Problem 1

Given two hot and two cold streams with the following data:

Name	Type	T_s °C	T_t °C	Q kW
H1	Hot	250	40	31500
H2	Hot	200	80	30000
C1	Cold	20	180	32000
C2	Cold	140	230	27000

a) Calculate the CP (kW/K) for each stream.

b) The minimum temperature difference in this process is set to 10°C. Draw composite curves for the hot and cold streams such that $\Delta T_{\min} = 10$°C.

c) What is minimum demand for external heating and cooling and what is maximum heat recovery?

d) Use the rules for design of heat exchanger networks (pinch design rules) and draw a network that may give maximum heat recovery.

a) Vet at $Q = C_p \Delta T \Rightarrow C_p = \frac{Q}{\Delta T}$

Dermed: $C_{p,H_1} = 150$ kW/K

$C_{p,H_2} = 250$ kW/K

$C_{p,C_1} = 200$ kW/K

$C_{p,C_2} = 300$ kW/K

b)

Strøm	Cp [kW/K]	$T_s - T_t$	$\Delta H / Q$	$T_s' - T_t'$
H_1	150	250-40	31500	245-35
H_2	250	200-80	30000	195-75
C_1	200	20-180	32000	25-185
C_2	300	140-230	27000	145-235

Hot composite curve:

$\Delta T'$	Streams	Energy
245-195	H_1	7500
195-75	$H_1 + H_2$	48000
75-35	H_1	6000

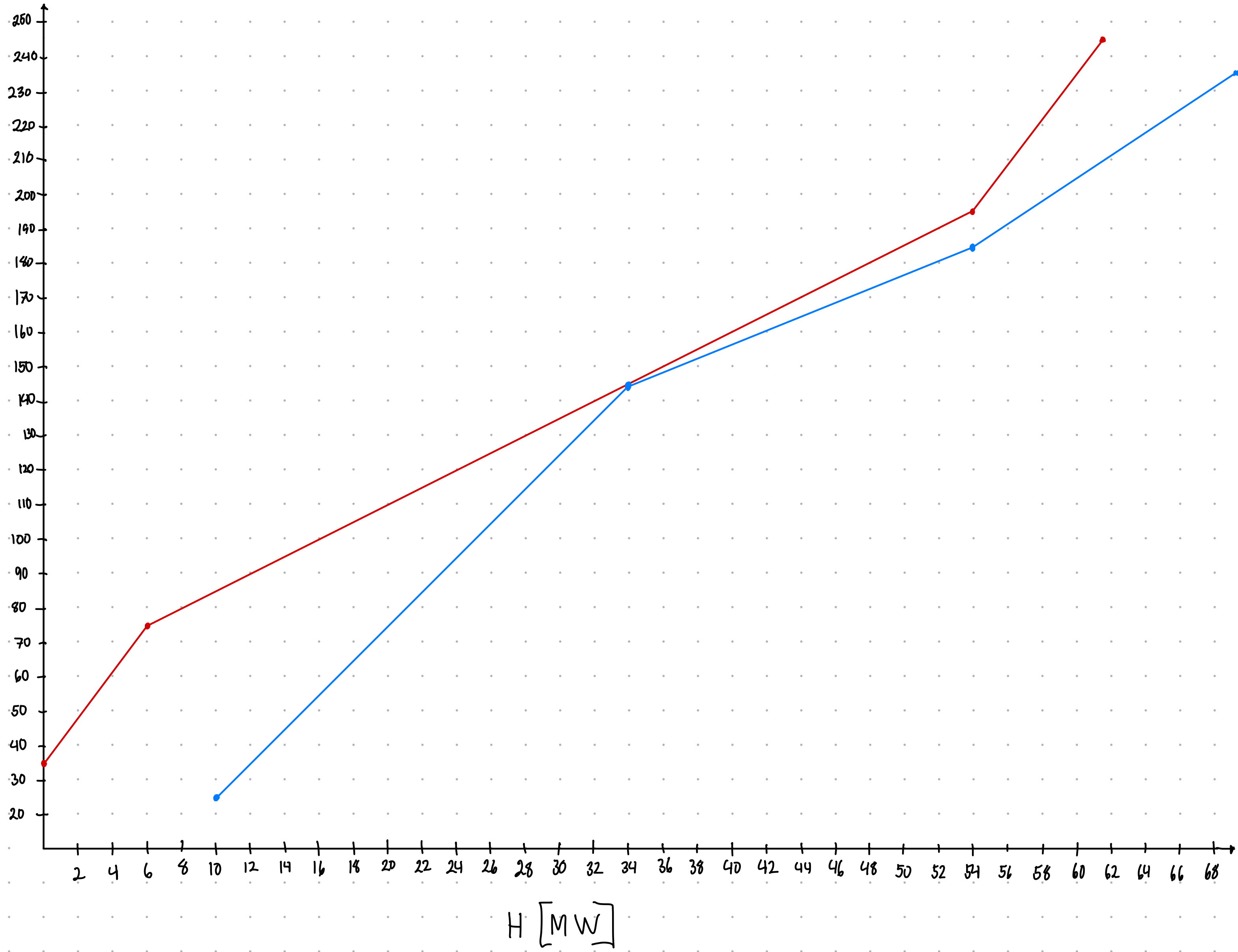
Cold composite curve

$\Delta T'$	Streams	Energy
25-145	C_1	24000
145-185	$C_1 + C_2$	20 000
185-235	C_2	15 000

Fra problem tabell (lenger ned), pinch ved 145 °C

Da har $H_{varm} = 6000 + (150+250) \cdot (145-75) = 34000$

$\Rightarrow$ Start H_{kald} på $34000 - 24000 = 10000$



c)

Problem tabell:

$\Delta H = [\sum C_{p,h} - \sum C_{p,c}]\Delta T$

T'	Strøm	ΔH	ST=0	ST=7500
245			0	7500
	H_1	+1500		
235			1500	9000
	H_1 C_2	-6000		
195			-4500	3000
	H_1 H_2 C_2	+1000		
185			-3500	4000
	H_1 H_2 C_1 C_2	-4000		
145			-7500	0 Pinch
	H_1 H_2 C_1	+14000		
75			6500	14000
	H_1 C_1	-2000		
35			4500	12000
	C_1	-2000		
25			2500	10000

Ser fra tabellen at minimum ekstern oppvarming er **7500 kW**

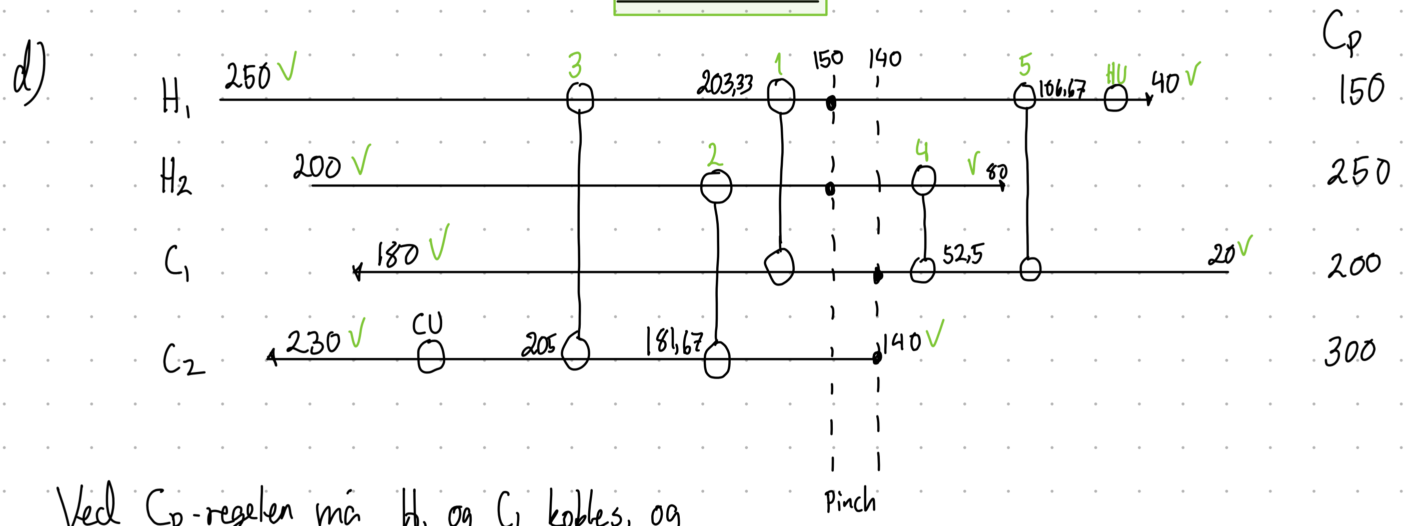
minimum ekstern kjøling er **10 000 kW**

$$Q_{rec} = \sum \Delta H_H - Q_{c,min}$$

$$= 61500 - 10\,000$$

$$= 51500 \text{ kW}$$

d)



Ved Cp-regelen må H_1 og C_1 kobles, og H_2 og C_2 ved pinch varmeveksler

HX1: H_1: $(250-150) \cdot 150 = 15000$
C_1: $(180-140) \cdot 200 = 8000$ } C_1 blir "tomt"

$$T_{H_1,ut} = 150 + \frac{8000}{150} = 203{,}33$$

HX2: H_2: $(200-150) \cdot 250 = 12500$
C_2: $(230-140) \cdot 300 = 27\,000$ } H_2 ferdig

$$T_{C_2,ut} = 140 + \frac{12500}{300} = 181{,}67$$

Henter ut resterende varme i H_1 ved HX3

HX3: H_1: $(250-203{,}33) \cdot 150 = 7000$
C_2: $(230-181{,}67) \cdot 300 = 14500$ } H_1 ferdig

$$T_{C_2,ut} = 181{,}67 + \frac{7000}{300} = 205 \Rightarrow \Delta T_{min} \text{ er bevart i HX3}$$

CU: $Q_h = 14500 - 7000 = 7500 \Rightarrow$ Stemmer med c)

Under pinch : $C_{p,c} \leq C_{p,h}$

Kobler H_2 og C_1

HX4: $H_2 : (150 - 80) \cdot 250 = 17500$
$C_1 : (140 - 20) \cdot 200 = 24000$ } H_2 ferdig

$$T_{C_1,ut} = 140 - \frac{17500}{200} = 52,5$$

Kjøler ned H_1 med "resten" av C_1

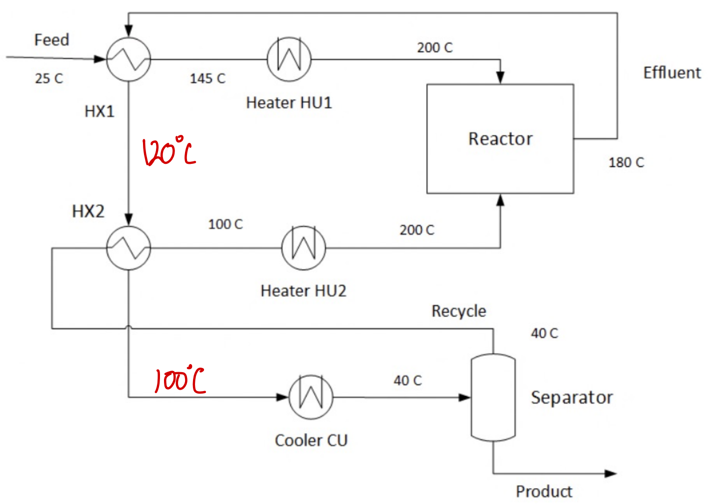
HX5: $H_1 : (150-40) \cdot 150 = 16500$
$C_1 : (52,5-20) \cdot 300 = 6500$ } C_1 "tomt"

$$T_{H_1,ut} = 150 - \frac{6500}{150} = 106,67 \Rightarrow \Delta T_{min} \text{ er opprettholdt.}$$

HU: $Q_h = 16500 - 6500 = 10\,000$ som stemmer med oppgave c)

Problem 2

An existing process is as described in the figure below.



For the existing design:

a) Calculate the temperature of the effluent stream after the two heat exchangers, HX1 and HX2

b) Calculate the duty of the two heaters and the cooler

c) Calculate the necessary area of the second heat exchanger (HX2) when the overall heat transfer is 100 W/(m²K)

The existing process may not be a maximum energy recovery design.

d) Calculate the minimum external heating and cooling when the minimum temperature approach between cold and hot streams is 10 °C and find the pinch temperature

e) If the existing process is not a maximum energy recovery design, make a new design of the heat exchanger network that obtain maximum energy recovery

f) Is it possible to reduce the number of heat exchangers? Draw the new design similar to the figure above

The start and target temperatures of the three streams are as indicated in the figure and data are given in the table below.

Stream	Start temperature [°C]	Target temperature [°C]	Overall heat capacity [kW/°C]
Feed	25	200	3
Effluent	180	40	6
Recycle	40	200	2

a) Assuming no heat loss, $Q_h = Q_c$

HX1: $(180 - T) \cdot 6 = (145 - 25) \cdot 3$

$\Rightarrow$ $T = 120°C$

HX2: $(120 - T) \cdot 6 = (100 - 40) \cdot 2$

$\Rightarrow$ $T = 100°C$

b)

$Q_{HU1} = (200-145)\cdot 3 = 165$

$Q_{HU2} = (200-100)\cdot 2 = 200$

$Q_{CU} = (100-40)\cdot 6 = 360$

c)

$$Q = UA\cdot \Delta T_{lm}$$

$$A = \frac{Q}{\Delta T_{lm}}$$

HX1:

$Q = 360$ kW

Antar motstrøm

$$\left.\begin{array}{l}\Delta T_1 = 180-145 = 35 \\ \Delta T_2 = 120-25 = 95\end{array}\right\} \Delta T_{lm} = \frac{\Delta T_2 - \Delta T_1}{\ln \frac{\Delta T_2}{\Delta T_1}} = 60{,}088\ K$$

$$A = \frac{360\cdot 10^3\ W}{60{,}088\ K\cdot 100\ W/m^2K} = \underline{\underline{59{,}91\ m^2}}$$

HX2:

$Q = 120$ kW

Antar motstrøm

$$\left.\begin{array}{l}\Delta T_1 = 120-100 = 20 \\ \Delta T_2 = 100-40 = 60\end{array}\right\} \Delta T_{lm} = \frac{\Delta T_2 - \Delta T_1}{\ln \frac{\Delta T_2}{\Delta T_1}} = 36{,}410\ K$$

$$A = \frac{120\cdot 10^3\ W}{36{,}410\ K\cdot 100\ W/m^2K} = \underline{\underline{32{,}96\ m^2}}$$

d)

Strøm	Cp [kW/K]	$T_s - T_t$	$T_s' - T_t'$
Feed (F)	3	25 - 200	30 - 205
Effluent (E)	6	180 - 40	175 - 35
Recycle (R)	2	40 - 200	45 - 205

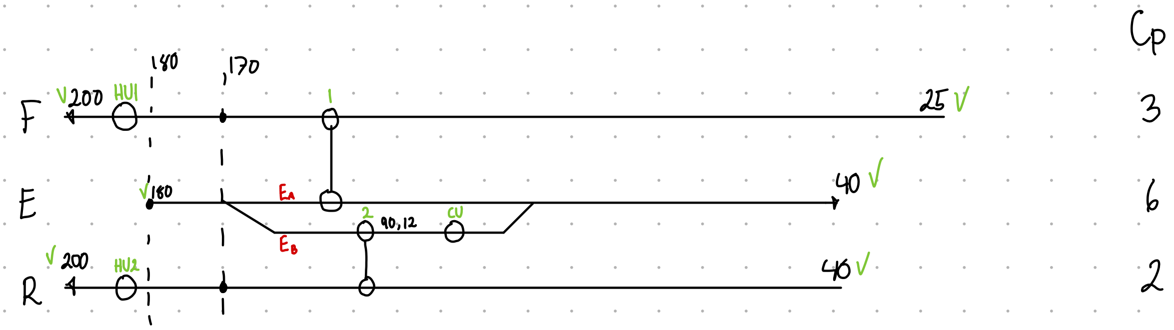
$T' = T \pm \frac{1}{2}\Delta T_{min}$

T'	Strøm	$\Delta H = (\sum C_{ph} - \sum C_{pc})\Delta T$	ST=0	ST=150	
205			0	150	
	F R	−150			
175			−150	0	Pinch
	F E R	+130			
45			−20	130	
	F E	+30			
35			10	160	
	F	−15			
30			−5	145	

Fra tabellen: $Q_{h,min} = 150$
$Q_{c,min} = 145$

Pinch temperature $T' = 175 \Rightarrow$ Pinch: 180-170

e) Ser at $Q_{h,min} < Q_{HU1} + Q_{HU2}$ og $Q_{c,min} < Q_{CU} \Rightarrow$ Ikke MER



Over pinch

Har ingen varm strøm å bruke ⇒ kun ekstern oppvarming

HU1: $Q = (200-170)\cdot 3 = 90$

HU2: $Q = (200-170)\cdot 2 = 60$

Tot: $Q_h = 150$, hvilket er lik $Q_{h,min}$

Under pinch

For å opprettholde ΔT_{min}, må vi splitte E i 2

Antar at vi har splittet slik at E_A "fullfører" F
Dermed

HX1: F: $(170-25)\cdot 3 = \underline{435}$
E_A: $(180-40)C_{pE_A} = \underline{435}$
} F + E_A ferdig

$\Rightarrow C_{pE_A} = \frac{435}{180-40} = 3{,}107$

81/28

$C_{pE_B} = 6 - C_{pE_A} = 2{,}893$

HX2: E_B: $(180-40)\cdot 2{,}893 = 405$
R: $(170-40)\cdot 2 = \underline{260}$
} R er ferdig

$T_{E_B,ut} = 180 - \frac{260}{2{,}893} = 90{,}12$

CU: $Q_c = 405 - 260 = 145$, stemmer med $Q_{c,min}$

f) Får samme antall varmevekslere