new topic

November 21th

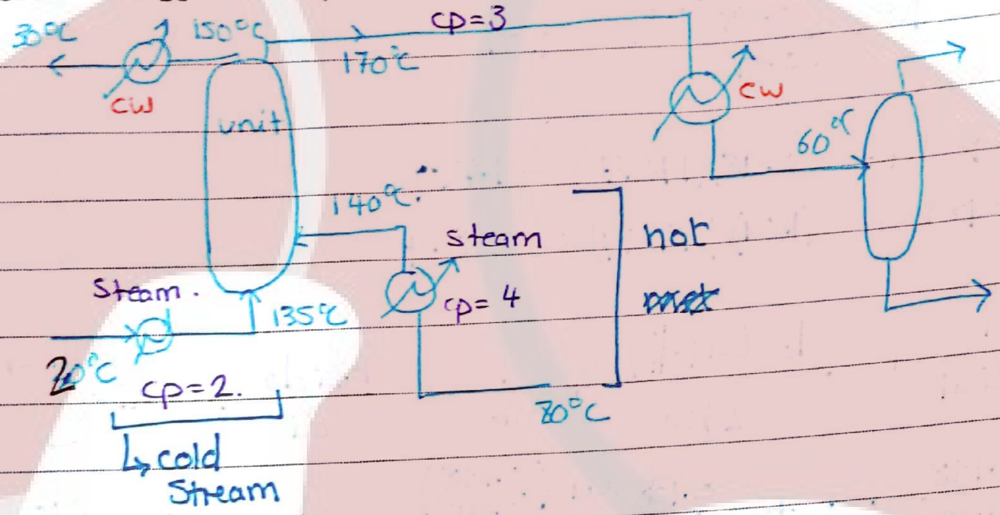
HEAT INTEGRATION : PINCH TECHNOLOGY

No.

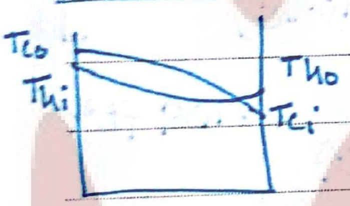
* heating utility : ST

→ HOW TO REDESIGN EQUIPMENTS TO HAVE THE LEAST AMOUNT OF EXCHANGER

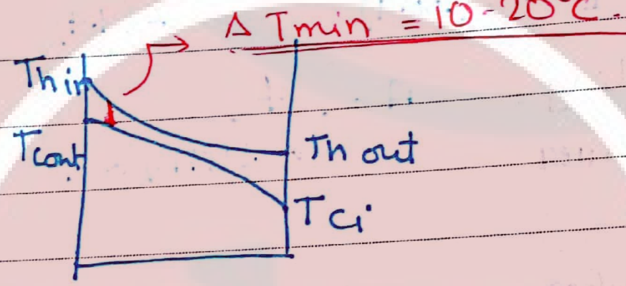
ILLUSTRATED EXAMPLE



➤ Sub case:

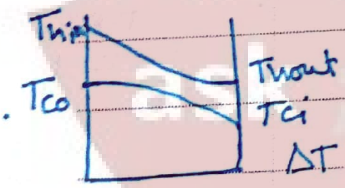


⟹



Can't be : haven't reach achieved.

→ originally :



$\Delta T_{min} \simeq 10°C$

hot ⟶ add $\frac{\Delta T_{min}}{2}$ to cold stream.

↝ cold

subtract $\frac{\Delta T_{min}}{2}$ from hot stream.

↝ ↑ cp ↑ q.

→ For simplicity: all calculations are based on unit flow rate.

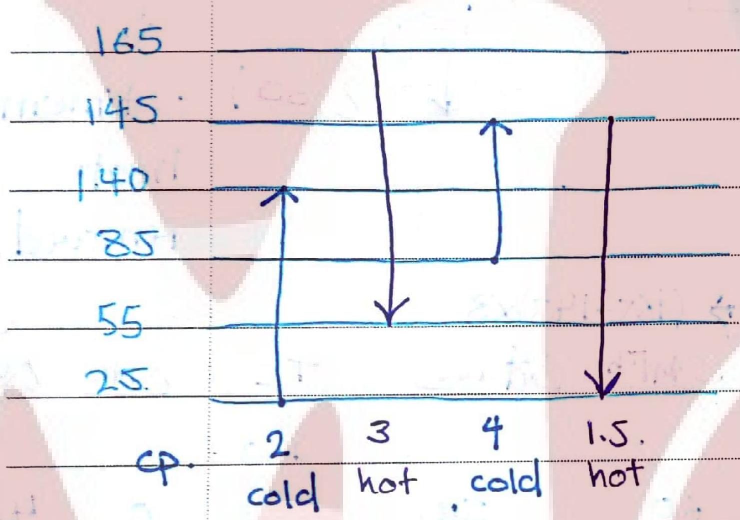
$\frac{\Delta T_{min}}{2} = \frac{10}{2}$ → add to cold, subtract from hot.

new values. November 21th.

No.

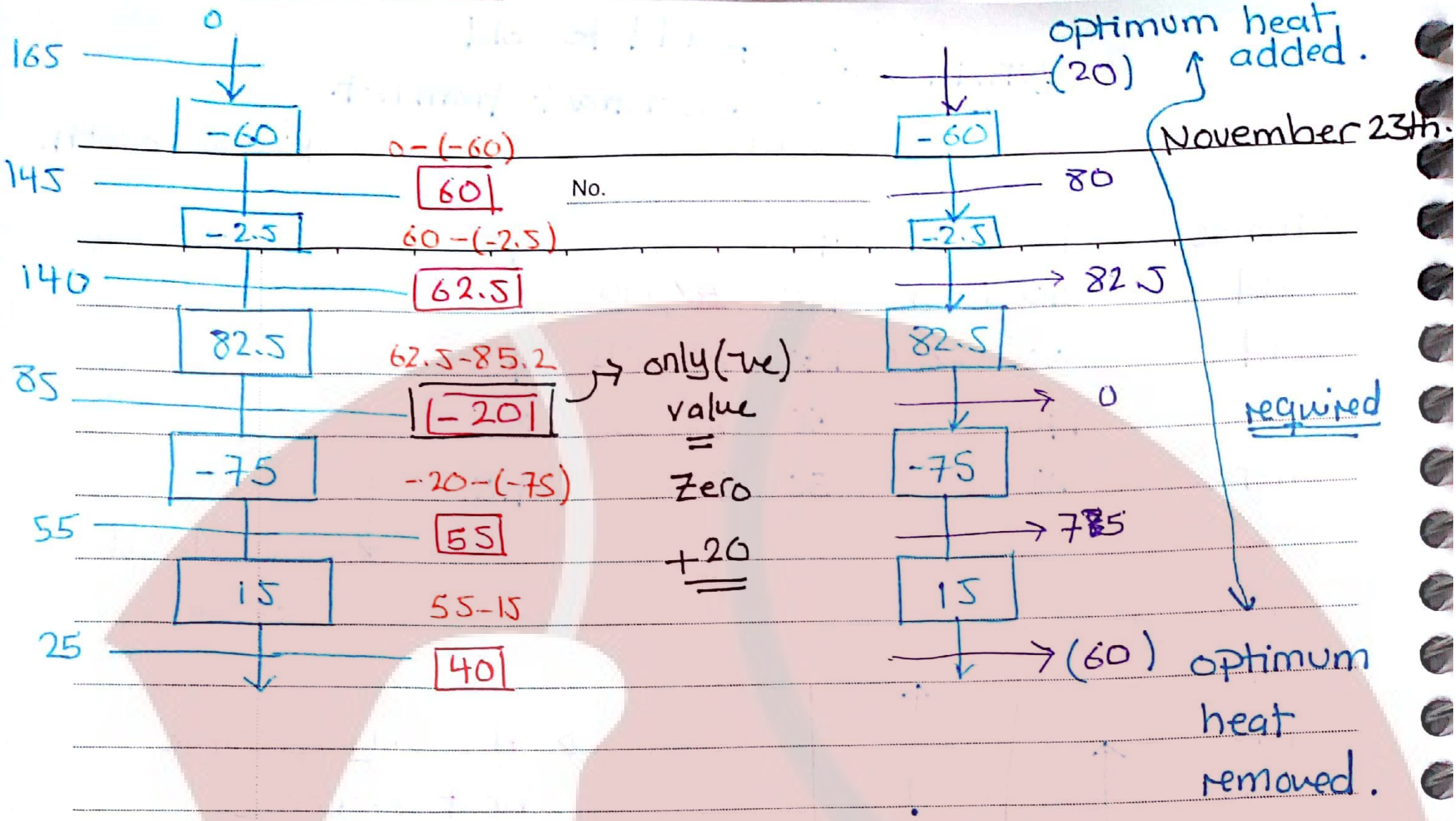
streams	Ts		Tf		cp
cold	20	(25)	135	(~~[illegible]~~) 140	2
cold	80	(~~[illegible]~~) 85	140	(~~[illegible]~~) 145	4
hot	170	(165)	60	(~~[illegible]~~) 55	3
hot	150	(145)	30	(25)	1.5

include all streams



⇒ the only possible heat exchange.

T	interval	$T_i - T_{i+1}$	$\Sigma Cp_c - \Sigma Cp_H$	$Cp\Delta T$ / ΔH_i	excess heat Surpulus / Defisit
165					
	1	20	$\Sigma 0 - \Sigma 3 = -3$	−60 kW	S
145					
	2	5	$4-(3+1.5) = -0.5$	−2.5 kW	S
140					
	3	55	$(4+2)-(3+1.5) = 1.5$	82.5 kW	D
85					
	4	30	$(2)-(3+1.5) = -2.5$	−75 kW	S
55					
	5	30	$(2)-1.5 = 0.5$	15 kW.	D
25					



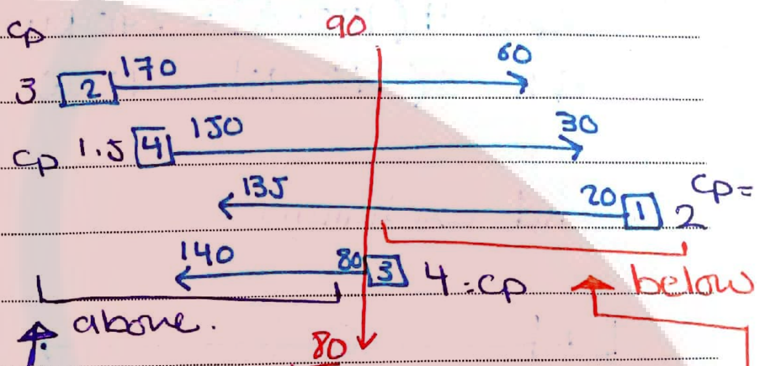
Method I.

→ (165-145)x3

T	ΣCp_c	ΣCp_h	T_h	ΔH_h	ΔH_h acc	T_c	ΔH_c	acc ΔH_c
165			170			160		
	0	3	~~170~~	60	510		0	470
145			150			140		
	4	4.5	~~150~~	22.5	450		20	470
140			~~[illegible]~~ 145			135		
	6	4.5	~~[illegible]~~	247.5	427.5		330	450
85			90			50		
	2	4.5	~~90~~	135	180		60	120
55			60			20		
	2	1.5		45	45		60	60
25			30					

↑ accumilation up wards.

T	$\Delta H_{acc\,h}$	$\Delta H_{acc\,C}$	T
170			160
	510	470	
150			140
	450	470	
145			135
	427.5	450	
90			80
	180	120	
60			50
	45	60	
30			20



→ NO HEAT EXCHANGE ACROSS THE PINCH (80-90)

→ DON'T USE COLD UTILITY ABOVE THE PINCH

→ DON'T USE HOT UTILITY BELOW THE PINCH.

Matching: → work above the pinch.

$\boxed{Cp_c > Cp_h}$, max $|Cp_c - Cp_h| \Delta t$.

stream 1 can match with stream 4 only.

→ $Cp_c = 2 > Cp_h = 1.5$

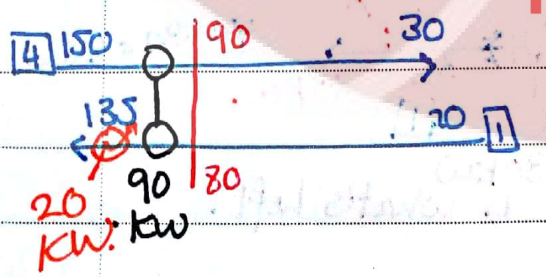
Find duty:

$Q_c = Cp_c (Tc_2 - Tc_1) = 2(135-80) = 110$ kW.

$Q_h = Cp_h (Th_2 - Th_1) = 1.5(150-90) = 90$ kw (pinch)

First exchanger:-

+ heater



→ this stream still needs heating.

Mach [2] v.s. [3] November 26.

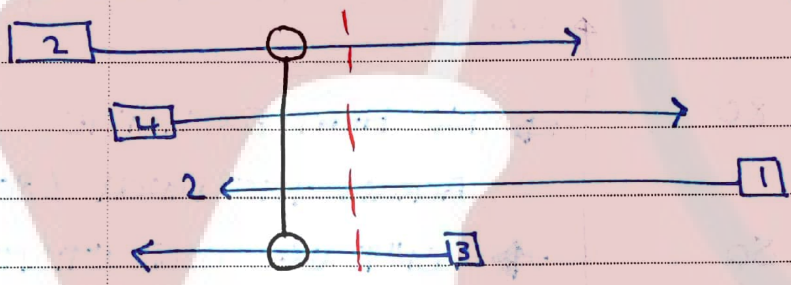
No.

$Cp_c = 4 > Cp_h = 3.$

$Q_c = 4(140-80) = 240\,kw$ } perfect match

$Q_h = 3(170-90) = 240\,kw$

Second exchanger:-



240kw.

⇒ THIS ALL FOR Above the pinch.

⇒ <u>BELOW THE PINCH</u>:-

$Cp_h > Cp_c$ max $|Cp_h - Cp_c| \Delta t$

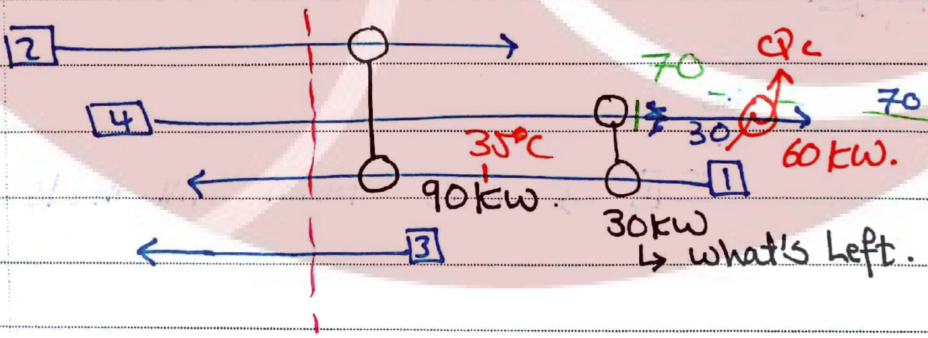
Stream [2] with [1]

$Q_h = Cp_h (T_2 - T_1) = 3(90-60) = 90\,kw$ ↓ isn't enoug.

$Q_c = 2(80-20)\ 120\,kw$ → $Q_c = \cancel{120}$

$90 = 2(80 - T_{c\,new})$

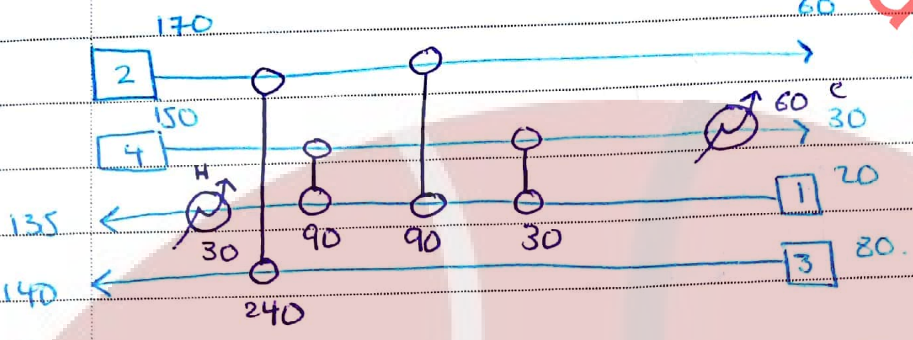
$T = 35°C.$

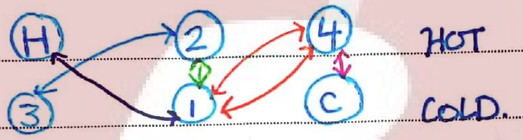


70 - 30 = 40 + add cooler.

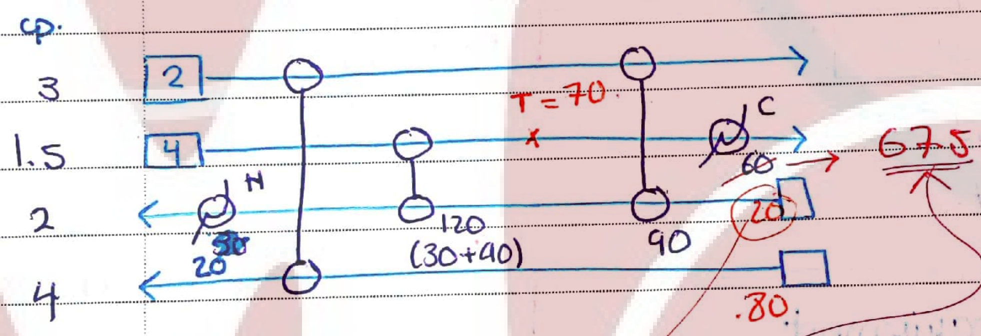
$Q_h = Cp(90 - T_h) = 30°C$

$90 - T_h = \frac{30}{1.5} = 20°C$ $T_h = 90 - 20 = 70°C$





☒ you can only manipulate streams with heaters/coolers



$Q = 120 = 1.5(150 - T) = 70°C.$ } ΔTmin = 5 < 10 violation.
$Q = 90 = 2(T - 20) = 65°C$ } ⇒ need either to 70 → 75, 65 → 60.

$T_{new} = 75°C$: $Q = 1.5(75 - 30) = 67.5$.

→ old duty.

Old Temp $Q = 112.5 \neq 2(120 - 65) = 110$

$Q = (112.5) = 2(T - 65)$ ⇒ $T = 121°C$.

⇒ new $Q_H = 2(135 - 121) = 27.5$ kW.

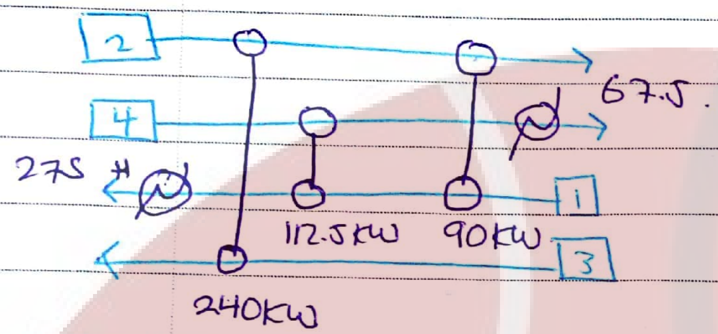
New $Q_c = 67.5$ kW $- 27.5$ kW $=$

* Relaxation of energy to maintain the pinch point.

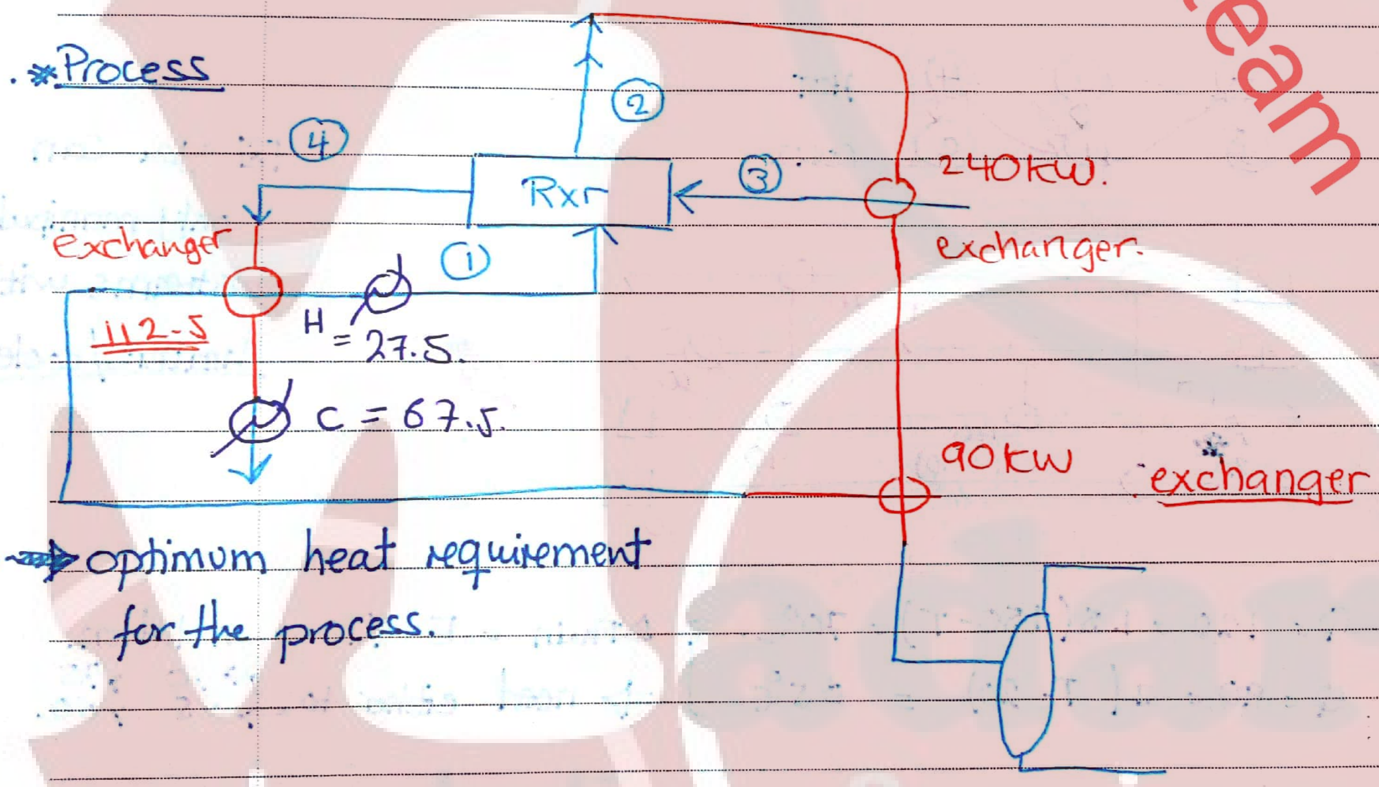
⇒ 67.5: optimum/minimum value to have Nov. 28th

No.

Finally min ΔT.



* Process



→ optimum heat requirement for the process.

→ Total heat duty = |hot| + |cold|

$= 240 + 90 + 112.5 + 67.5 + 27.5$

$= 537.5 \text{ kW}$.

→ * no. of exchangers = 3 + cooler + heater

Resolve:

* $\Delta T_{min} = 20^\circ$

find the total heat duty.

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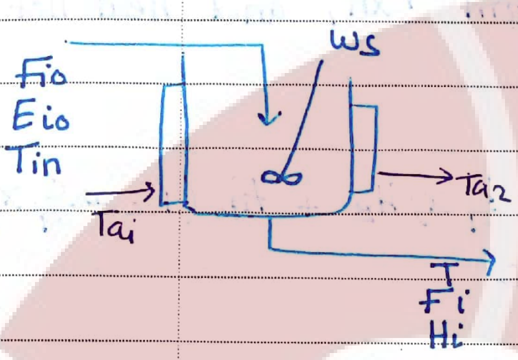
⇒ non isothermal CSTR design.



* energy balance =

energy in − energy out + $\dot{Q} - \dot{W} = \frac{dE}{dt}$.

$$\underbrace{F_i E_i}_{in} - \underbrace{F_o E_o}_{out} + \dot{Q} - WT = \frac{dE}{dt}$$

$$E = U_i + \cancel{KE} + \cancel{PE} + \cancel{h_L}^{\text{friction}}$$

$$\boxed{E \cong U_i}$$

$$\frac{dE_{sys}}{dt} = \dot{Q} - \dot{W} + \underbrace{\sum F_i H_i}_{in} - \underbrace{\sum F_i H_i}_{out}$$

(enthalpy)

NOTE : $\sum F_i H_{i\,in} = \sum F_i H_i^{\circ}$ (standard)

$\sum F_i H_{i\,out}$ = all energy associated with rxn and heat in the stream.

$$I + A + \frac{b}{a}B \longrightarrow \frac{c}{a}C + \frac{d}{a}D + I$$

$$\sum F_i H_i = F_A H_A + F_B H_B + F_C H_C + F_D H_D + F_I H_I$$

$F_A = F_{Ao}(1 - x)$

$F_B = F_{Ao}\left(\theta_B - \frac{b}{a}x\right)$ $\quad \theta_B = \frac{F_{Bo}}{F_{Ao}}$

$F_C = F_{Ao}\left(\theta_C + \frac{c}{a}x\right)$

$F_D = F_{Ao}\left(\theta_D + \frac{d}{a}x\right)$

outlet stream

↳ we need to seperate heat from rxn, and heat not accosciated.

$$\sum_{out} F_i H_i = F_{A0}(1-x)H_A + F_{A0}\left(\Theta_B - \frac{b}{a}x\right)H_B + F_{A0}\left(\Theta_C + \frac{c}{a}x\right)H_C + F_{A0}\left(\Theta_D + \frac{d}{a}x\right)H_D$$

$$= \left(F_{A0}H_A + F_{A0}\Theta_B H_B + F_{A0}\Theta_C H_C + F_{A0}\Theta_D H_D + F_{A0}\Theta_I H_I \right.$$

$+$ اكو ايضا.

$$\sum_{out} F_i H_i = \left(\sum_{i=1}^{n} F_i \Theta_i H_i\right) + X F_{A0}\left[\frac{d}{a}H_D + \frac{c}{a}H_C - \frac{b}{a}H_B - H_A\right] + \text{inert}$$

$$\sum_{out} F_i H_i = \sum F_i \Theta_i H_i + X F_{A0}\Delta H_R(T)$$

$$\dot{Q} - \dot{W}_s = F_{A0}\sum \int_{T_0}^{T} \Theta_i C_{P_i}\, dT - [\Delta H_R(T)] F_{A0} X = 0.$$

↓

split to two terms.

T_R standard | of the reaction.

$T_0 \rightarrow T_R$ | $T_R \rightarrow T$

energy equation

$$\dot{Q} - \dot{W}_s - F_{A0}\sum_{i=1}^{n}\int_{T_0}^{T} \Theta_i C_{P_i}\, dT - \underbrace{\left[\Delta H_R^{\circ}(T) + \int_{T_R}^{T} \Delta C_p\, dT\right] F}$$

↳ X

↳ T

need a coupling equation.

⇒ Design equation of CSTR

No. December 5th.

Design equation : $V = \frac{F_{A0} - F_A}{-r_A} = \frac{F_{A0} X}{-r_A} = f(X, T)$.

$r_A = f(T, X)$ $\quad r_A = k C_A^{\alpha}$ $\quad k = Ae^{-\frac{E_A}{RT}}$) polymath

Q: changes with temp of Jacket.
temp of Jacket changes with reaction Temp.

need to Find it

$Q = UA\,\Delta T_{LM}$ multiplied with correction factor
Simple $\boxed{f=1}$

Substitute in energy transfered.

LMTD equation. $LMTD = \frac{(T - T_{a1}) - (T - T_{a2})}{\ln\left(\frac{T - T_{a1}}{T - T_{a2}}\right)}$ T: temp in CSTR

$= \frac{T_{a2} - T_{a1}}{\ln\left(\frac{T - T_{a1}}{T - T_{a2}}\right)}$

energy balance across the Jacket

Rate in − Rate out = Rate of heat transfered to Rx

$\dot{m}\,c_p(T_{a1} - T_R) - \dot{m}\,c_p(T_{a2} - T_R) = \frac{UA(T_{a1} - T_{a2})}{\ln\left(\frac{T - T_{a1}}{T - T_{a2}}\right)}$

at inlet $\quad$ ref. $\quad$ at outlet

madar_team

ask ;; believe & recieve

No.

energy balance :

$$\dot{Q} - \dot{W}_s - F_{A0} \sum \int_{T_0}^{T} \Theta_i C_{p_i} dT - \left[\Delta H_R^\circ(T_R) + \int_{T_R}^{T} \Delta C_p dT \right] F_{A0} X = 0$$

$\dot{Q}$ ↓

* relate it with Q for Jacket
* Q Jacket changes with temp. → Ta_2 → get an expression

energy balance : across the Jacket

$$m c_p (Ta_1 - T_R) - m c_p (Ta_2 - T_R) = UA \frac{(Ta_1 - Ta_2)}{\ln\left(\frac{Ta_1 - T}{Ta_2 - T}\right)}$$

madar_team

⊛ Rewriting:

$$m c_p (Ta_1 - Ta_2) = UA \frac{(Ta_1 - Ta_2)}{\ln\left(\frac{Ta_1 - T}{Ta_2 - T}\right)}$$

T in side the other in side

$$Ta_2 = T - (T - Ta_1) e^{\left(\frac{-UA}{m c_p}\right)}$$

→ * expression for Ta_2

$$Q = m c_p (Ta_1 - Ta_2)$$

$$= m c_p \left(Ta_1 - \left(T - (T - Ta_1) e^{\left(\frac{-UA}{m c_p}\right)} \right) \right)$$

$$Q = m c_p \left[(Ta_1 - T) \left\{ 1 - e^{\frac{-UA}{m c_p}} \right\} \right]$$

ask, believe & recieve

Simplify using Tyler Series

$$e^{-x} = 1 - x + \ldots$$

$$Q = m c_p (Ta_1 - T) \left[1 - \left(1 - \frac{UA}{m c_p} \right) \right]$$

$$\dot{Q} = UA (Ta_1 - T)$$

↳ overall heat cofficient related to (h) → local heat coefficient effected by temp

NOT added to unknown (is included in volume)

December 7th.

No.

$\Delta H_R^\circ (T_R) + \Delta c_p (T - T_R)$

$$\boxed{\frac{UA}{F_{A0}}(T_a - \overset{?}{T}) - \sum \Theta_i C_{pi} (\overset{?}{T} - T_0) - \Delta \overset{?}{H_R}(T) \overset{?}{X} = 0}$$

(Shaft work) $= 0$

Design equation

$$\boxed{\overset{?}{V} = \frac{F_{A0} X^{?}}{-r_A^{?}}}$$

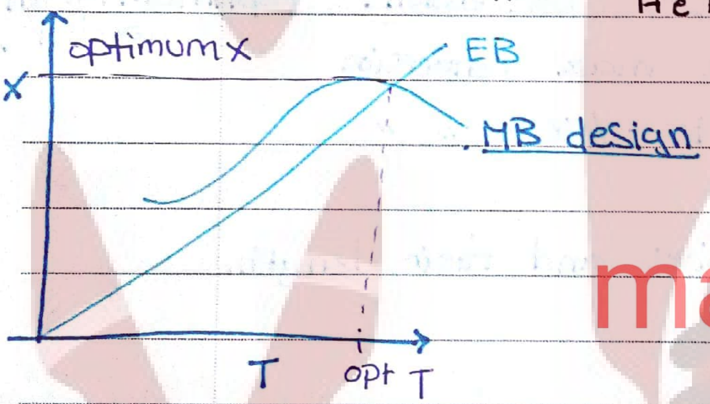
$r_A = k C_A^{\alpha}$

$k = A e^{-\frac{E_a}{RT}}$

$\Rightarrow$ Assume a value of volume $\xrightarrow{\text{then}}$ Find $\boxed{X}$ $\boxed{T}$

example: $r_A = -k C_A$

$$V = \frac{F_{A0} X}{k C_A} = \frac{F_{A0} X}{A e^{\frac{-E_A}{RT}} C_A (1-X)} = f(T, X).$$



* HW: Repeat the Design for $A + 2B \longrightarrow C$ *

Design of steady state December 10th, 2017

tubular reactor.

if exothermic ⇒ going down ↑ ~~Temp~~ Temp. buildup.

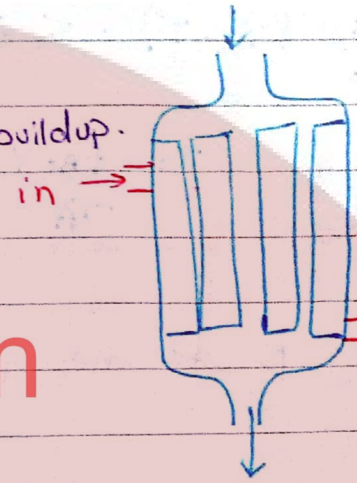
∴ conversion ↓ with time

(X) (need it to stay constant)

⇒ and vice versa for endothermix.

a Jacket is added.

to ~~de~~ maintain temp. constant.



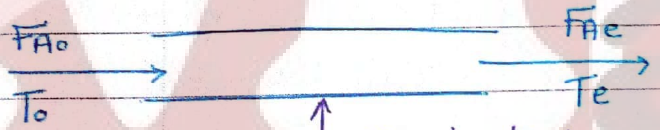
tubular
NOT
plug
Flow.
ما بيعطي
ع
ال
tubular
بيعطي
pf ع

→ length of tubes ⇒ affects conversion. (optimum length needed)

→ optimise temp to achieve max. conversion

→ " no. of tubes to achieve " "

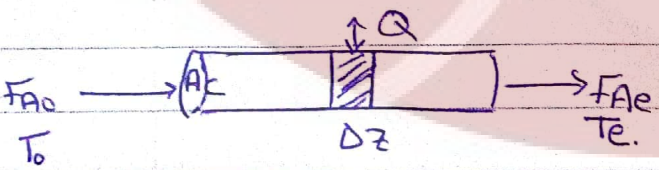
⇒ Ratio between no. of tubes and their length.



↕ Q: heat removal. (NOT constant)

⇒ need an expression

energy balance :
$$\dot{Q} - F_{Ao}\int_{T_o}^{T} \Sigma Q_i C_{P_i}\, dT - \left[\Delta H^\circ_R(T_R) + \int_{T_R}^{T} \Delta C_p\, dT\right] F_{Ao} X$$
$$= 0$$



$\{\Delta V = A_c * \Delta z\}$

→ with respect to length

December 10th

No.

→ variation of T/X with volume

$$\frac{dQ}{dV} - F_{A_0}\sum \Theta_i C_{p_i}\frac{dT}{dV} - \Big[\Delta H^\circ_R(T_R)\,F_{A_0}\frac{dX}{dV}$$

$$+\ \Delta C_p F_{A_0} X \frac{dT}{dV} + \Big(F_{A_0}\int_{T_R}^{T}\Delta C_p\, dT\Big)\frac{dX}{dV}\Big] = 0$$

$\dot{Q} = UA(T_a - T)$

نشتق بالنسبة للحجم

$$\frac{d\dot{Q}}{dV} = Ua(T_a - T)$$

$\boxed{a = A/\Delta V} \Rightarrow a = \dfrac{\pi D L}{\frac{\pi D^2}{4}L} = \dfrac{4}{D}$

unit area / unit volume

لا يرسم الآخر

* Rearrange:
$$\frac{dT}{dV} = \frac{Ua(T_a - T) + \Big(F_{A_0}\boxed{\frac{dX}{dV}}\Big)\Big[-\Delta H^\circ_R(T_R) - \int_{T_R}^{T}\Delta C_p\, dT\Big]}{F_{A_0}\left(\sum \Theta_i C_{p_i} + X\Delta C_p\right)}$$

Design equation:
$$-\frac{F_{A_0}\,dX}{dV} = r_A$$

given, standard (given), Func. of temp.

$$\frac{dT}{dV} = \frac{Ua(T_a - T) + (\boxed{-r_A})\Big[-\Delta H^\circ_R(T_R) - \int_{T_R}^{T}\Delta C_p\, dT\Big]}{F_{A_0}\left(\sum \Theta_i C_{p_i} + X\cdot\Delta C_p\right)}$$

↓

$f(X, T)$

couple this equation with other equation.

(II unknowns) (II equation).

other equation
$$\frac{dX}{dV} = \frac{-r_A}{F_{A_0}}$$

New Topic

December 10th.

No.

Packed bed flow reactor Design

⇒ catalyst.

⇒ find the rate with respect to mass of catalyst.

(*) Ratio between (mass | volume) catalyst. ⇒ DENSITY.

$$\rho = \frac{m}{V} \Rightarrow V\rho = m$$

$$\rho\, dV = dm$$

$$\boxed{dV = \frac{dm}{\rho}}$$

⇒

energy equation :
$$\frac{dT}{dw} = \frac{\frac{U_a}{U_b}(T_a - T) + \sum_{i=1}^{n_{RXN}} (-r_{ij})(-\Delta H_{Rij}(T))}{\sum_{k=1}^{n} F_k C_{P_k}}$$

k: no. of components.

w: weight of catalyst.

b: bulk

$$-\frac{1}{2}\frac{dC_A}{dw} = \frac{dC_c}{dt}$$

example: $A \longrightarrow B \quad = R_1$

$2A \longrightarrow C \quad = R_2$

$$\left[\begin{array}{l|l} r_1A = -k_1 C_A & r_1B = k_1 C_A \\ r_2A = -k_2 C_A^2 & r_2C = \frac{1}{2} k_2 C_A^2 \end{array}\right]$$

$$\frac{dT}{dw} = \frac{\frac{U_a}{U_b}(T_a - T) + \left[(-r_1)\left(\Delta H^\circ_{R_1}(T_R) + \int_{T_R}^{T} \Delta C_p\, dT\right|_{R_1}\right] + \left[(-r_2)\left\{\Delta H^\circ_{R_2}(T_R) + \int_{T_R}^{T} \Delta C_p\, dT\right|_{R_1}\right]}{F_A C_{P_A} + F_B C_{P_B} + F_C C_{P_C}}$$

net rxn.
$$\begin{cases} r_A = -k_1 C_A - k_2 C_A^2 \\ r_B = k_1 C_A \\ r_c = \frac{1}{2} k_2 C_{A_2} \end{cases}$$

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VAPOR PHASE REACTION.

December 10th

No.

$F_A = F_{A0}(1-x)$

$r_i = f(C_i)$

Design equation (each for comp)

$$\frac{dF_A}{dW} = r_A \qquad C_A = C_{T0}\frac{F_A}{F_T}\frac{T_0}{T}\frac{P}{P_0} \quad f(T,P,x)$$

$$\frac{dF_B}{dW} = r_B \qquad C_B = C_{T0}\frac{F_B}{F_T}\frac{T_0}{T}\frac{P}{P_0} \quad f(T,P,x)$$

$$\frac{dF_C}{dW} = r_C \qquad C_C = C_{T0}\frac{F_C}{F_T}\frac{T_0}{T}\frac{P}{P_0} \quad f(T,P,x)$$

$\vdots$

N-comp.

III equation III unknowns

$\Rightarrow$ need to resolve with an equation

December 12

Energy equation

$$\frac{dT}{dW} = \frac{\frac{Ua(T_a-T)}{\rho_b} + \sum_{i=1}^{n}(1-\nu_{ij})(-\Delta H_{R_{ij}}(T))}{\sum_{i=1}^{n_{comp}} F_i C_{p_i}}$$

$\Rightarrow$ Pressure drop equation

$$\frac{dP}{dW} = \frac{-\alpha}{2}\frac{T}{T_0}\frac{P_0}{(P/P_0)}\frac{F_T}{F_{T0}}$$

$$\alpha = \frac{2\beta_0}{A_c\rho_c(1-\phi)P_0}$$

$$\beta_0 = \frac{G(1-\phi)}{\rho_0 g_c D_p \phi^3}\left[\frac{150(1-\phi)\mu}{D_p} + 1.75G\right]$$

$$W = (1-\phi)A_c Z \rho_c$$