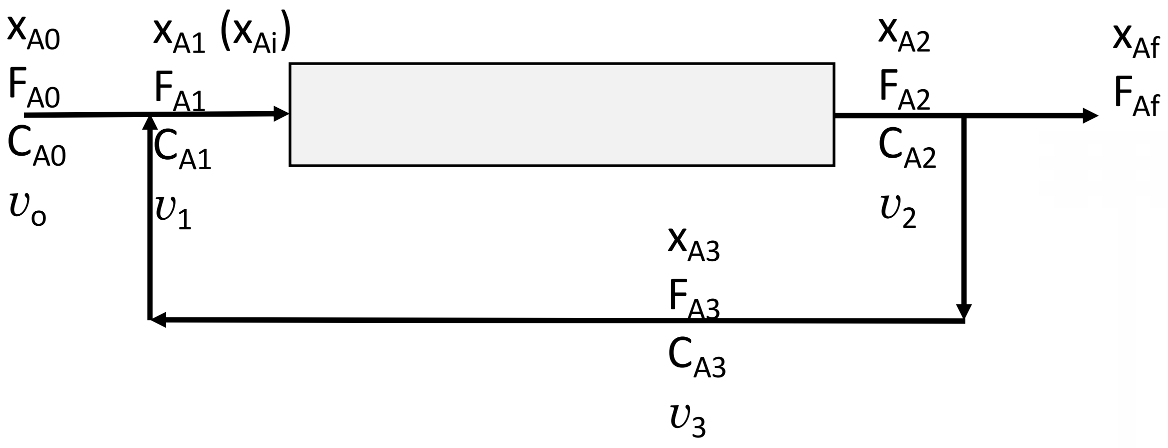
solution

C_{A0}, mmol/m^3	2	5	6	6	11	14	16	24
C_A, mmol/m^3	0.5	3	1	2	6	10	8	4
τ, min	30	1	50	8	4	20	20	4
$\frac{1}{-r_A} = \frac{\tau}{C_{A0} - C_A}$, $\frac{m^3 \cdot min}{mmol}$	20	0.5	10	2	0.8	5	2.5	0.2

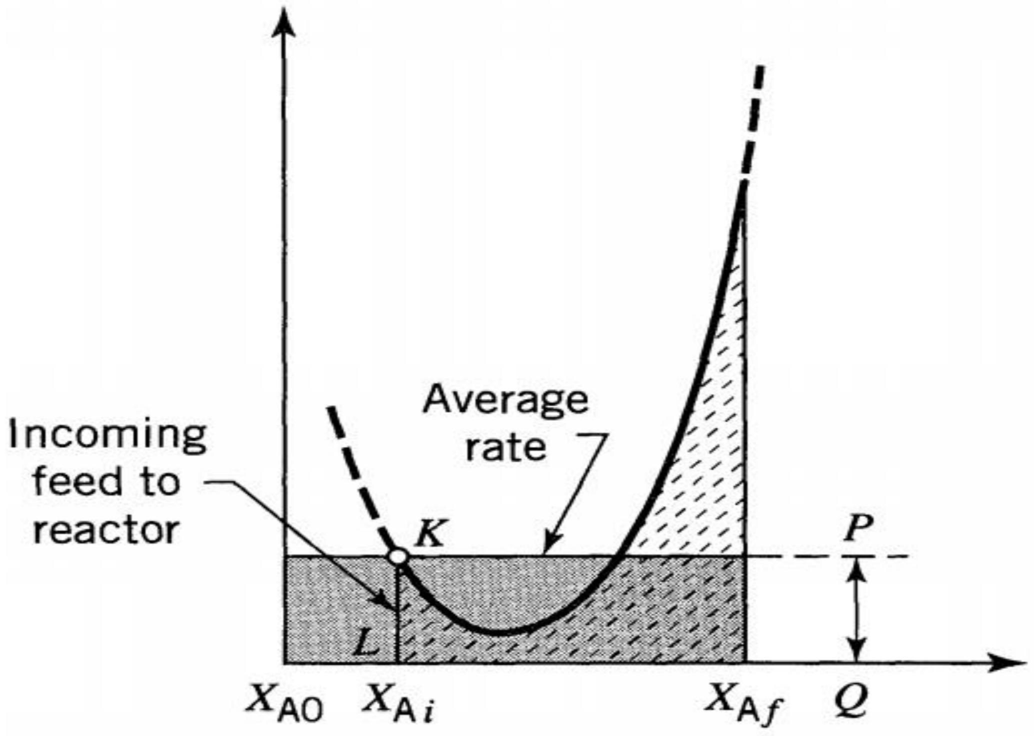


✓From the -l/r, vs. C, curve we see that we should use plug flow with recycle

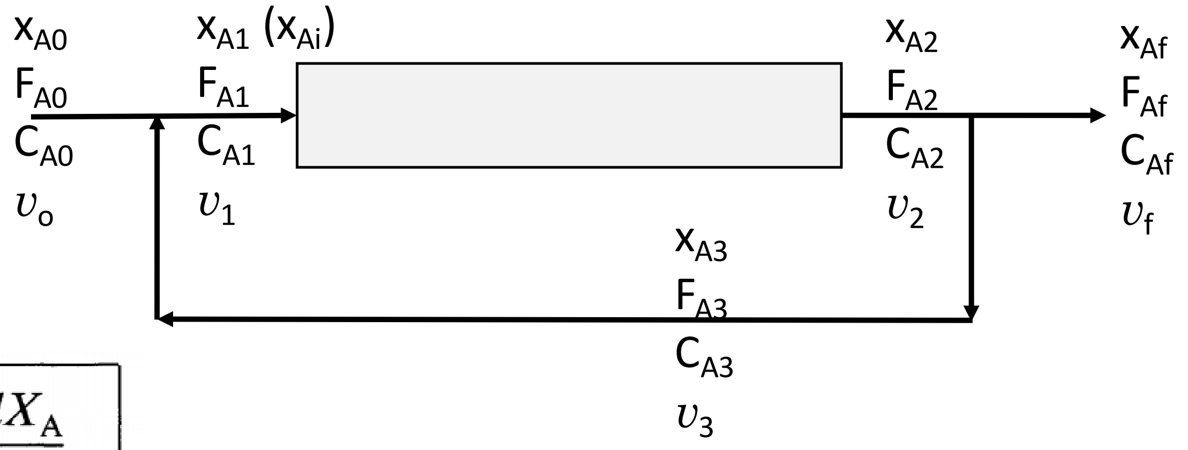
optimum recycle ratio (R)



$$\left.\frac{1}{-r_A}\right|_{X_{Ai}} = \frac{\int_{X_{Ai}}^{X_{Af}} \frac{dX_A}{-r_A}}{(X_{Af} - X_{Ai})}$$



✓In words, the optimum recycle ratio introduces to the reactor a feed whose $1/(-r_A)$ value (KL in Fig.) equals the average $1/(-r_A)$ value in the reactor as a whole (PQ in Fig.).



$$\boxed{\left.\frac{1}{-r_A}\right|_{X_{Ai}} = \frac{\int_{X_{Ai}}^{X_{Af}} \frac{dX_A}{-r_A}}{(X_{Af} - X_{Ai})}}$$

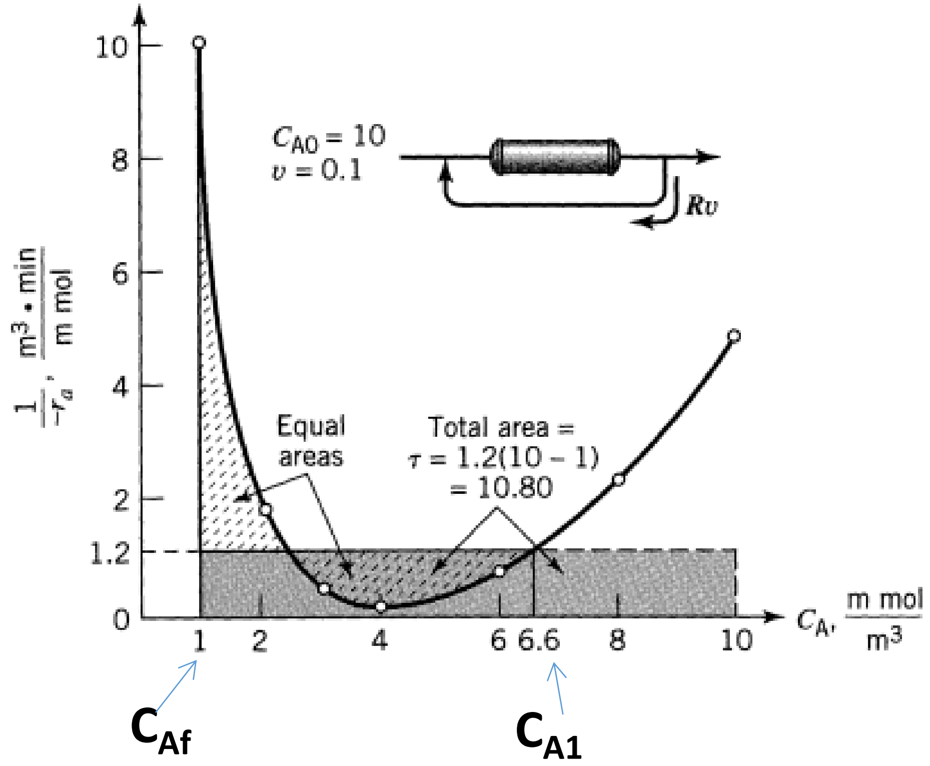
BY TRAIL AND ERROR METHOD $C_{A1} = 6.6\ \text{mmol/m}^3$

$$X_{Ai} = \left(\frac{R}{R+1}\right) X_{Af}$$

R=0.607

$$\frac{V}{F_{A0}} = \frac{\tau}{C_{A0}} = (R+1)\int_{\left(\frac{R}{R+1}\right)X_{Af}}^{X_{Af}} \frac{dX_A}{-r_A}$$

V=1.08 m3



Problem 3

We wish to explore various reactor setups for the transformation of A into R. The feed contains 99% A, 1% R; the desired product is to consist of 10% A, 90% R. The transformation takes place by means of the elementary reaction

$$A + R \rightarrow R + R$$

with rate constant $k = 1$ liter/mol · min. The concentration of active materials is

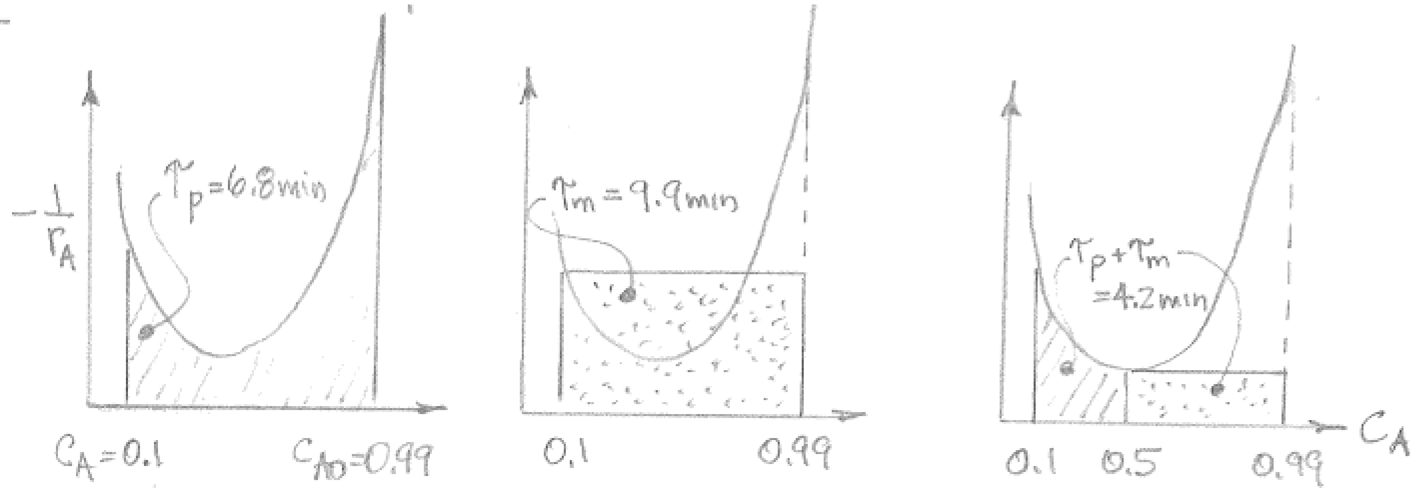
$$C_{A0} + C_{R0} = C_A + C_R = C_0 = 1 \text{ mol/liter}$$

throughout.

What reactor holding time will yield a product in which $C_R = 0.9$ mol/liter (a) in a plug flow reactor, (b) in a mixed flow reactor, and (c) in a minimum-size setup without recycle?

solution

C_A	C_R	$-r_A = kC_AC_R$	$\frac{1}{-r_A}$
0.99	0.01	0.0099	101.01
0.95	0.05	0.0475	21.05
0.90	0.1	0.09	11.11
0.70	0.3	0.21	4.76
0.50	0.5	0.25	4.00
0.30	0.7	0.21	4.76
0.10	0.9	0.09	11.11



So

$\tau_p = 6.8\ \text{min}$ ← a)

$\tau_m = 9.9\ \text{min}$ ← b)

$\tau_{best} = \tau_m + \tau_p = 2 + 2.2 = 4.2\ \text{min}$ ← c)