

Pertemuan 10

PLUG FLOW REACTORS (PFR/ RAP)

REAKTOR ALIR PIPA (RAP), ATAU PLUG FLOW REACTORS (PFR)

- ✘ Pada bab ini dipelajari analisis unjuk kerja dan perancangan RAP
- ✘ Seperti RATB, RAP selalu dioperasikan secara kontinyu pada keadaan tunak, selain daripada periode startup dan shutdown
- ✘ Tidak seperti RATB yg digunakan terutama untuk reaksi2 fasa cair, RAP dapat digunakan untuk reaksi2 fasa cair dan fasa gas.

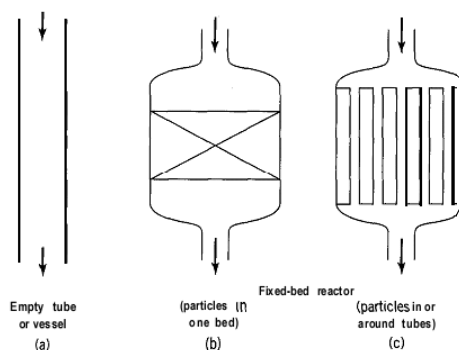
CIRI-CIRI UTAMA RAP

1. Pola aliran adalah PF, dan RAP adalah vesel tertutup
2. Kecepatan aliran volumetris dapat bervariasi secara kontinyu kearah aliran sebab perubahan densitas
3. Setiap elemen fluida mrp sistem tertutup (dibandingkan RATB); yaitu, tidak ada pencampuran kearah axial, meskipun terjadi pencampuran sempurna searah radial (dalam vesel silinder)
4. Sebagai konsekuensi dari (3) sifat2 fluida dapat berubah secara kontinyu kearah axial, tapi konstan secara radial (pada posisi axial tertentu)
5. Setiap elemen fluida mempunyai residence time yg sama seperti yg lain (dibandingkan RATB)

KEGUNAAN RAP

- ✘ Model RAP seringkali digunakan untuk sebuah reaktor yg mana sistem reaksi (gas atau cair) mengalir pada kecepatan relatif tinggi ($Re \gg$, sampai mendekati PF) melalui suatu vesel kosong atau vesel yg berisi katalis padat yg di packed
- ✘ Disini tidak ada peralatan seperti pengaduk, untuk menghasilkan backmixing
- ✘ Reaktor dapat digunakan dalam operasi skala besar untuk produksi komersial, atau di laboratorium atau operasi skala pilot untuk mendapatkan data perancangan

ILUSTRASI CONTOH RAP SKEMATIK



PERSAMAAN PERANCANGAN UNTUK RAP

Tinjau reaksi: $A + \dots \rightarrow \nu_c C$

Neraca Massa:
$$\frac{dV}{df_A} - \frac{F_{A0}}{(-r_A)} = 0 \quad (15.2-1)$$

Untuk mendapatkan volume:

$$V = F_{A0} \int df_A / (-r_A) \quad (15.2-2)$$

Pers 2 dinyatakan dalam space time $\tau = V/q_0$

$$\tau = c_{A0} \int df_A / (-r_A) \quad (15.2-3)$$

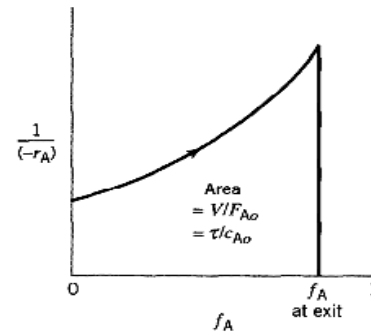
KARENA $c_{A0} = F_{A0}/q_0$

Bila pers (1) dituliskan kembali dalam gradien f_A terhadap perubahan posisi x dalam RAP
Asumsi reaktor berbentuk silinder dg jari-jari R .
Volume reaktor dari pemasukan sampai posisi x adalah:

$$V(x) = \pi R^2 x, \text{ or } dV = \pi R^2 dx$$

Substitusi dV ke pers (1) diperoleh

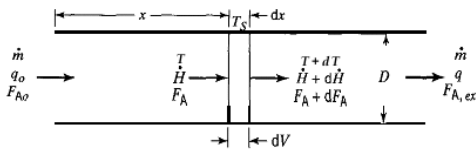
$$\frac{df_A}{dx} - \frac{\pi R^2 (-r_A)}{F_{A0}} = 0 \quad (15.2-4)$$



Gambar: Interpretasi pers (2) atau (3) secara grafik

NERACA ENERGI

- ✱ Pengembangan neraca energi untuk RAP, kita pertimbangkan hanya operasi keadaan tunak, jadi kecepatan akumulasi diabaikan.
- ✱ Kecepatan entalpi masuk dan keluar oleh (1) aliran, (2) transfer panas, (3) reaksi mungkin dikembangkan atas dasar diferensial kontrol volume dV seperti gambar berikut:



- 1) Kecepatan entalpi masuk oleh aliran – kecepatan entalpi keluar oleh aliran

$$= \dot{H} - (\dot{H} + d\dot{H}) = -d\dot{H} = -\dot{m}c_p dT$$

- 2) Kecepatan transfer panas ke (atau dari) kontrol volume

$$= \delta \dot{Q} = U(T_S - T)dA_p$$

Dengan U adalah koef perpindahan panas keseluruhan, T_S adalah temperatur sekitar diluar pipa pada titik tinjauan, dan dA adalah perubahan luas bidang transfer panas

- 3) Kecepatan entalpi masuk/ terbentuk (atau keluar/ terserap) oleh reaksi

$$= (-\Delta H_{RA})(-r_A)dV$$

Jadi persamaan neraca energi keseluruhan (1), (2), dan (3) menjadi:

$$-\dot{m}c_p dT + U(T_S - T)dA_p + (-\Delta H_{RA})(-r_A)dV = 0 \quad (15.2-5)$$

Persamaan (5) mungkin lebih sesuai ditransformasi ke hubungan T dan f_A , karena

$$dA_p = \pi D dx \quad (15.2-6)$$

$$\text{dan} \quad dV = (\pi D^2/4)dx \quad (15.2-7)$$

dengan D adalah diameter pipa atau vesel, substitusi (6) ke (7):

$$dA_p = (4/D)dV \quad (15.2-8)$$

Jika digunakan pers (1) dan (8) untuk mengeliminasi dV dan dA_p dari pers (5), didapatkan

$$\dot{m}c_p dT = \left[(-\Delta H_{RA}) + \frac{4U(T_S - T)}{D(-r_A)} \right] F_{A0} df_A \quad (15.2-9)$$

Secara alternatif, pers (5) dapat ditransformasi ke temperatur sebagai fungsi x (panjang reaktor), gunakan pers (6) dan (7) untuk eliminasi dA_p dan dV

$$\dot{m}c_p dT = [(-\Delta H_{RA})(-r_A)(D/4) + U(T_s - T)]\pi D dx \quad (15.2-10)$$

Untuk kondisi adiabatik pers (9) dan (10) dapat disederhanakan dg menghapus term U ($\delta Q = 0$)

NERACA MOMENTUM; OPERASI NONISOBARIK

- ✘ Sebagai Rule of Thumb, untuk fluida kompresibel, jika perbedaan tekanan antara pemasukan dan pengeluaran lebih besar dp 10 sampai 15%, perubahan tekanan seperti ini mempengaruhi konversi, dan harus dipertimbangkan jika merancang reaktor.
- ✘ Dalam situasi ini, perubahan tekanan disepanjang reaktor harus ditentukan secara simultan dengan perubahan f_A dan perubahan T
- ✘ Dapat ditentukan dengan pers Fanning atau Darcy untuk aliran dalam pipa silinder dapat digunakan (Knudsen and Katz, 1958, p. 80)

$$-\frac{dP}{dx} = \frac{2\rho u^2 f}{D} = \frac{32\rho q^2 f}{\pi^2 D^5} \quad (15.2-11)$$

DENGAN P ADL TEKANAN, X ADL POSISI AXIAL DLM REAKTOR, P ADL DENSITAS FLUIDA, U ADL KECEPATAN LINIER, F ADL FAKTOR FRIKSI FANNING, D ADL DIAMETER REAKTOR, DAN Q ADL LAJU ALIR VOLUMETRIK; P, U, DAN Q DAPAT BERVARIASI DENGAN POSISI

Nilai f dapat ditentukan melalui grafik utk pipa smooth atau dari korelasi. Korelasi yg digunakan untuk aliran turbulen dalam pipa smooth dan untuk bilangan Re antara 3000 dan 3000.000

$$f = 0.00140 + 0.125(Re)^{-0.32} \quad (15.2-12)$$

Pertemuan 11

CONSTANT-DENSITY SYSTEM

1. ISOTHERMAL OPERATION

- ✘ For a constant-density system, since

$$f_A = (c_{A0} - c_A)/c_{A0} \quad 14.3-12$$

$$\text{then } df_A = -(1/c_{A0})dc_A \quad 15.2-13$$

The residence time t and the space time τ are equal.

$$t = \int dV/q = V/q_0 = \tau \quad (\text{constant density}) \quad 15.2-14$$

$$\text{and } dt = dV/q_0 = d\tau \quad 15.2-15$$

THE ANALOGY FOLLOWS IF WE CONSIDER AN ELEMENT OF FLUID (OF ARBITRARY SIZE) FLOWING THROUGH A PFR AS A CLOSED SYSTEM, THAT IS, AS A BATCH OF FLUID. ELAPSED TIME (T) IN A BR IS EQUIVALENT TO RESIDENCE TIME (T) OR SPACE TIME (T) IN A PFR FOR A CONSTANT-DENSITY SYSTEM. FOR DV FROM EQUATION 15 AND FOR DFA FROM 13, WE OBTAIN, SINCE $F_{A0} = C_{A0}Q_0$,

$$\frac{dc_A}{dt} + (-r_A) = 0 \quad 15.2-16$$

we may similarly write equation 2 as

$$V/q_0 = - \int dc_A/(-r_A) = \tau \quad 15.2-17$$

A GRAPHICAL INTERPRETATION OF THIS RESULT IS GIVEN IN FIGURE 15.4.

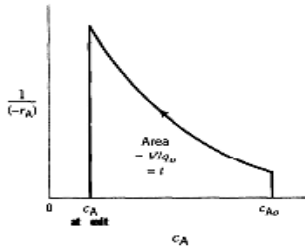


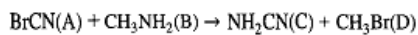
Figure 15.4 Graphical interpretation of equation 15.2-17 (constant-density system)

EXAMPLE 15-2

A liquid-phase double-replacement reaction between bromine cyanide (A) and methyl-amine takes place in a PFR at 10°C and 101 kPa. The reaction is first-order with respect to each reactant, with $k_A = 2.22 \text{ L mol}^{-1} \text{ s}^{-1}$. If the residence or space time is 4 s, and the inlet concentration of each reactant is 0.10 mol L^{-1} , determine the concentration of bromine cyanide at the outlet of the reactor.

SOLUTION

The reaction is:



Since this is a liquid-phase reaction, we assume density is constant. Also, since the inlet concentrations of A and B are equal, and their stoichiometric coefficients are also equal, at all points, $c_A = c_B$. Therefore, the rate law may be written as

$$(-r_A) = k_A c_A^2 \quad \text{A}$$

FROM EQUATIONS 16 AND (A),

$$-dc_A/dt = k_A c_A^2$$

which integrates to

$$k_A t = \frac{1}{c_A} - \frac{1}{c_{A0}}$$

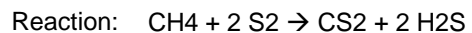
On insertion of the numerical values given for k_A , t , and c_{A0} , we obtain

$$c_A = 0.053 \text{ mol L}^{-1}$$

EXAMPLE 15-3

A gas-phase reaction between methane (A) and sulfur (B) is conducted at 600°C and 101 kPa in a PFR, to produce carbon disulfide and hydrogen sulfide. The reaction is first-order with respect to each reactant, with $k_B = 12 \text{ m}^3 \text{ mole}^{-1} \text{ h}^{-1}$ (based upon the disappearance of sulfur). The inlet molar flow rates of methane and sulfur are 23.8 and 47.6 mol h^{-1} , respectively. Determine the volume (V) required to achieve 18% conversion of methane, and the resulting residence or space time.

SOLUTION



Although this is a gas-phase reaction, since there is no change in T , P , or total molar flow rate, density is constant. Furthermore, since the reactants are introduced in the stoichiometric ratio, neither is limiting, and we may work in terms of B (sulphur), since k , is given, with $f_B (= f_A) = 0.18$. It also follows that $c_A = c_B/2$ at all points. The rate law may then be written as

$$(-r_B) = k_B c_A c_B = k_B c_B^2/2 \quad (A)$$

From the material-balance equation 17 and (A),

$$v = -q_0 \int_{c_{B0}}^{c_B} dc_B / (-r_B) = -q_0 \int_{c_{B0}}^{c_B} \frac{dc_B}{k_B c_B^2/2} = \frac{2q_0}{k_B} \left(\frac{1}{c_B} - \frac{1}{c_{B0}} \right) \quad (B)$$

Since $F_{B0} = c_{B0} q_0$, and, for constant-density, $c_B = c_{B0}(1 - f_B)$, equation (B) may be written as

$$V = \frac{2q_0^2}{k_B F_{B0}} \left(\frac{f_B}{1 - f_B} \right) \quad (C)$$

To obtain q_0 in equation (C), we assume ideal-gas behavior; thus,

$$q_0 = (F_{A0} + F_{B0})RT/P = 71.4(8.314)873/101,000 = 5.13 \text{ m}^3 \text{ h}^{-1}$$

From equation (C),

$$V = \frac{2(5.13)^2 0.18}{12(47.6)0.82} = 0.020 \text{ m}^3$$

From equation 14, we solve for τ :

$$\tau = \tau = V/q_0 = 0.020/5.13 = 0.00390 \text{ h} = 14.0 \text{ s}$$

2. NON ISOTHERMAL OPERATION

□ To characterize the performance of a PFR subject to an axial gradient in temperature, the material and energy balances must be solved simultaneously.

□ This may require numerical integration using a software package such as E-Z Solve. Example 15-4 illustrates the development of equations and the resulting profile for f_A , with respect to position (x) for a constant-density reaction.

EXAMPLE 15-4

A liquid-phase reaction $A + B \rightarrow 2C$ is conducted in a non isothermal multi tubular PFR. The reactor tubes (7 m long, 2 cm in diameter) are surrounded by a coolant which maintains a constant wall temperature. The reaction is pseudo-first-order with respect to A, with $k_A = 4.03 \times 10^5 e^{-5624/T}$, s^{-1} . The mass flow rate is constant at 0.06 kg s^{-1} , the density is constant at 1.025 g cm^3 , and the temperature at the inlet of the reactor (T_0) is 350 K .

- (a) Develop expressions for df_A/dx and dT/dx .
 (b) Plot $f_A(x)$ profiles for the following wall temperatures (T_S): 350 K , 365 K , 400 K , and 425 K .

Data: $C_{A0} = 0.50 \text{ mol L}^{-1}$; $c_p = 4.2 \text{ J g}^{-1} \text{ K}^{-1}$;
 $\Delta H_{RA} = -210 \text{ kJ mol}^{-1}$; $U = 1.59 \text{ kW m}^{-2} \text{ K}^{-1}$.

SOLUTION

(a) The rate law is

$$(-r_A) = k_A c_A = k_A c_{A0}(1 - f_A) \quad (A)$$

where k_A is given in Arrhenius form above. Substitution of equation (A) in the material-balance equation 15.2-4, $(F_{A0}/\pi r^2)df_A/dx$,

results in (with $R = D/2$ and $F_{A0}/C_{A0} = q_0$):

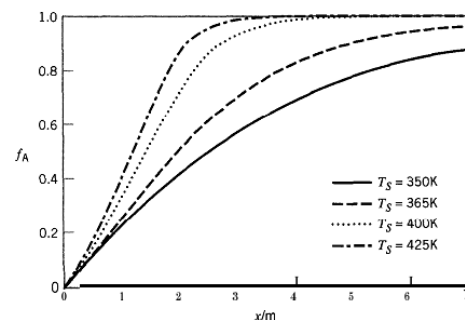


Figure 15.5 Effect of wall temperature (T_S) on conversion in a non-isothermal PFR (Example 15-4)

3. VARIABLE-DENSITY SYSTEM

- ✗ When the density of the **reacting system is not constant through a PFR**,
- ✗ The general forms of performance **equations of Section 15.2.1 must be used**.
- ✗ The effects of continuously varying density are usually **significant only for a gas-phase reaction**.
- ✗ Change in density may result from any one, or a combination, of: **change in total moles (of gas flowing), change in T, and change in P**.
- ✗ We illustrate these effects by examples in the following sections.

ISOTHERMAL, ISOBARIC OPERATION

Example 15.6

Consider the gas-phase decomposition of ethane (A) to ethylene at 750 °C and 101 kPa (assume both constant) in a PFR. If the reaction is first-order with $k_A = 0.534 \text{ s}^{-1}$ (Froment and Bischoff, 1990, p. 351), and τ is 1 s, calculate f_A . For comparison, repeat the calculation on the assumption that density is constant. (In both cases, assume the reaction is irreversible.)

SOLUTION

The reaction is $\text{C}_2\text{H}_6(\text{A}) \rightarrow \text{C}_2\text{H}_4(\text{B}) + \text{H}_2(\text{C})$. Since the rate law is

$$\tau = c_{A0} \int \frac{df_A}{(-r_A)} = \frac{1}{k_A q_0} \int_0^{f_A} \frac{q df_A}{1 - f_A} \quad (\text{A})$$

Stoichiometric table is used to relate q and q_0 . The resulting expression is

$$q = q_0 (1 + f_A)$$

With this result, equation (A) becomes

$$\tau = \frac{1}{k_A} \int_0^{f_A} \frac{(1 + f_A) df_A}{1 - f_A} \quad (\text{B})$$

THE INTEGRAL IN THIS EXPRESSION MAY BE EVALUATED ANALYTICALLY WITH THE SUBSTITUTION:

$z = 1 + f_A$, the result is:

$z = 1 - f_A$. The result is

$$-f_A - 2 \ln(1 - f_A) = k_A \tau = 0.534 \quad (\text{C})$$

Solution of equation (C) leads to $f_A = 0.361$

If the change in density is ignored, integration of equation 15.2-17, with $(-r_A) = k_A C_A = k_A C_{A0}(1 - f_A)$, leads to

$$\ln(1 - f_A) = -k_A \tau$$

from which

$$f_A = 0.414$$

NONISOTHERMAL, ISOBARIC OPERATION

Example 15.7

A gas-phase reaction between butadiene (A) and ethene (B) is conducted in a PFR, producing cyclohexene (C). The feed contains equimolar amounts of each reactant at 525 °C (T_0) and a total pressure of 101 kPa. The enthalpy of reaction is $-115 \text{ kJ (mol A)}^{-1}$, and the reaction is first-order with respect to each reactant, with $k_A = 32,000 e^{-13,850/T} \text{ m}^3 \text{ mol}^{-1} \text{ S}^{-1}$. Assuming the process is adiabatic and isobaric, determine the space time required for 25% conversion of butadiene.

Data: $C_{pA} = 150 \text{ J mol}^{-1} \text{ K}^{-1}$; $C_{pB} = 80 \text{ J mol}^{-1} \text{ K}^{-1}$; $C_{pC} = 250 \text{ J mol}^{-1} \text{ K}^{-1}$

SOLUTION

The reaction is $\text{C}_4\text{H}_6(\text{A}) + \text{C}_2\text{H}_4(\text{B}) \rightarrow \text{C}_6\text{H}_{10}(\text{C})$. Since the molar ratio of A to B in the feed is 1: 1, and the ratio of the stoichiometric coefficients is also 1: 1, $C_A = C_B$ throughout the reaction. Combining the material-balance equation (15.2-2) with the rate law, we obtain

$$\begin{aligned} V &= F_{A0} \int \frac{df_A}{(-r_A)} = F_{A0} \int \frac{df_A}{k_A C_A C_B} = F_{A0} \int \frac{df_A}{k_A C_A^2} \\ &= F_{A0} \int \frac{df_A}{k_A (F_A/q)^2} = \frac{1}{F_{A0}} \int_0^{f_A} \frac{q^2 df_A}{k_A (1 - f_A)^2} \quad (\text{A}) \end{aligned}$$

Since k_A depends on T , it remains inside the integral, and we must relate T to f_A . Since the density (and hence q) changes during the reaction (because of changes in temperature and total moles), we relate q to f_A and T with the aid of a stoichiometric table and the ideal-gas equation of state.

Species	Initial moles	Change	Final moles
A	F_{A0}	$-f_A F_{A0}$	$F_{A0}(1-f_A)$
B	F_{A0}	$-f_A F_{A0}$	$F_{A0}(1-f_A)$
C	0	$f_A F_{A0}$	$F_{A0} f_A$
total	$2F_{A0}$		$F_I = F_{A0}(2-f_A)$

Since at any point in the reactor, $q = F_i RT/P_i$, and the process is isobaric, 4 is related to the inlet flow rate q_0 by

$$\frac{q}{q_0} = \frac{F_{A0}(2-f_A)T}{2F_{A0}T_0}$$

That is, $q = q_0(1 - 0.5f_A)T/T_0$

Substitution of equation (B) into (A) to eliminate q results in

$$\tau = \frac{V}{q_0} = \frac{1}{c_{A0}T_0^2} \int_0^{f_A} \frac{(1-0.5f_A)^2 T^2}{k_A(1-f_A)^2} df_A \quad (C)$$

To relate f_A and T , we require the energy balance (15.2-9)

$$\dot{m}c_p dT = F_i C_p dT = (-\Delta H_{RA})F_{A0} df_A \quad (D)$$

$$\begin{aligned} F_i C_p &= F_A C_{PA} + F_B C_{PB} + F_C C_{PC} \\ &= F_{A0}(1-f_A)C_{PA} + F_{A0}(1-f_A)C_{PB} + F_{A0}f_A C_{PC} \\ &= F_{A0}[(C_{PA} + C_{PB}) + (C_{PC} - C_{PA} - C_{PB})f_A] \end{aligned} \quad (E)$$

Substituting equation (E) in (D), and integrating on the assumption that $(-\Delta H_{RA})$ is constant, we obtain

$$T = T_0 + (-\Delta H_{RA}) \int_0^{f_A} \frac{df_A}{(C_{PA} + C_{PB}) + (C_{PC} - C_{PA} - C_{PB})f_A} \quad (F)$$

$$\begin{aligned} T &= 798 + 115,000 \int_0^{f_A} \frac{df_A}{230 + 20f_A} \\ &= 798 + \frac{115,000}{20} [\ln(230 + 20f_A) - \ln 230] \\ &= 798 + 5750[\ln(230 + 20f_A) - 5.4381] \end{aligned} \quad (G)$$

RECYCLE OPERATION OF A PFR

In a chemical process, the use of recycle, that is, the return of a portion of an outlet stream to an inlet to join with fresh feed, may have the following purposes:

- (1) to conserve feedstock when it is not completely converted to desired products, and/or
- (2) to improve the performance of a piece of equipment such as a reactor.

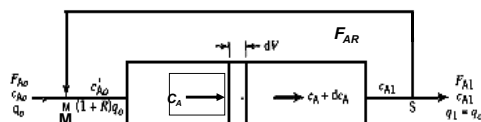


Figure 15.6 Flow diagram and terminology for recycle PFR (constant density)

$$\begin{aligned} R &= \frac{\text{molar flow rate of A in recycle stream}}{\text{molar flow rate of A in product stream}} \\ &= \frac{F_{AR}}{F_{A1}} = \frac{c_{A1} q_R}{c_{A1} q_1} = \frac{q_R}{q_1} \quad (15.3-1) \\ &= \frac{\text{volumetric flow rate of recycle stream}}{\text{volumetric flow rate of product stream}} \end{aligned}$$

where subscript R refers to recycle and subscript 1 to the vessel outlet. Equation 15.3-1 is applicable to both constant-density and variable-density systems

R may vary from 0 (no recycle) to a very large value (virtually complete recycle).

Thus, as shown quantitatively below, we expect that a recycle PFR may vary in performance between that of a PFR with no recycle and that of a CSTR (complete recycle), depending on the value of R

Constant-Density System

$$R = q_R/q_0 \quad (\text{constant density}) \quad (15.3-2)$$

Material balance for A around M:

$$q_0 c_{A0} + R q_0 c_{A1} = (1+R) q_0 c'_{A0}$$

$$c'_{A0} = \frac{c_{A0} + R c_{A1}}{1+R} \quad (15.3-3)$$

MATERIAL BALANCE FOR A AROUND THE DIFFERENTIAL CONTROL VOLUME DV

$$(1+R)q_0 c_A = (1+R)q_0(c_A + dc_A) + (-r_A)dV$$

$$V/q_0 = \tau = -(1+R) \int_{c_{A0}}^{c_{A1}} \frac{dc_A}{(-r_A)} \quad (15.3-4)$$

$$\begin{aligned} (1+R)c'_{A0} &= c_{A0} + Rc_{A1} && \text{(from 15.3-3)} \\ &= c_{A0} + Rc_{A1} + Rc_{A0} - Rc_{A0} \\ &= (1+R)c_{A0} + R(c_{A1} - c_{A0}) \end{aligned}$$

Therefore,

$$\frac{c_{A0} - c'_{A0}}{c_{A0} - c_{A1}} = \frac{R}{1+R} \quad (15.3-5)$$

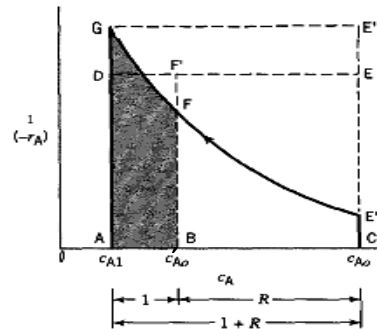


Figure 15.7 Graphical interpretation of equation 15.3-4 for recycle PFR (constant density)

EXAMPLE 15-9

- (a) For the liquid-phase autocatalytic reaction $A + \dots \rightarrow B + \dots$ taking place isothermally at steady-state in a recycle PFR, derive an expression for the optimal value of the recycle ratio, R_{opt} , that minimizes the volume or space time of the reactor. The rate law is $(-r_A) = k_A c_A c_B$.
- (b) Express the minimum volume or space time of the reactor in terms of R_{opt} .

VARIABLE-DENSITY SYSTEM

- ✕ For the reaction $A + \dots \rightarrow$ products taking place in a recycle PFR

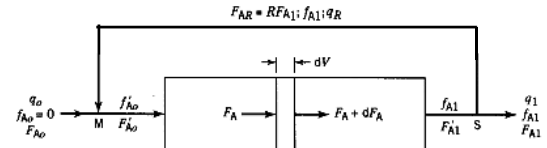


Figure 15.9 Flow diagram and terminology for recycle PFR (constant or variable density)

FROM A MATERIAL BALANCE FOR A AROUND THE MIXING POINT M, THE MOLAR FLOW RATE OF A ENTERING THE REACTOR IS

$$F'_{A0} = F_{A0} + RF_{A1} \quad (15.3-8)$$

At the exit from the system at S, or at the exit from the reactor,

$$\begin{aligned} f_{A1} &= \frac{F_{A0} - F_{A1}}{F_{A0}} = \frac{(1+R)F_{A0} - (1+R)F_{A1}}{(1+R)F_{A0}} \\ &= \frac{(1+R)F_{A0} - F'_{A1}}{(1+R)F_{A0}} \end{aligned}$$

$$\text{where } F'_{A1} = (1+R)F_{A1}$$

CORRESPONDINGLY, AT THE INLET OF THE REACTOR

$$\begin{aligned} f'_{A0} &= \frac{(1+R)F_{A0} - F'_{A0}}{(1+R)F_{A0}} = \frac{(1+R)F_{A0} - (F_{A0} + RF_{A1})}{(1+R)F_{A0}} \\ &= \frac{R}{1+R} \frac{F_{A0} - F_{A1}}{F_{A0}} = \frac{R}{1+R} f_{A1} \end{aligned} \quad (15.3-9)$$

and at any point in the reactor,

$$f_A = \frac{(1+R)F_{A0} - F_A}{(1+R)F_{A0}} \quad (15.3-10)$$

EQUATING MOLAR FLOW INPUT AND OUTPUT, FOR STEADY-STATE OPERATION, WE HAVE

$$F_A = F_A + dF_A + (-r_A)dV$$

$$dV = -\frac{dF_A}{(-r_A)} = (1 + R)F_{A0} \frac{df_A}{(-r_A)}$$

from equation 15.3-10. Therefore,

$$V = (1 + R)F_{A0} \int_{f_{A0}}^{f_{A1}} \frac{df_A}{(-r_A)} \quad (15.3-11)$$

That is, as $R \rightarrow 0$, V is that for a PFR without recycle; as $R \rightarrow \infty$, V is that for a CSTR

Sekian dan terimakasih