PROCESS INTEGRATION

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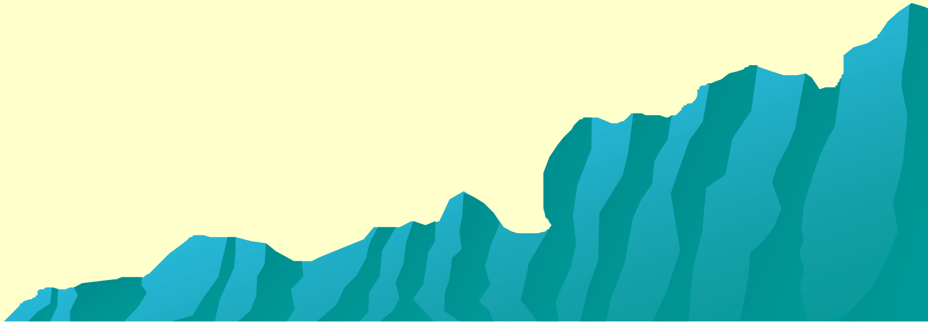
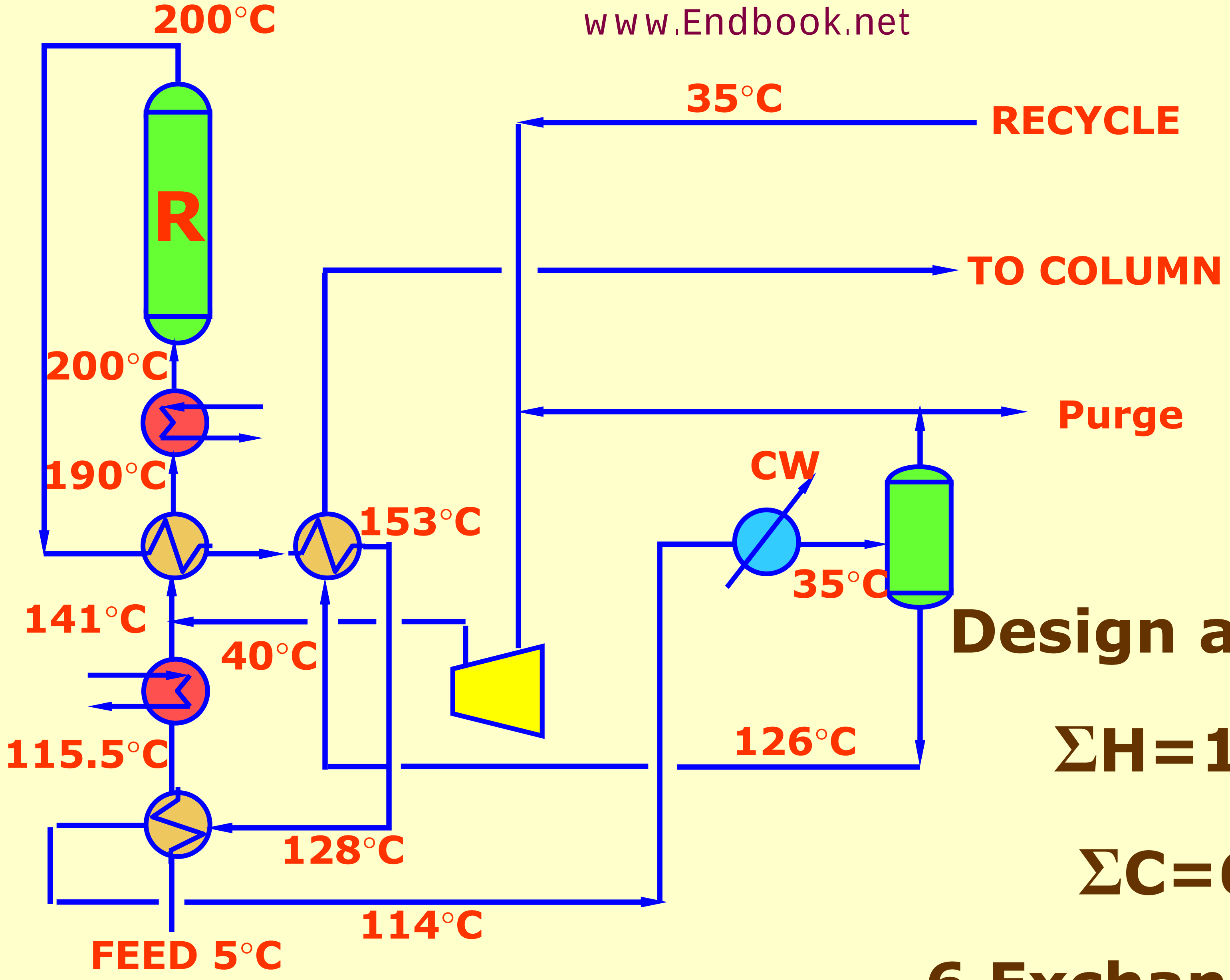
TMU

CHEMICAL ENGINEERING DEPARTMENT

LECTURE 1

Introduction





Design as usual

ΣH=1722

ΣC=645

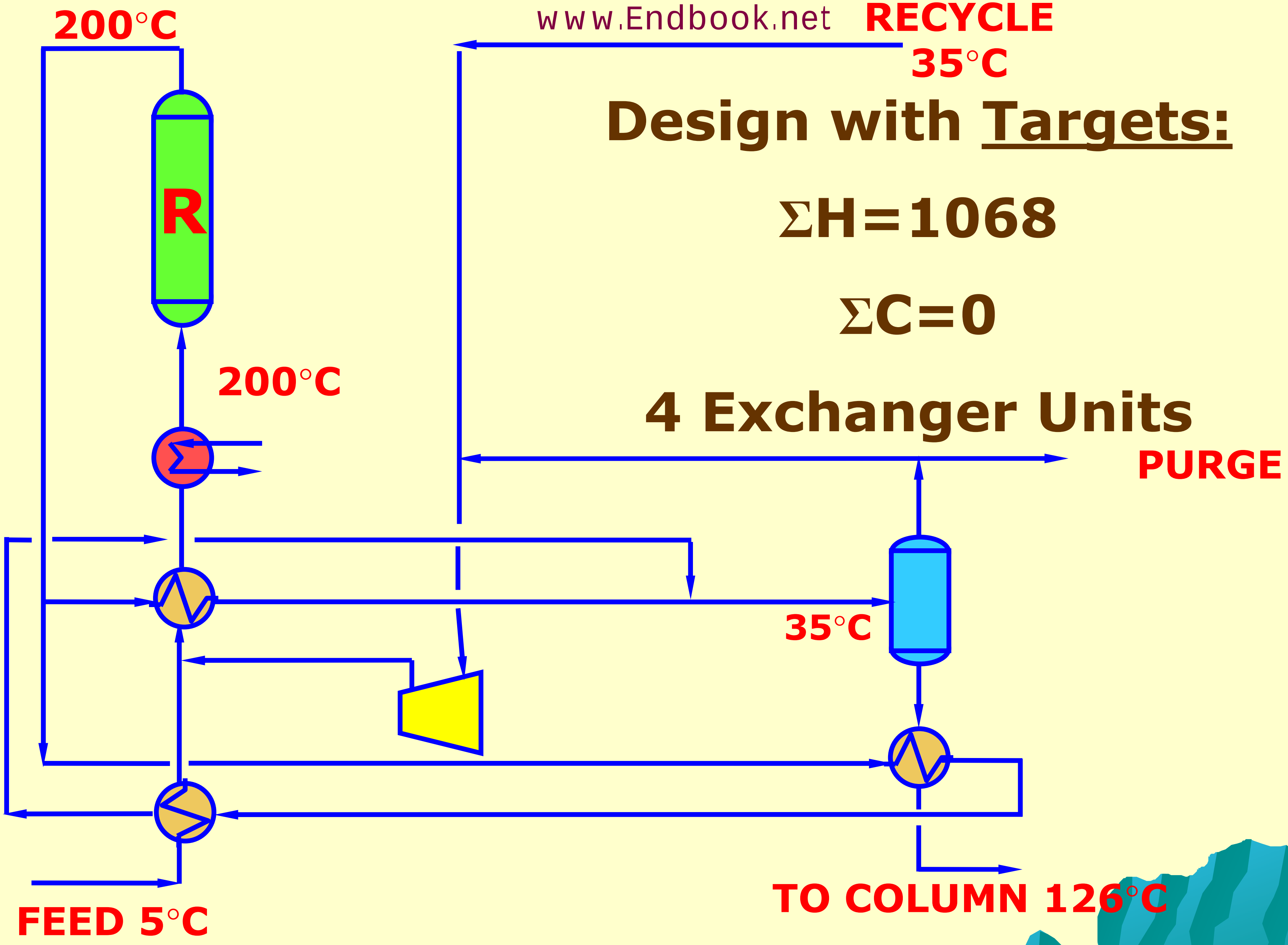
6 Exchanger Unit

Design with Targets:

$\Sigma H=1068$

$\Sigma C=0$

4 Exchanger Units

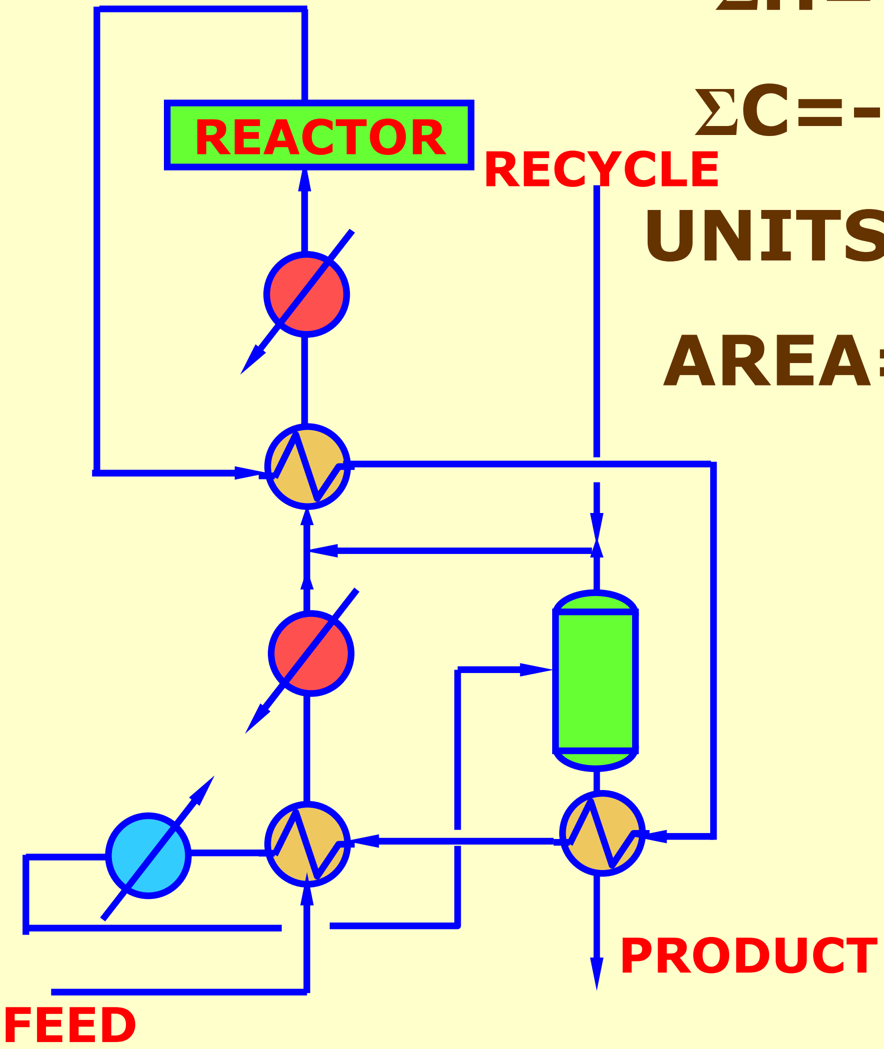


ΣH=-38%

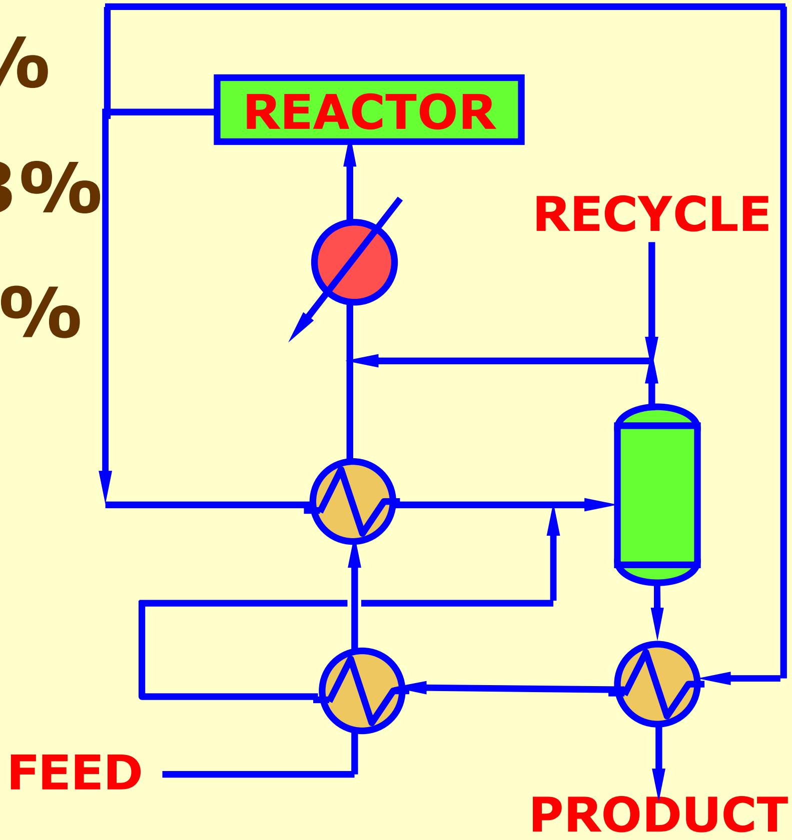
ΣC=-100%

UNITS=-33%

AREA=-15%



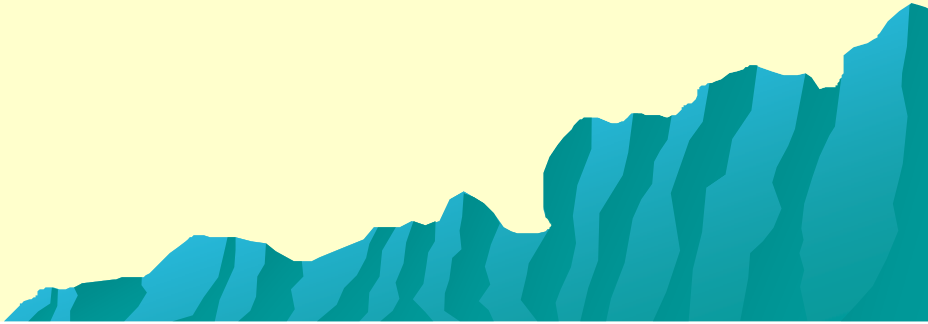
BASE CASE



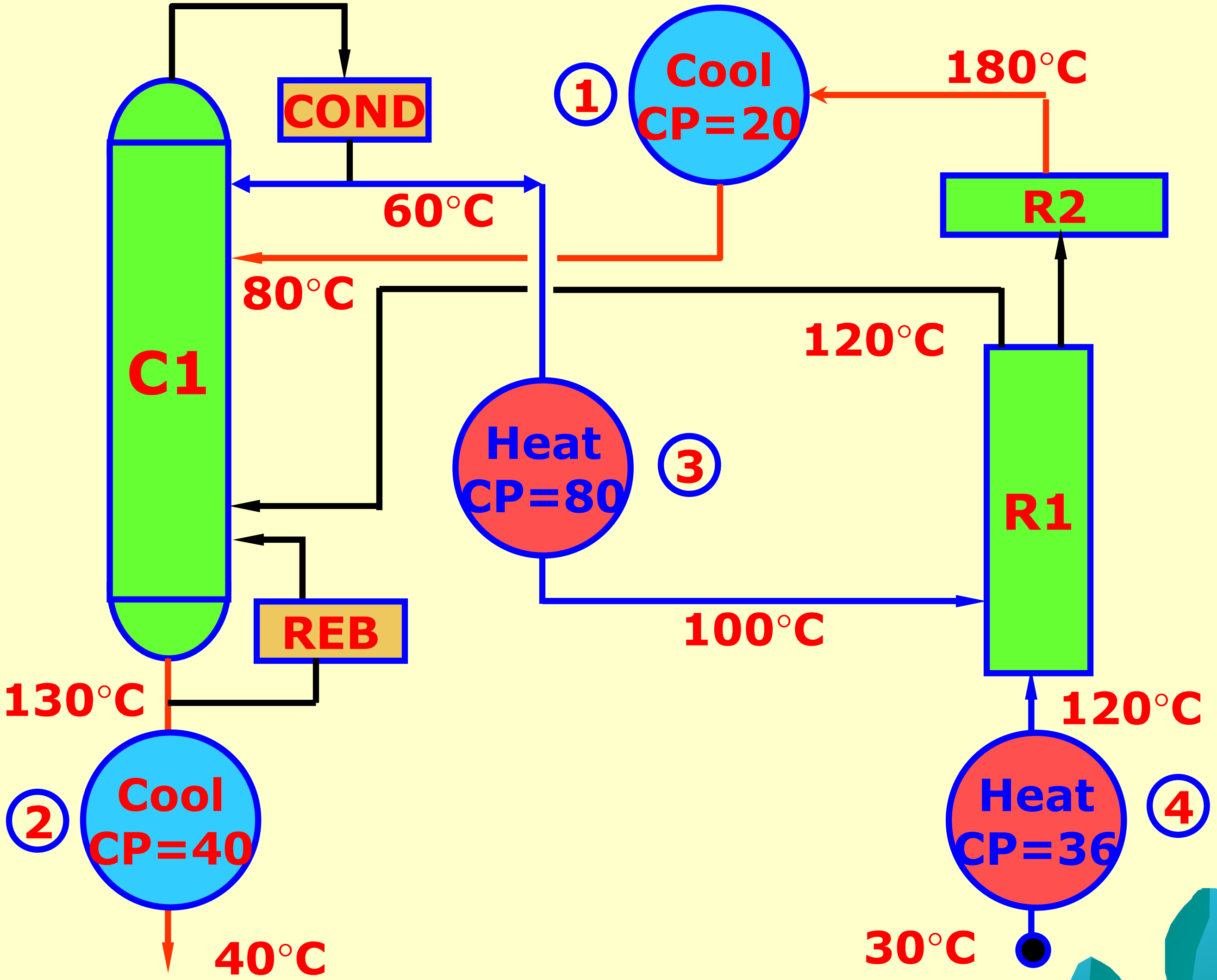
BETTER PROCESS INTEGRATION

What is better process integration all about?

- ✓ **Better process design**
- ✓ **Reduction in utility costs**
- ✓ **Reduction in emissions**
- ✓ **Better utilization of capital**



Example Problem 1



SOLUTION 1

Example Problem 1

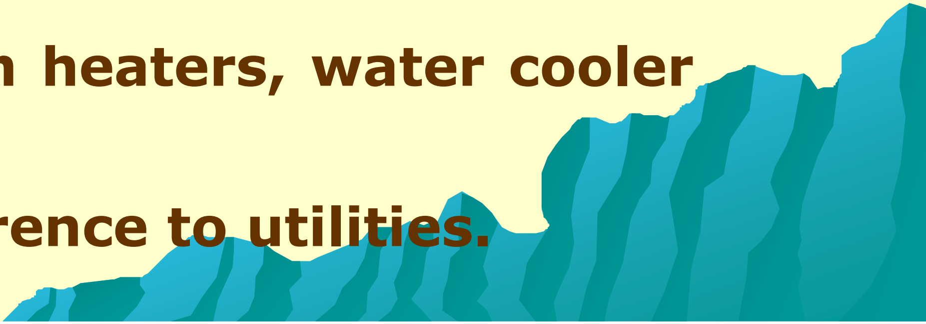
Stream No. & Type	Supply Temperature (^oC)	Target Temperature (^oC)	Heat Capacity Flowrate ($KW/^oC$)
1 Hot	180	80	20
2 Hot	130	40	40
3 Cold	60	100	80
4 Cold	30	120	36

$\Delta T_{min} = 10^oC$

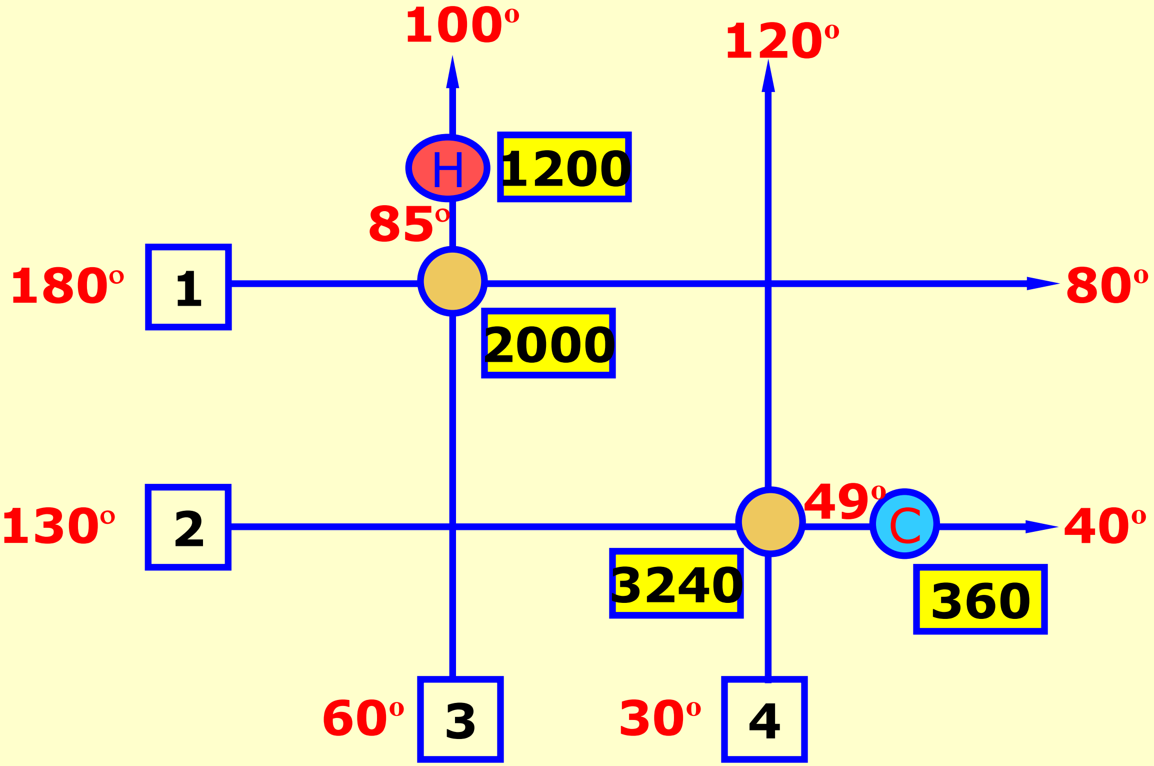
Utilities: Steam at 200^oC, C.W. at $25^oC \rightarrow 30^oC$

Design a network of steam heaters, water cooler and exchangers.

Use heat recovery in preference to utilities.



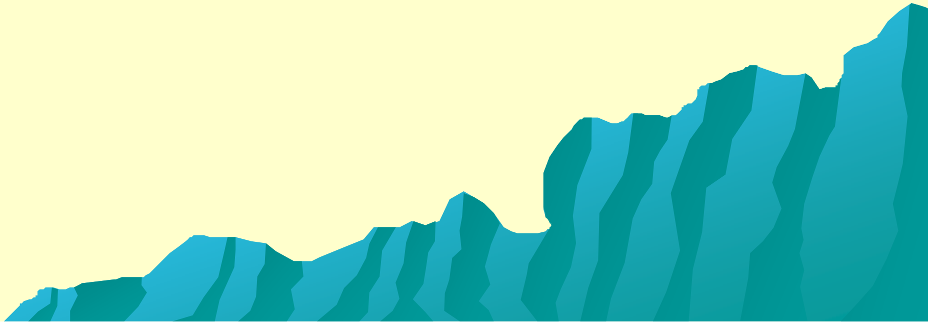
The Popular Favorite



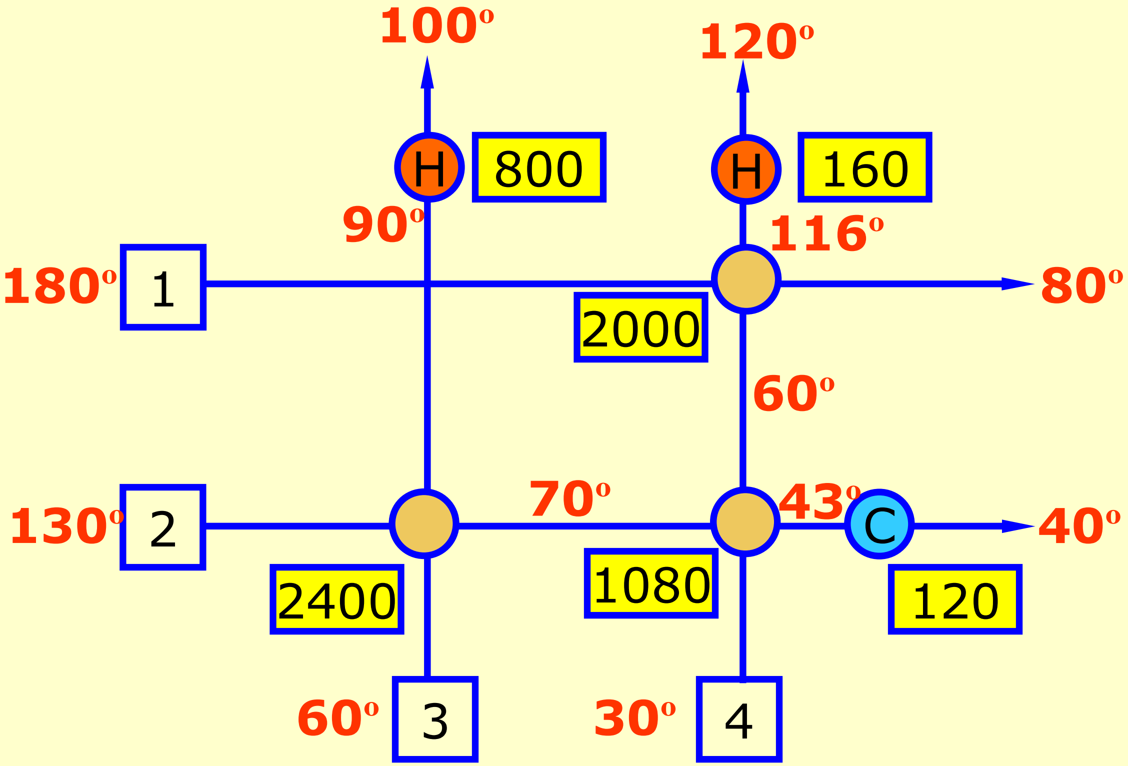
Steam	Cooling Water	No. of Units
1200	360	4

Experience

Most people have a cup of coffee once they have found the “popular favorite”

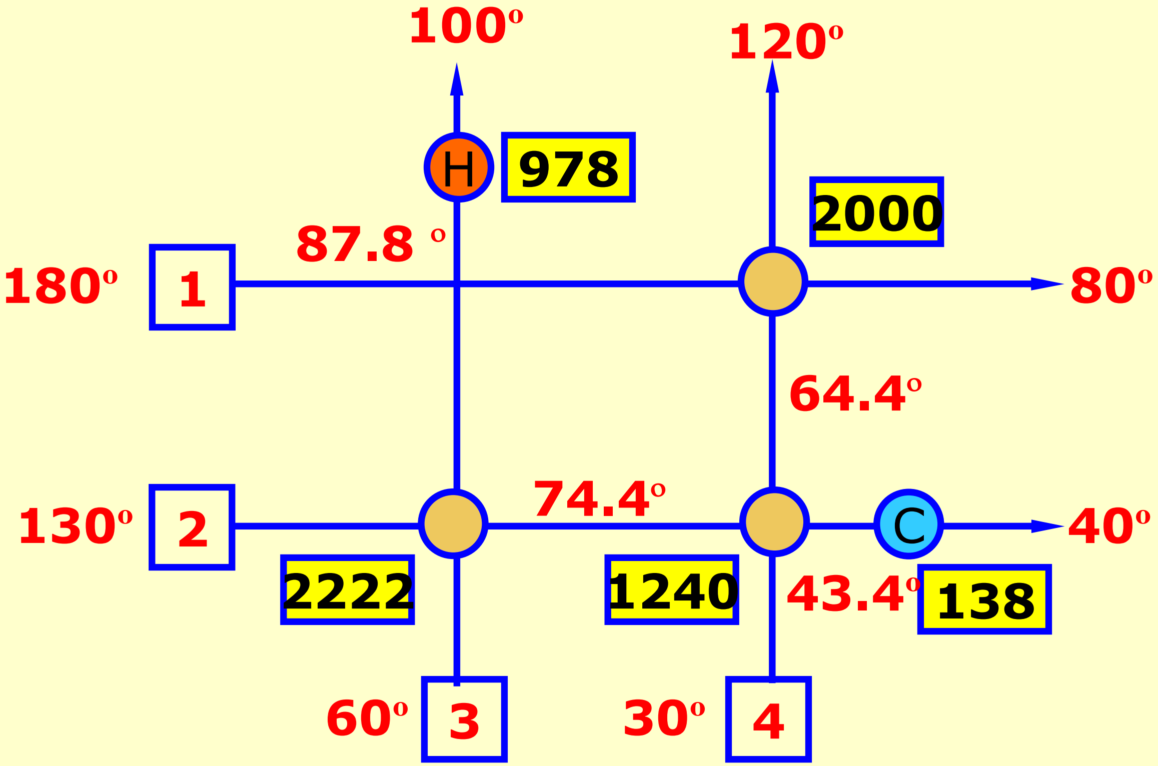


The "Winner"(Strictly Speaking)

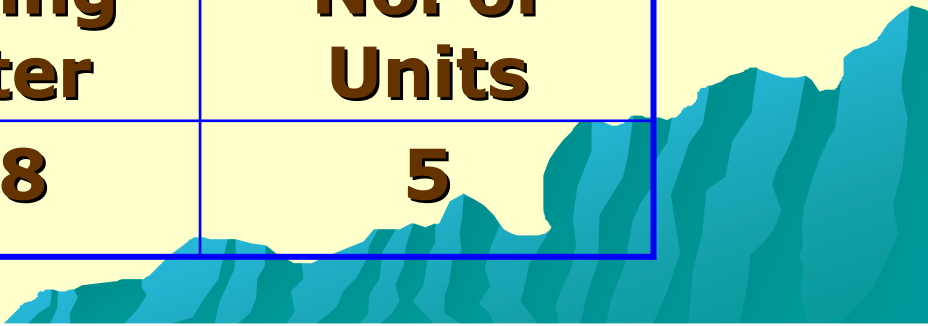


Steam	Cooling Water	No. of Units
960	120	6

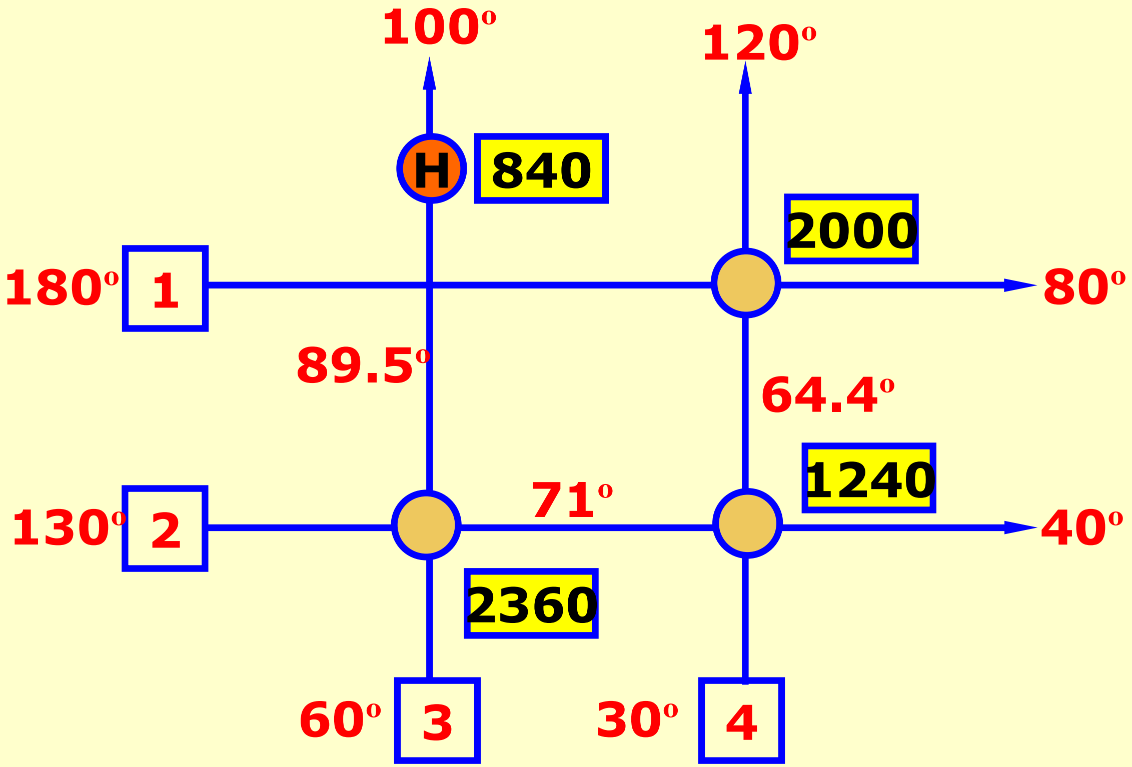
The "Winner"(Morally)



Steam	Cooling Water	No. of Units
978	138	5



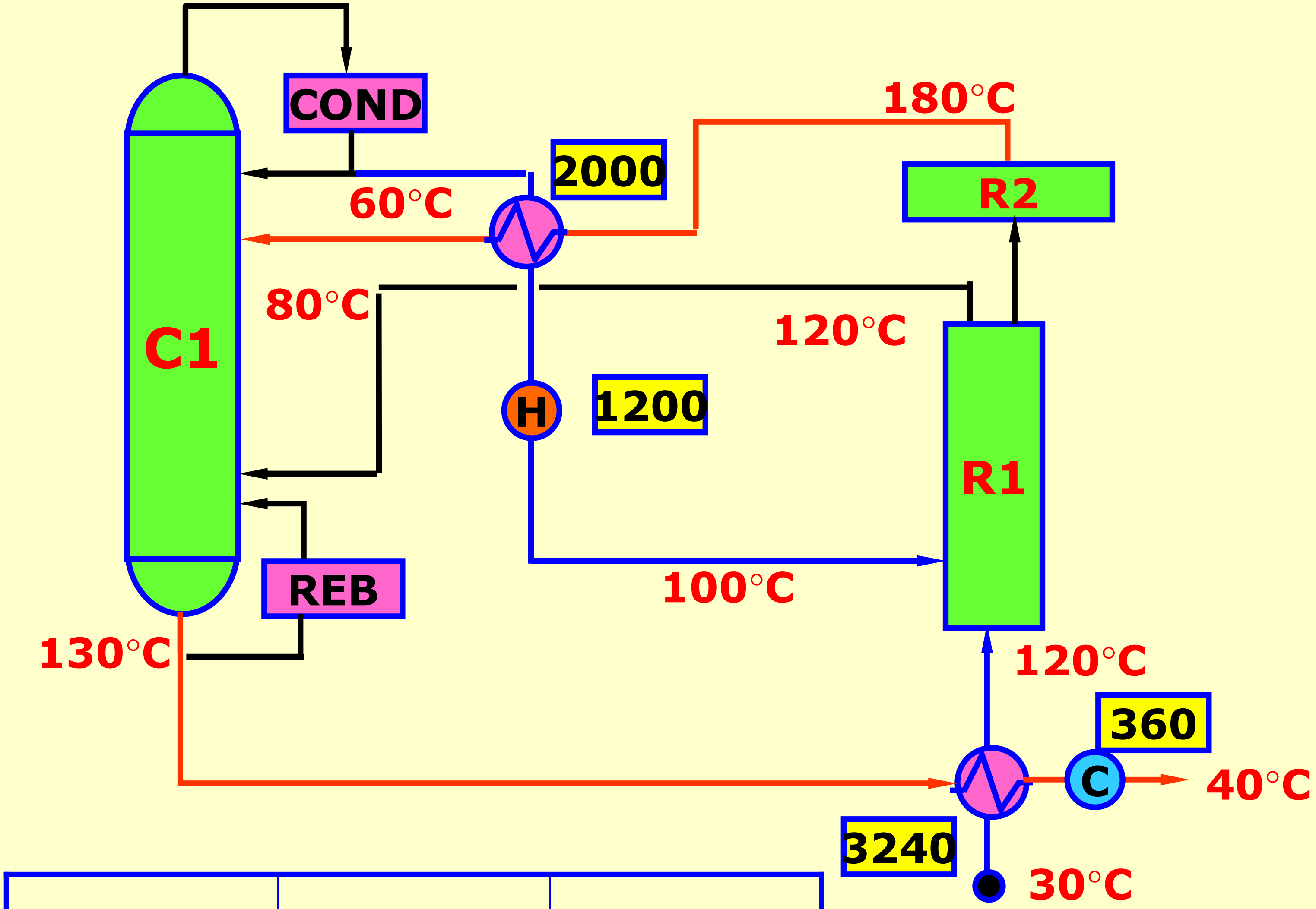
The “System Buster”($\Delta T_{min}=6.6^{o}C$)



Steam	Cooling Water	No. of Units
840	0	4

LECTURE 2

Setting Energy Targets

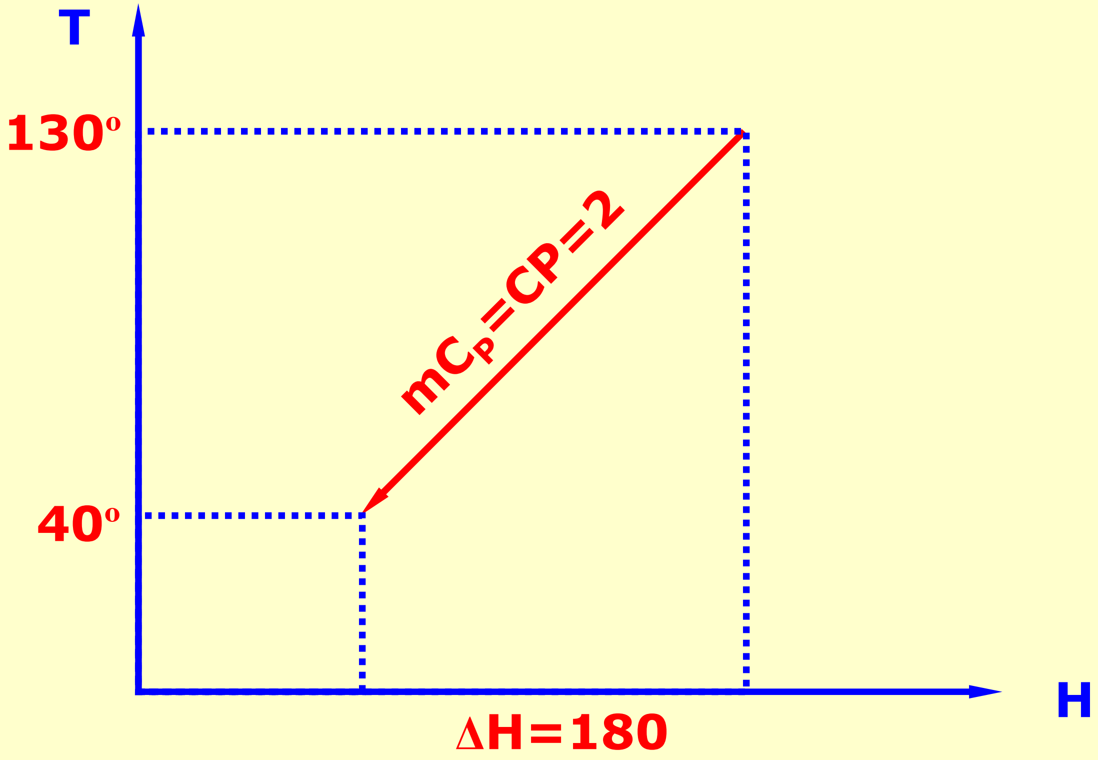


Steam	CW	Units
1200	360	4

- **Are 1200 units of steam necessary?**
- **What is the minimum energy requirement?**

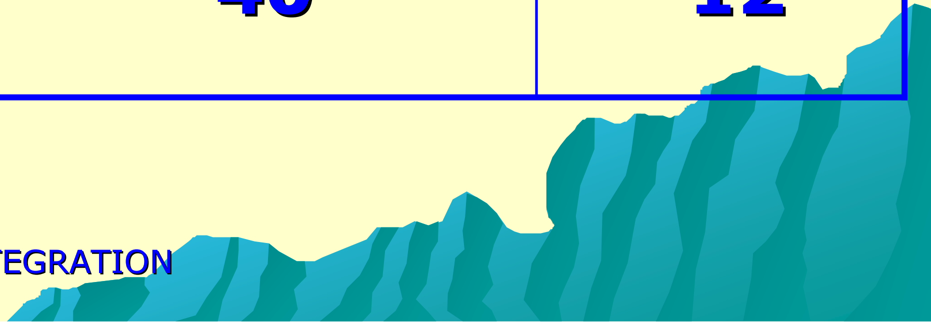
Let's first look at the concept of heat recovery

The T-H Diagram

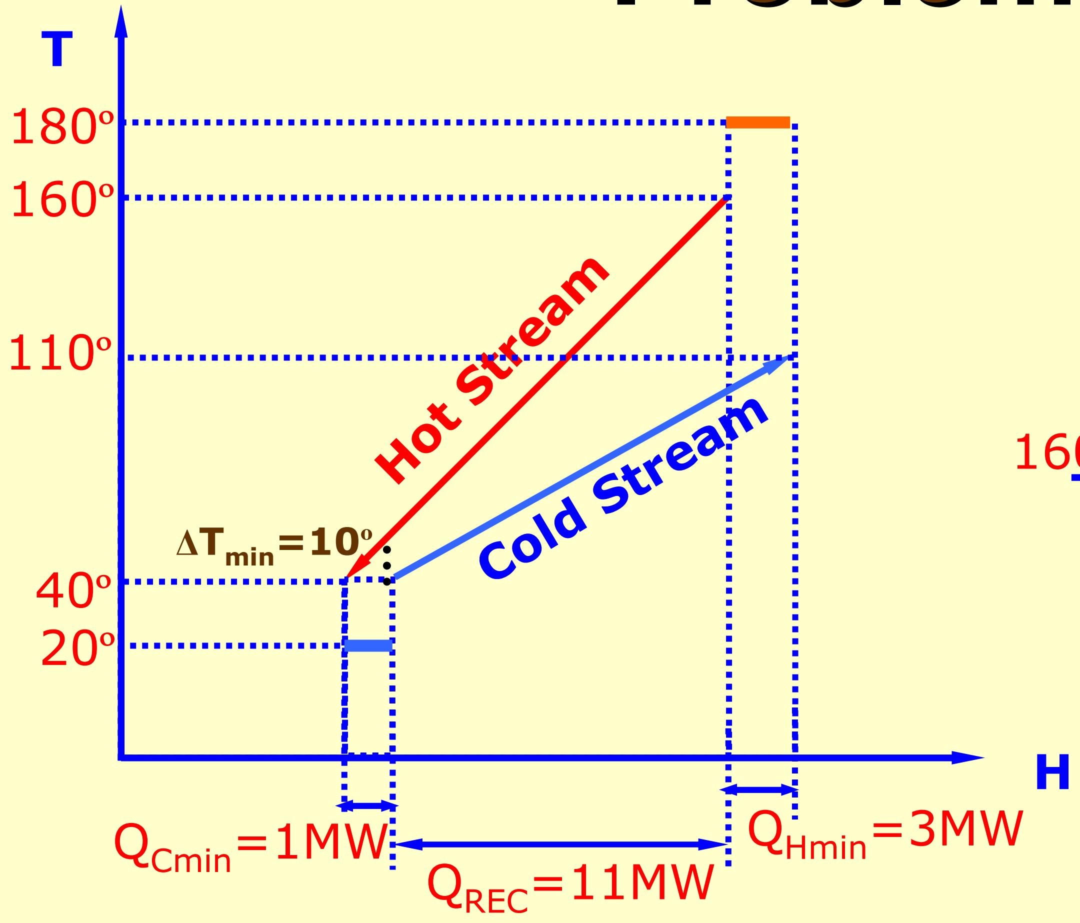


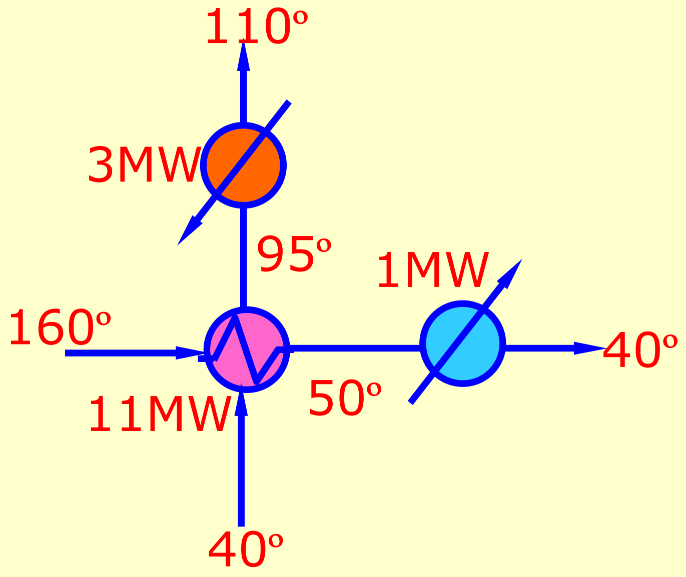
Two – Stream Heat Recovery Problem

Stream	Type	Supply Temp. $T_s(^{o}C)$	Target Temp $T_T(^{o}C)$	ΔH(MW)
1	Cold	40	110	14
2	Hot	160	40	-12

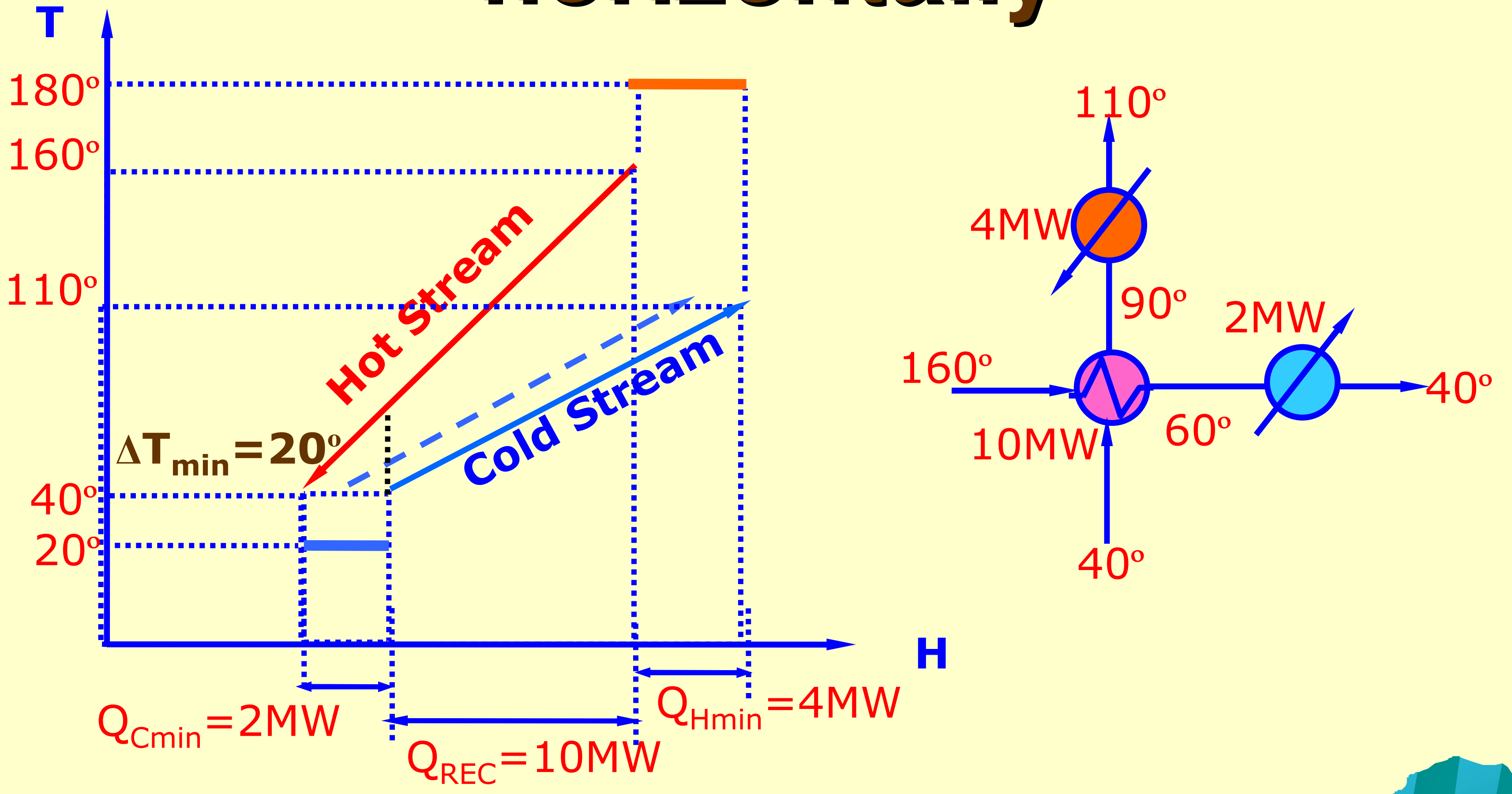


Two-Stream Heat Recovery Problem



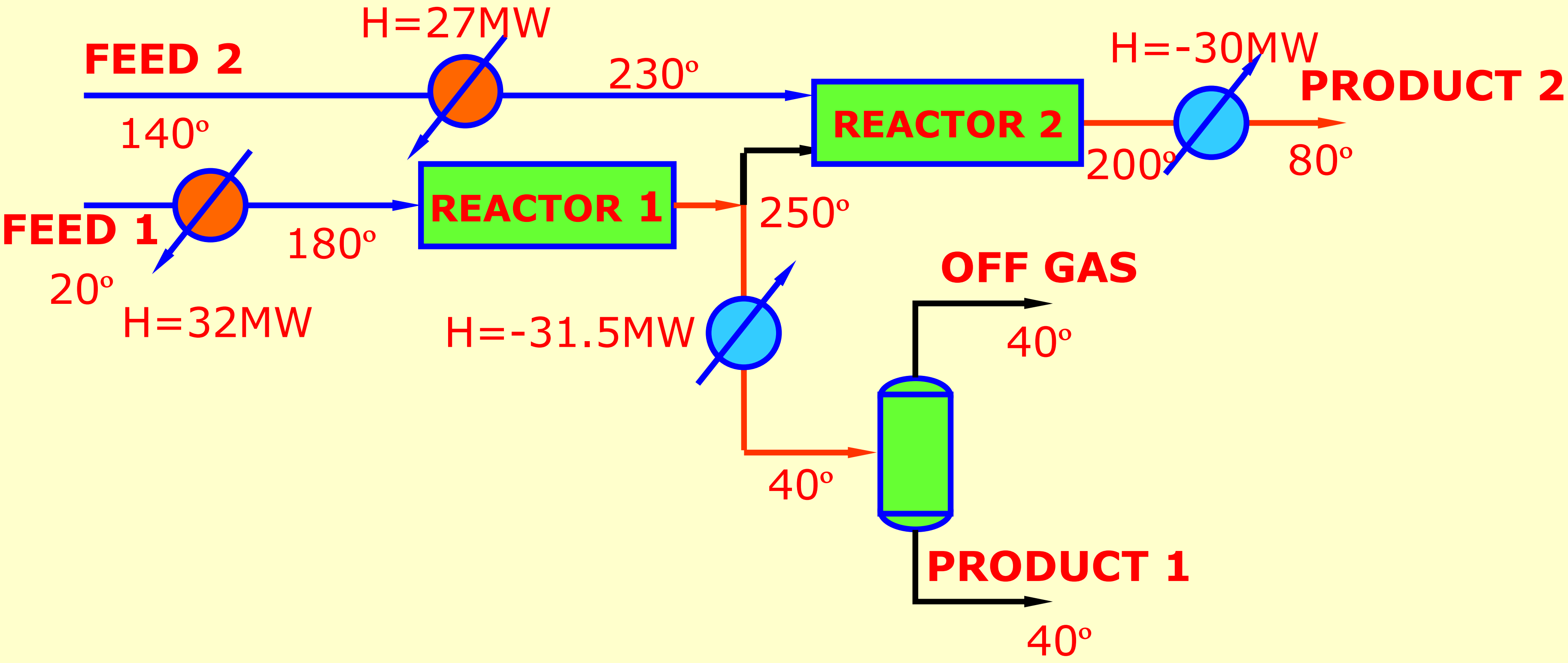


Streams can be shifted horizontally



What about several hot and several cold streams?

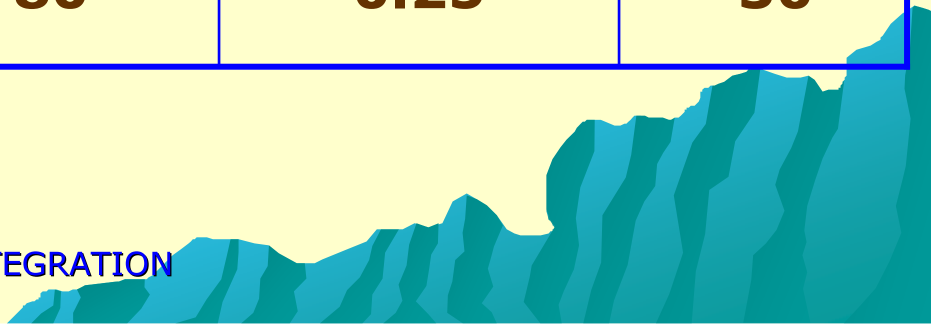
Example Problem



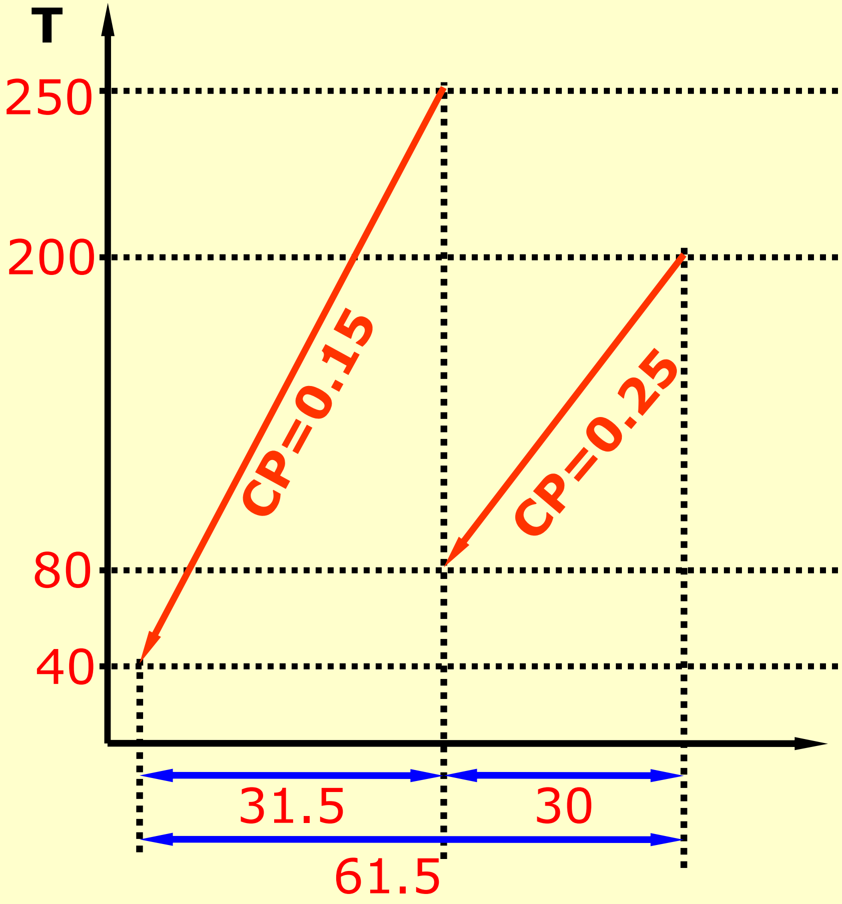
A simple flowsheet with two hot streams and two cold streams

Stream Data

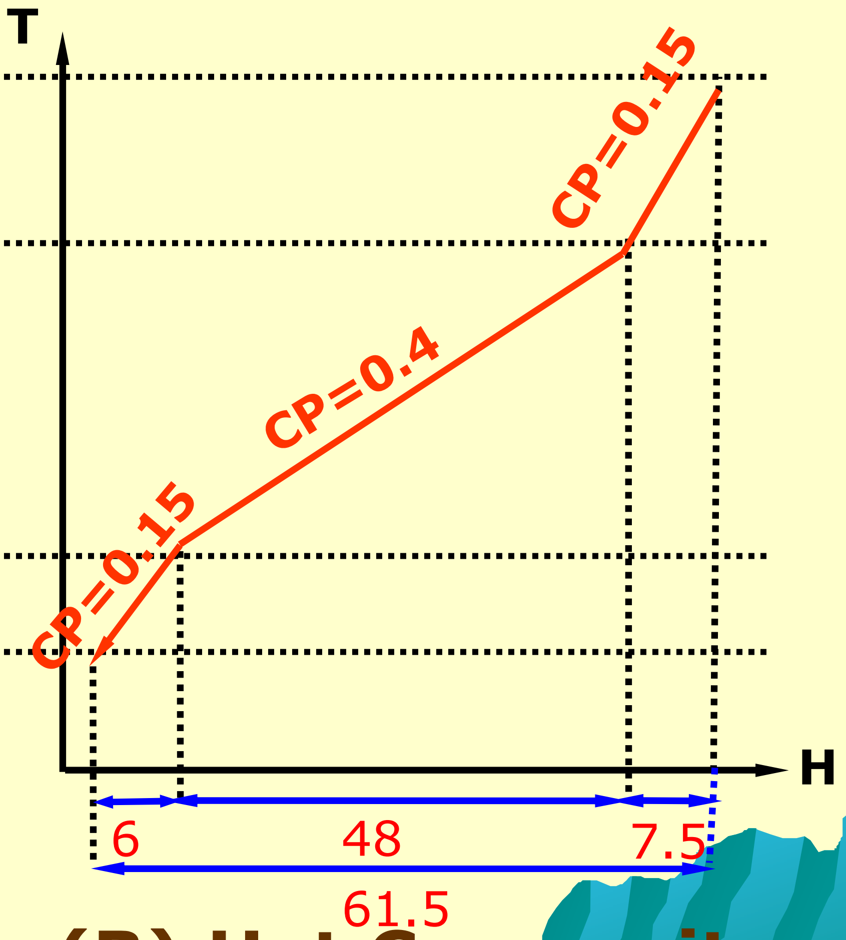
Stream	Type	Supply Temp. T_s(°C)	Target Temp T_T(°C)	Heat capacity flowrate CP(MW°C^{-1})	ΔH(MW)
Reactor 1 feed	Cold	20	180	0.2	32
Reactor 1 product	Hot	250	40	0.15	-31.5
Reactor 2 feed	Cold	140	230	0.3	27
Reactor 2 product	Hot	200	80	0.25	-30



Composite Curve

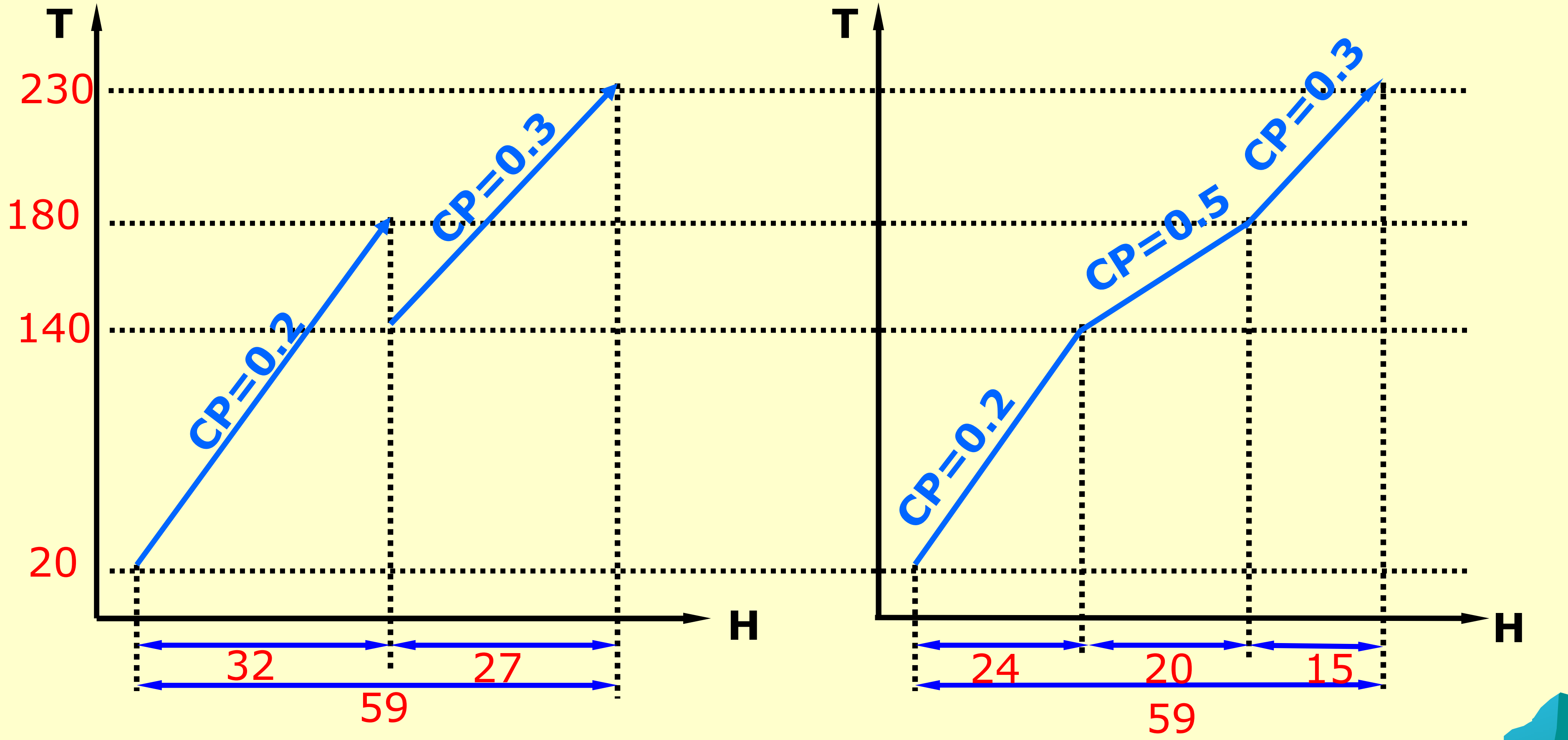


(A) Hot streams plotted separately



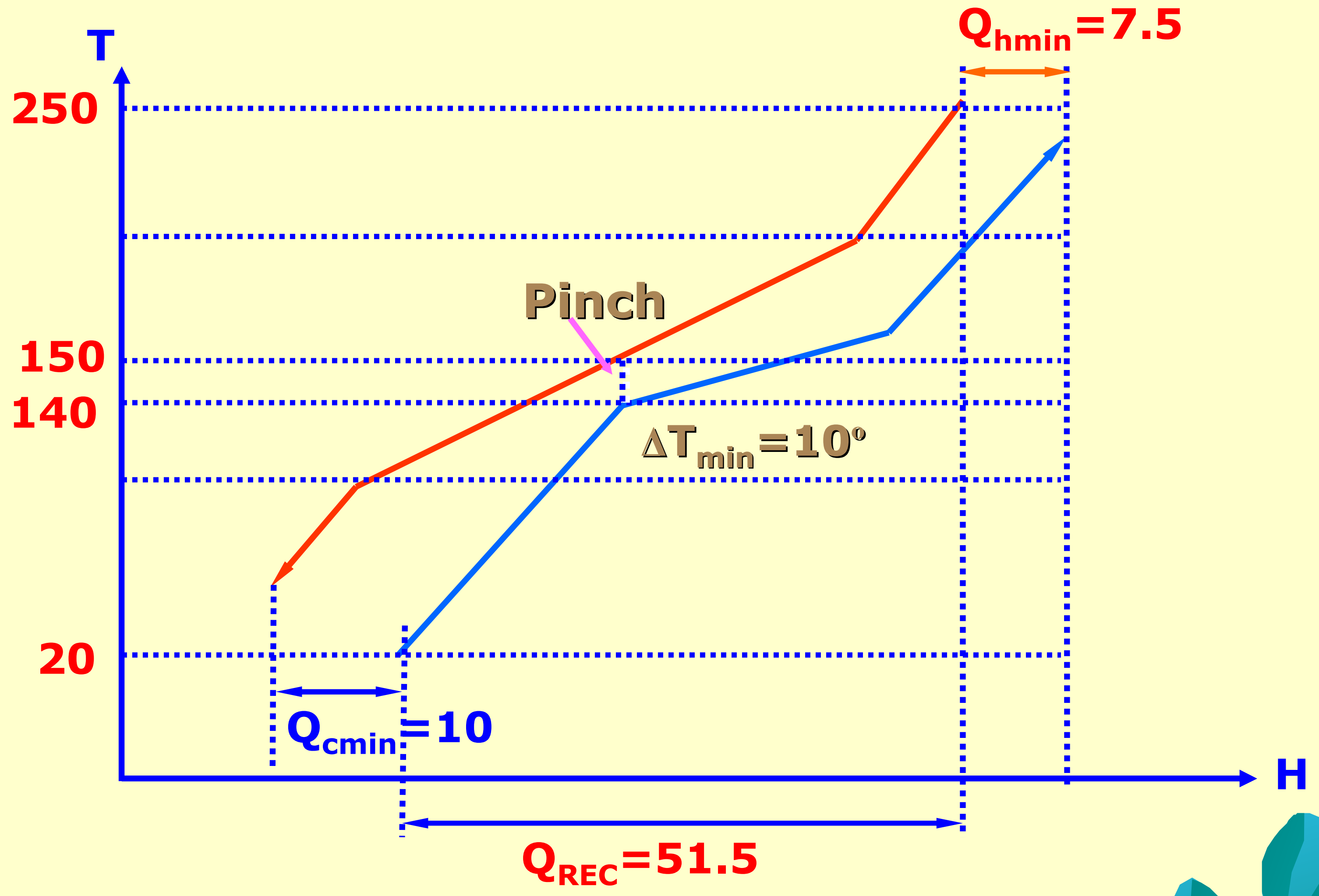
(B) Hot Composite

The cold streams can also be combined to obtain a cold composite

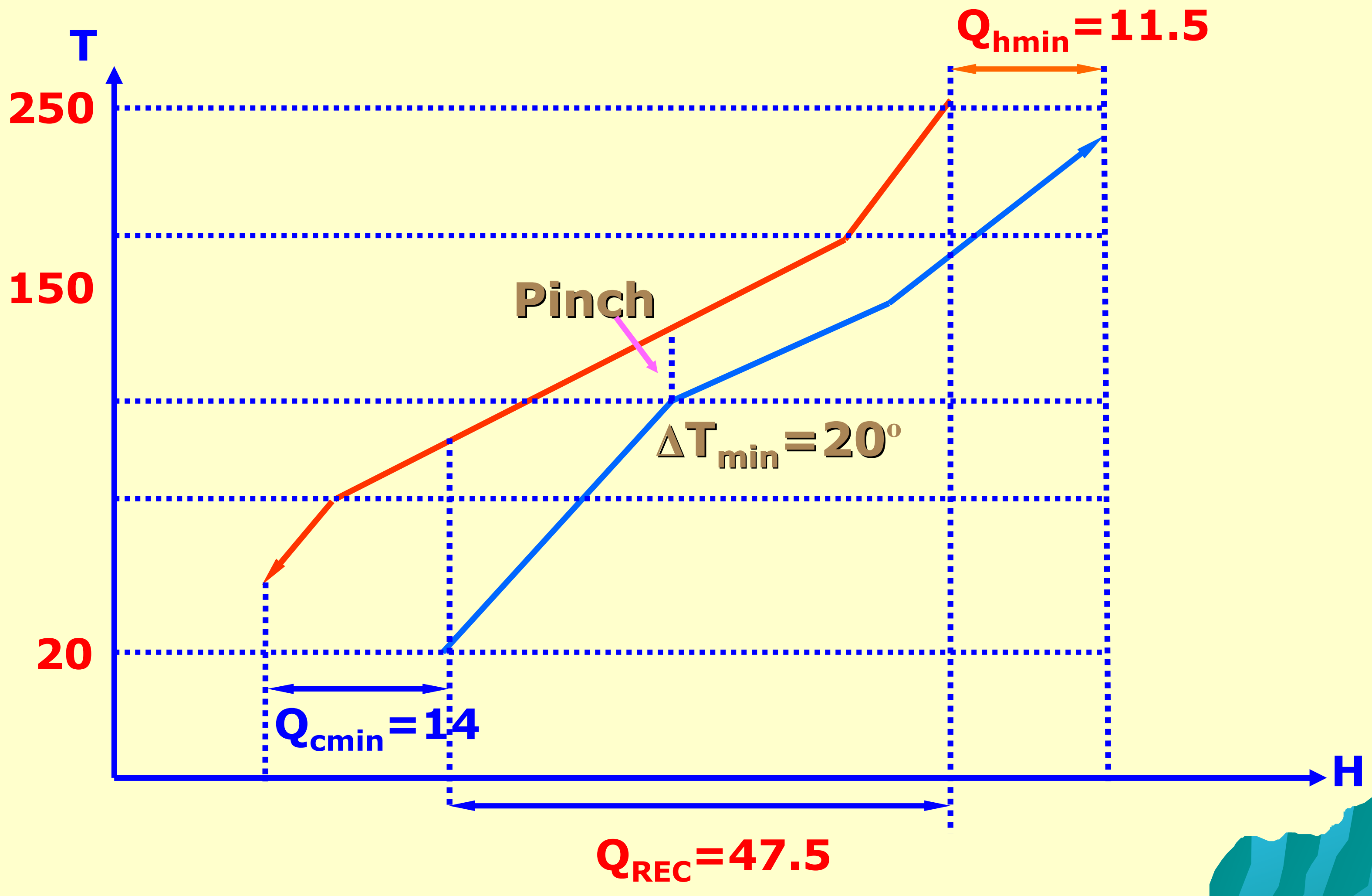


The cold streams can also be combined to obtain a **composite cold** stream.

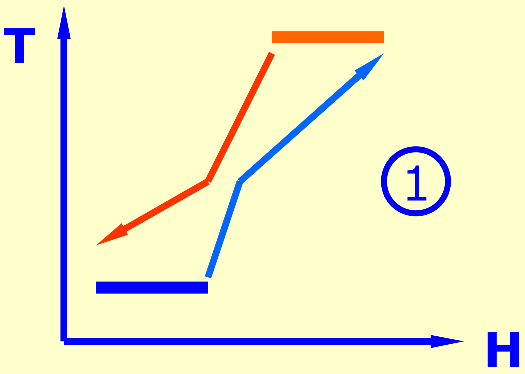
Plotting the hot and cold composite curves together gives the utility targets

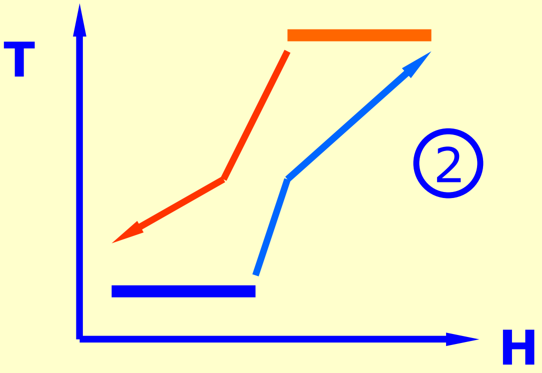


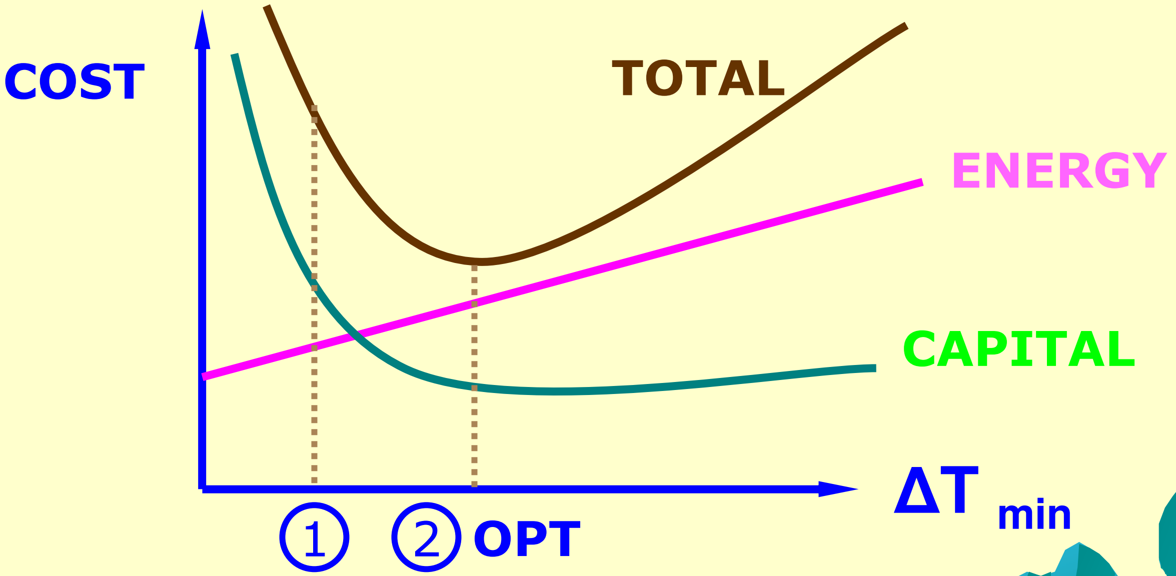
Increasing ΔT_{min} Increases hot and cold utilities



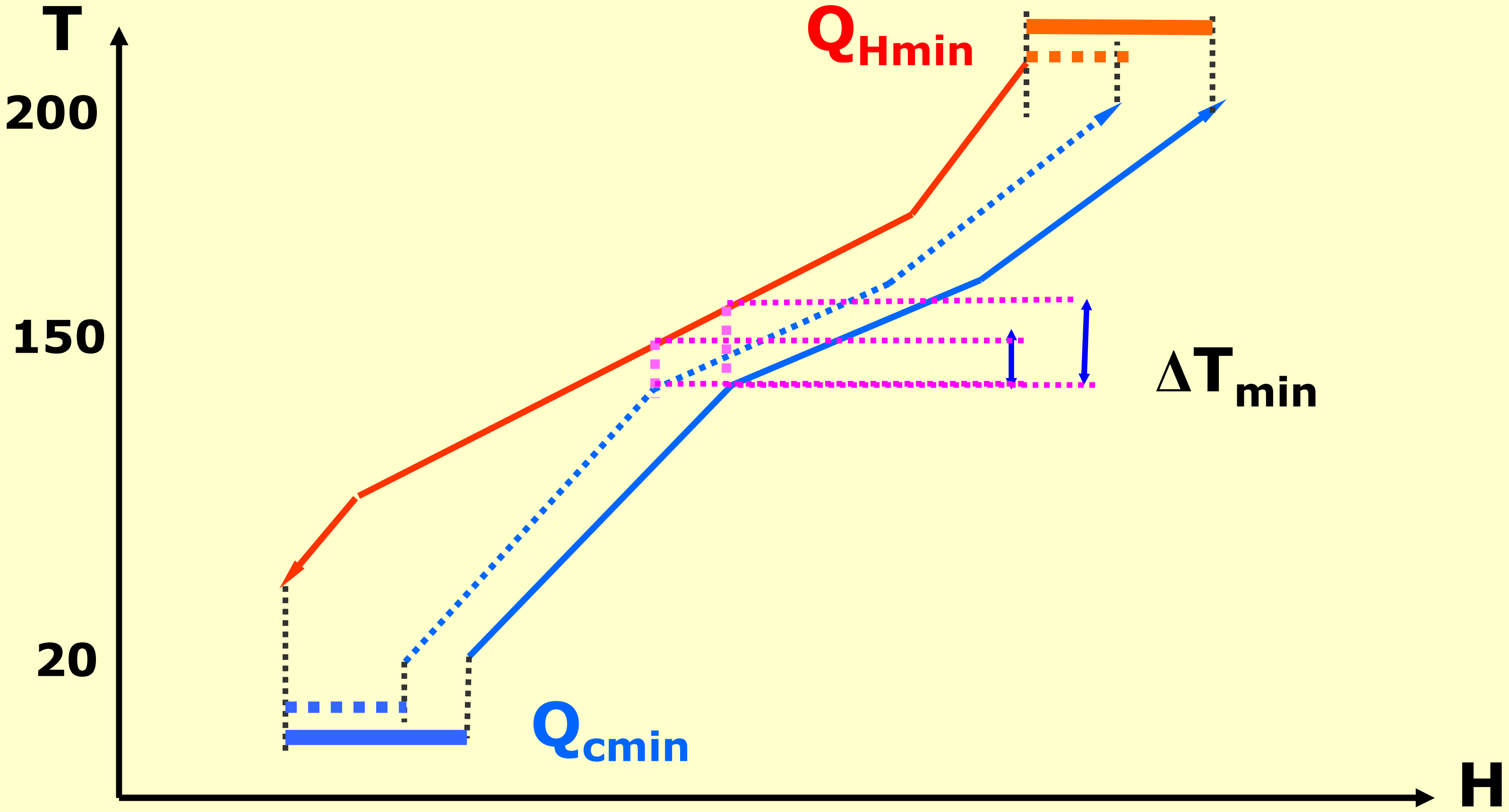
Optimum Δt_{min} Can be found by economic trade-offs between energy and capital







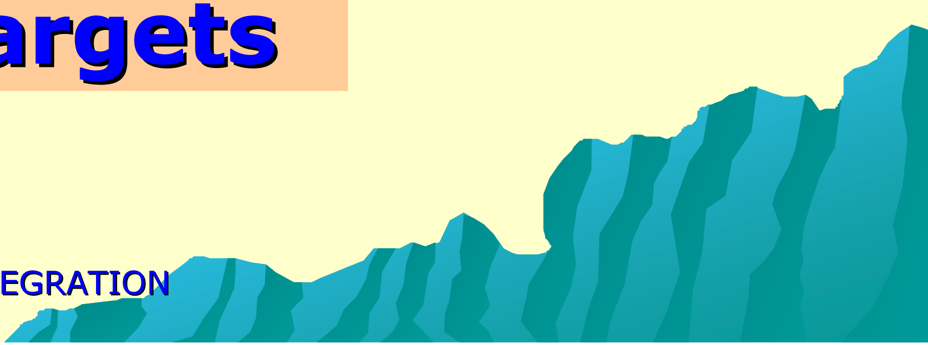
Summary



Stream data, ΔT $_{min}$

Construct composite curve

Energy targets



A Very Important Conclusion

We can set

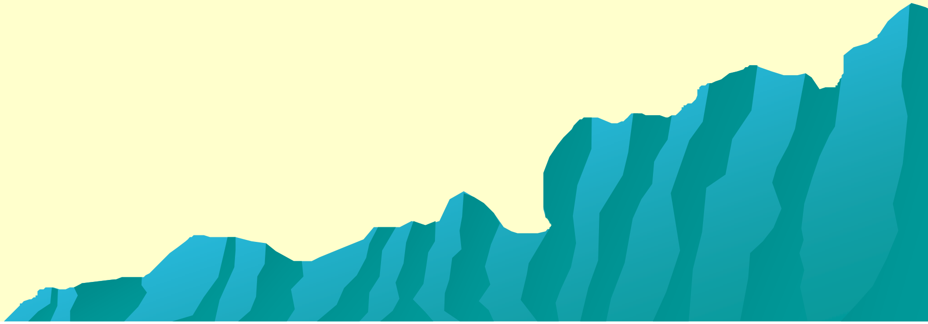
TARGETS

Prior to design

LECTURE 3

The Problem Table Algorithm

(Cascade Diagram)



Stream Data

↓

“Composite Curves”

↓

Energy Targets

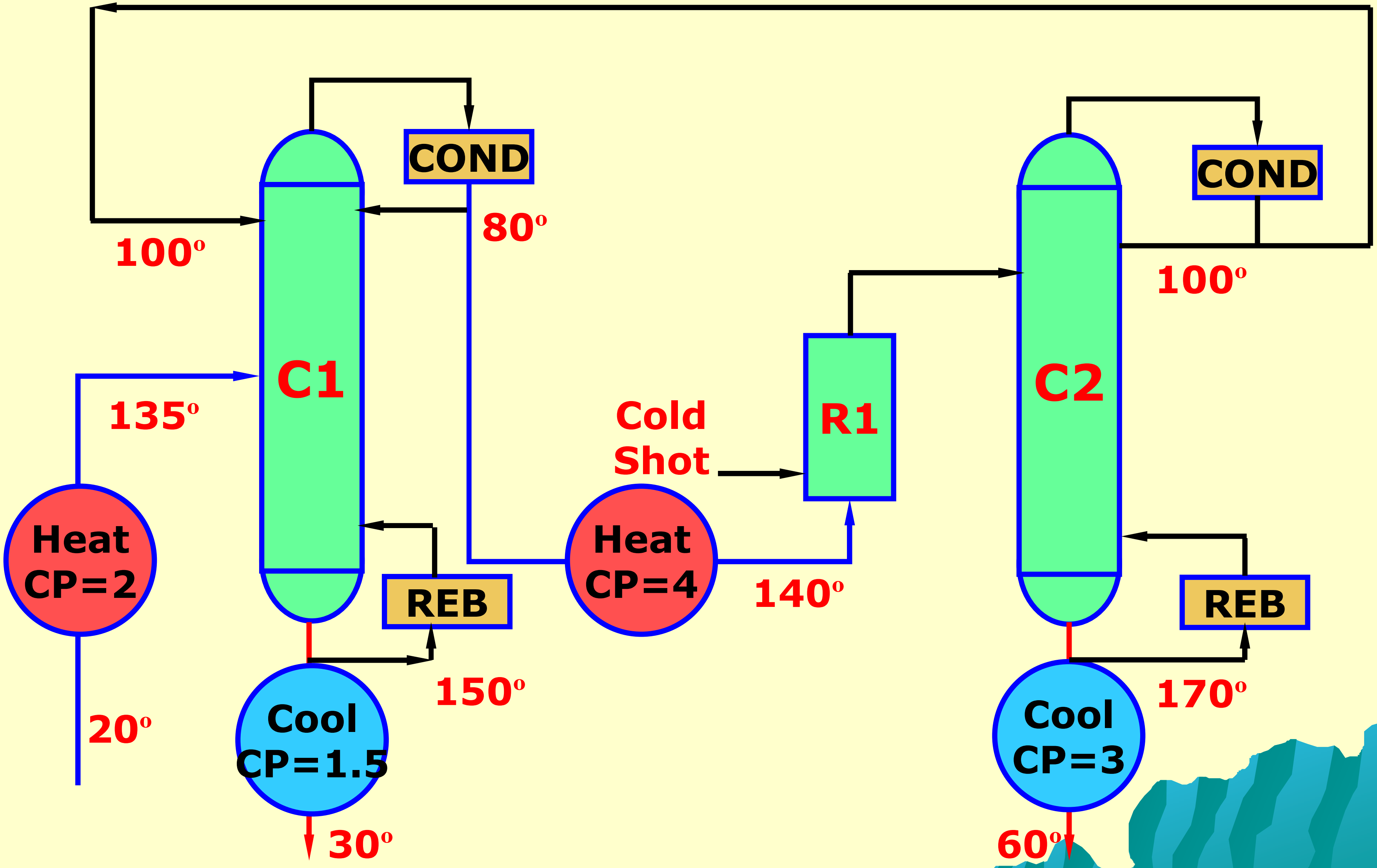
But,Complicated

Better:

↓

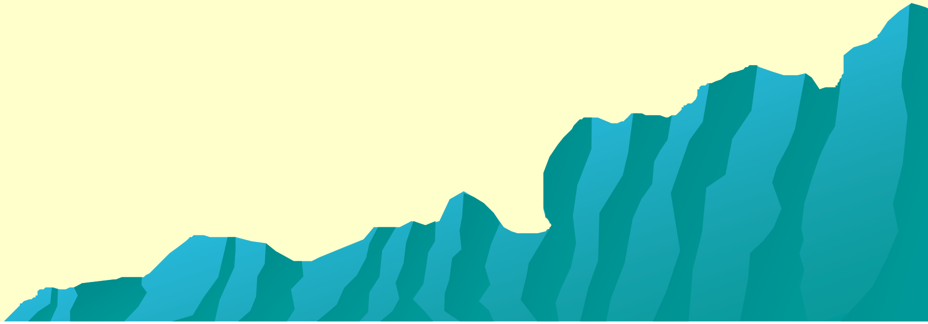
“The Problem Table”

Example Problem 2



Example Problem 2

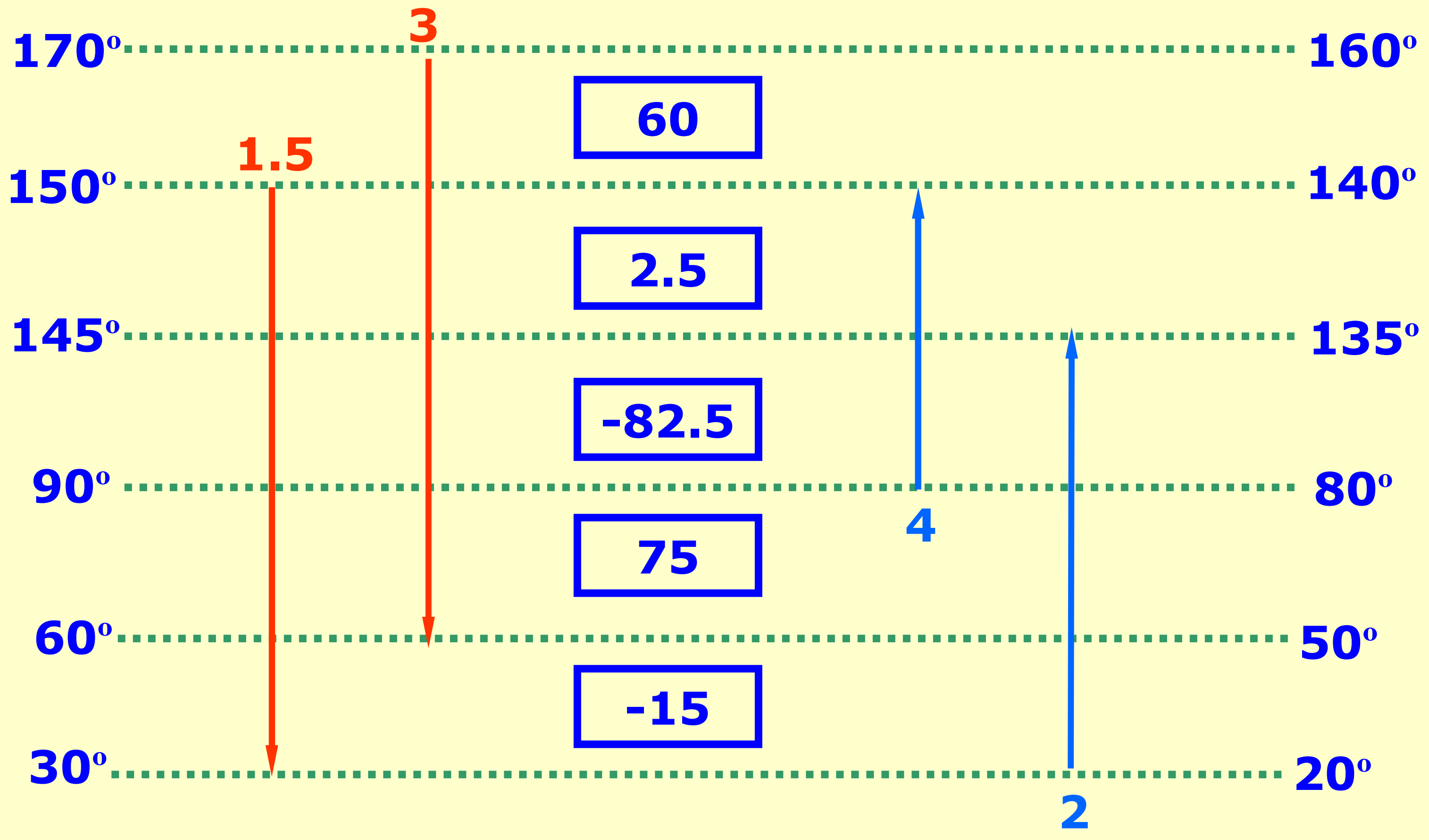
Stream	Type	Supply Temp. T_s(°C)	Target Temp T_T(°C)	Heat capacity flowrate CP(MW^{o}/C)
1	Cold	20	135	2
2	Hot	170	60	3
3	Cold	80	140	4
4	Hot	150	30	1.5



$\Delta T_{min}=10^o$

Hot Scale

Cold Scale



3

1.5

170° 160°

60

150° 140°

2.5

145° 135°

-82.5

90° 80°

4

75

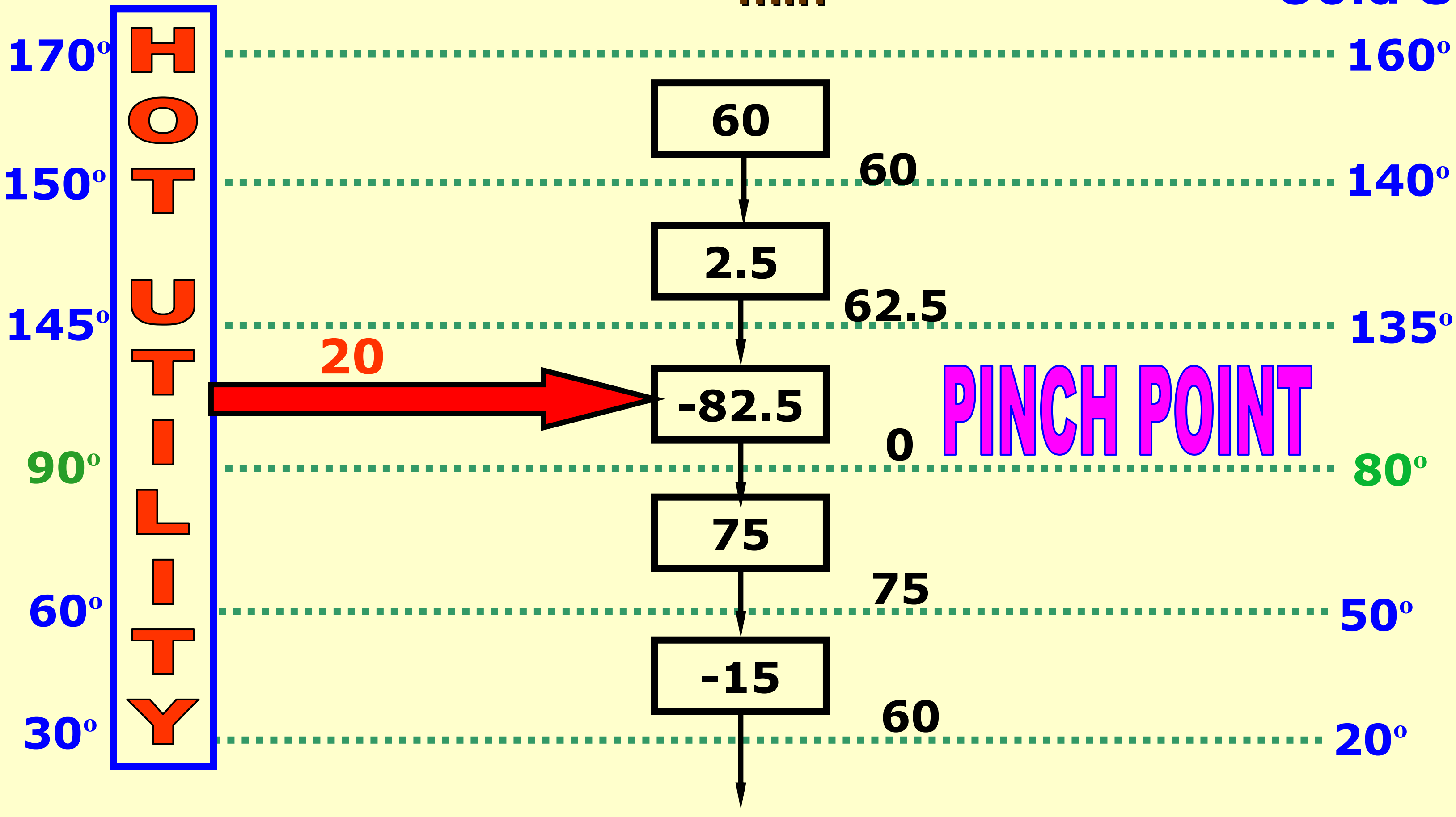
60° 50°

-15

30° 20°

2

$\Delta T_{min}=10^o$



Hot Scale

Cold Scale

170° **160°**

HOT UTILITY

60

150° **60** **140°**

2.5

145° **62.5** **135°**

20

-82.5

0 **PINCH POINT**

90° **80°**

75

60° **75** **50°**

-15

30° **60** **20°**

60 To cold utility

$Q_{Hmin} = 20$

$Q_{Cmin} = 60$

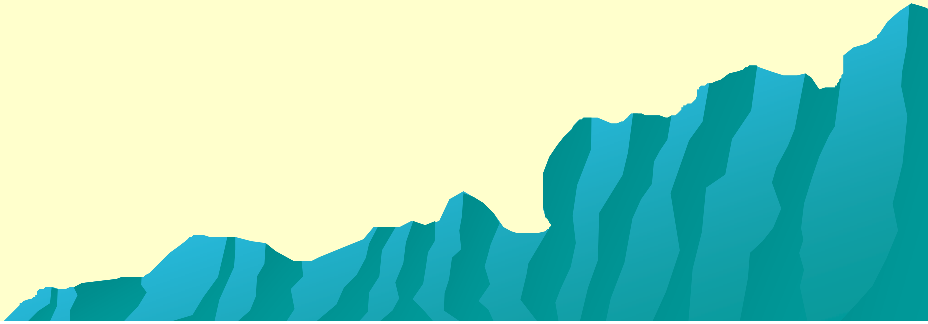
Pinch Temp.

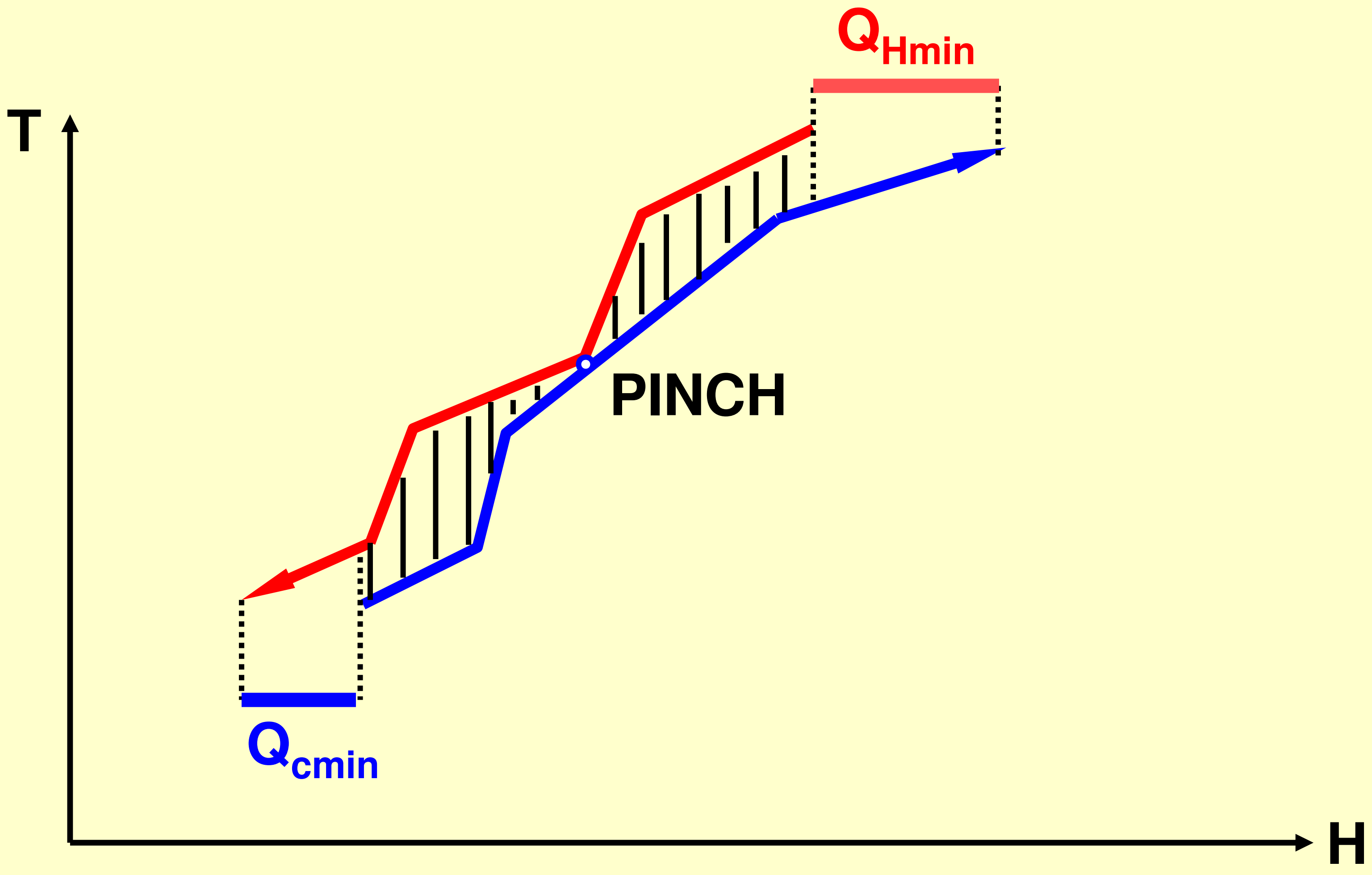
90º HOT

80º COLD

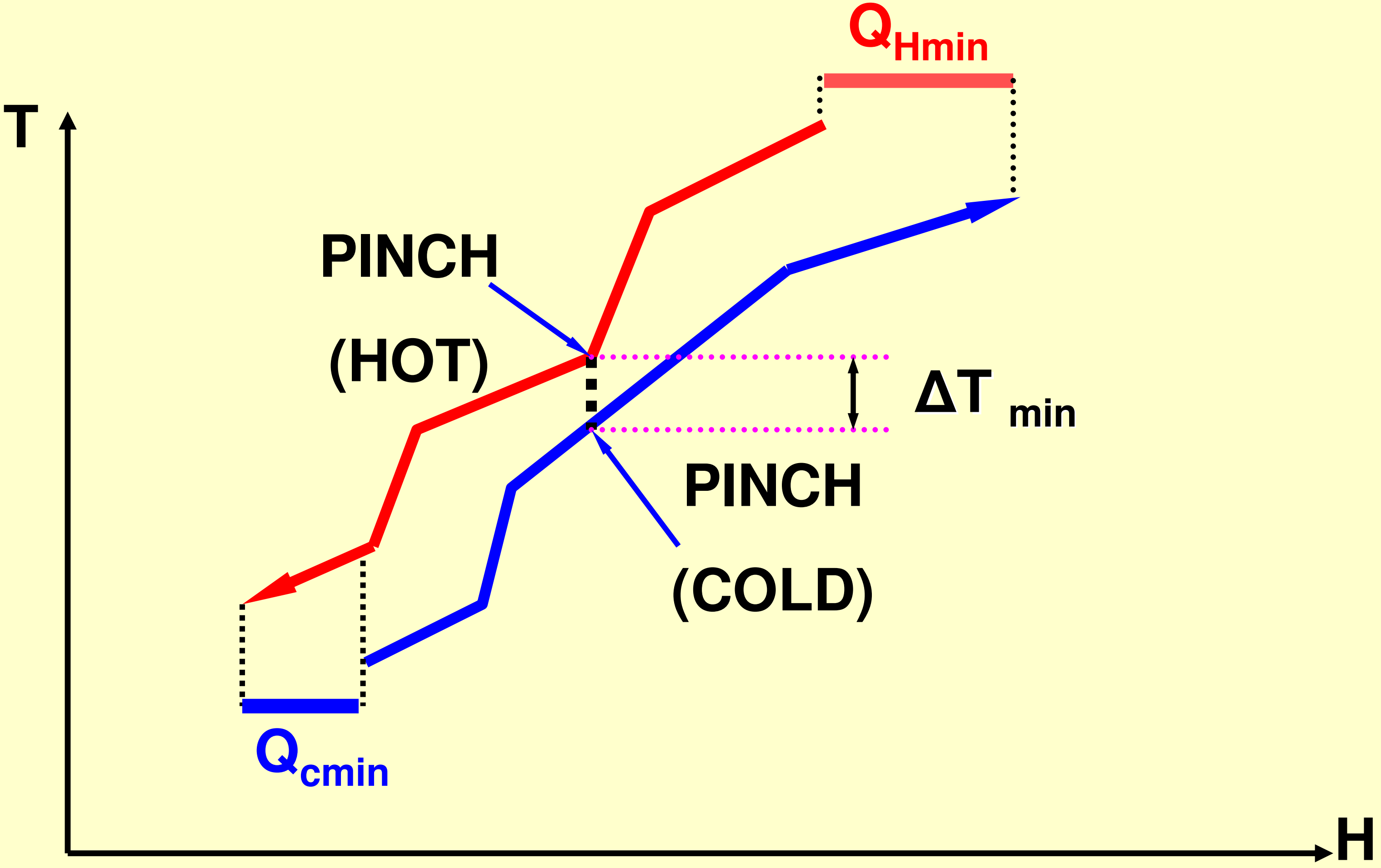
LECTURE 4

The Heat Recovery Pinch

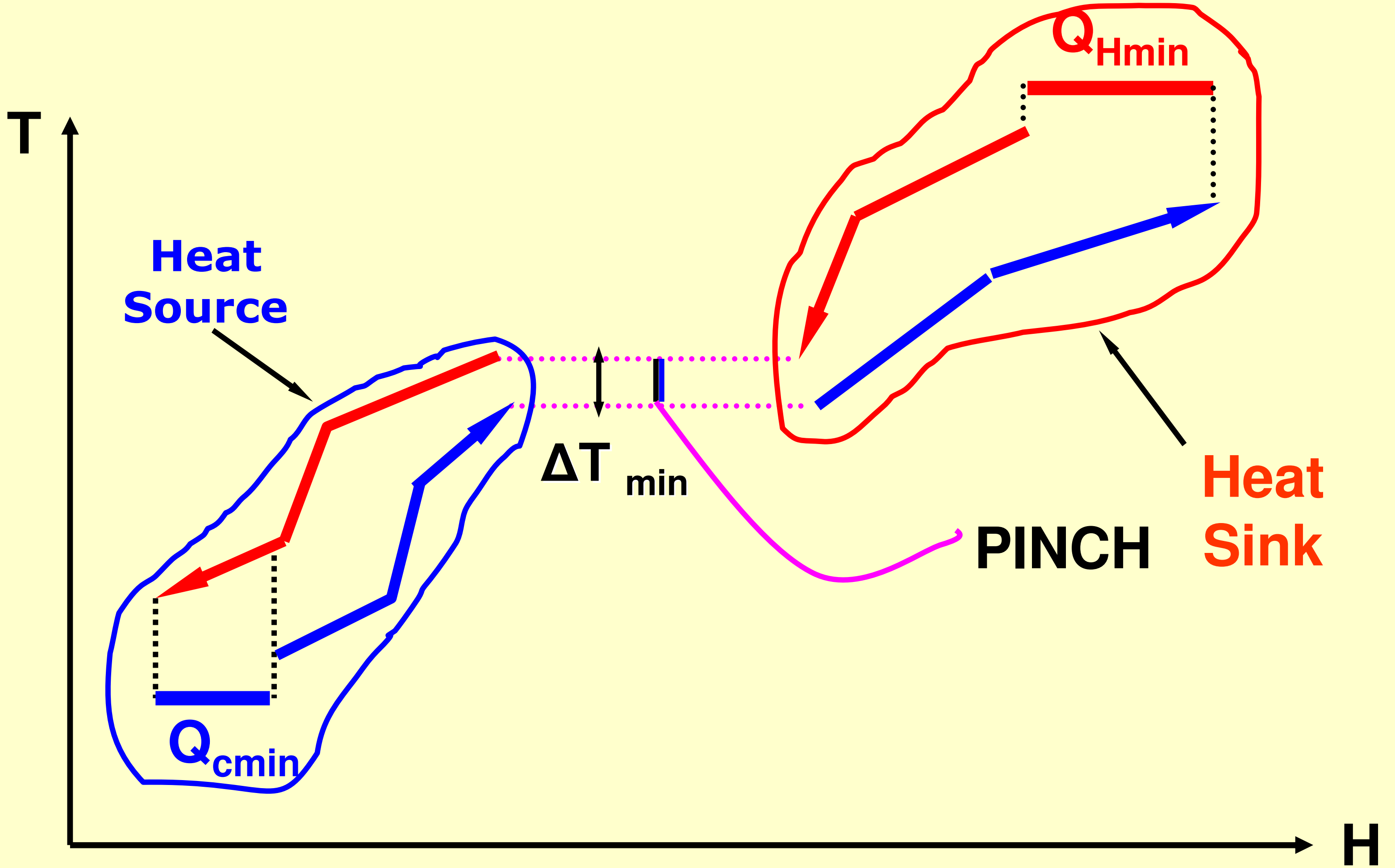




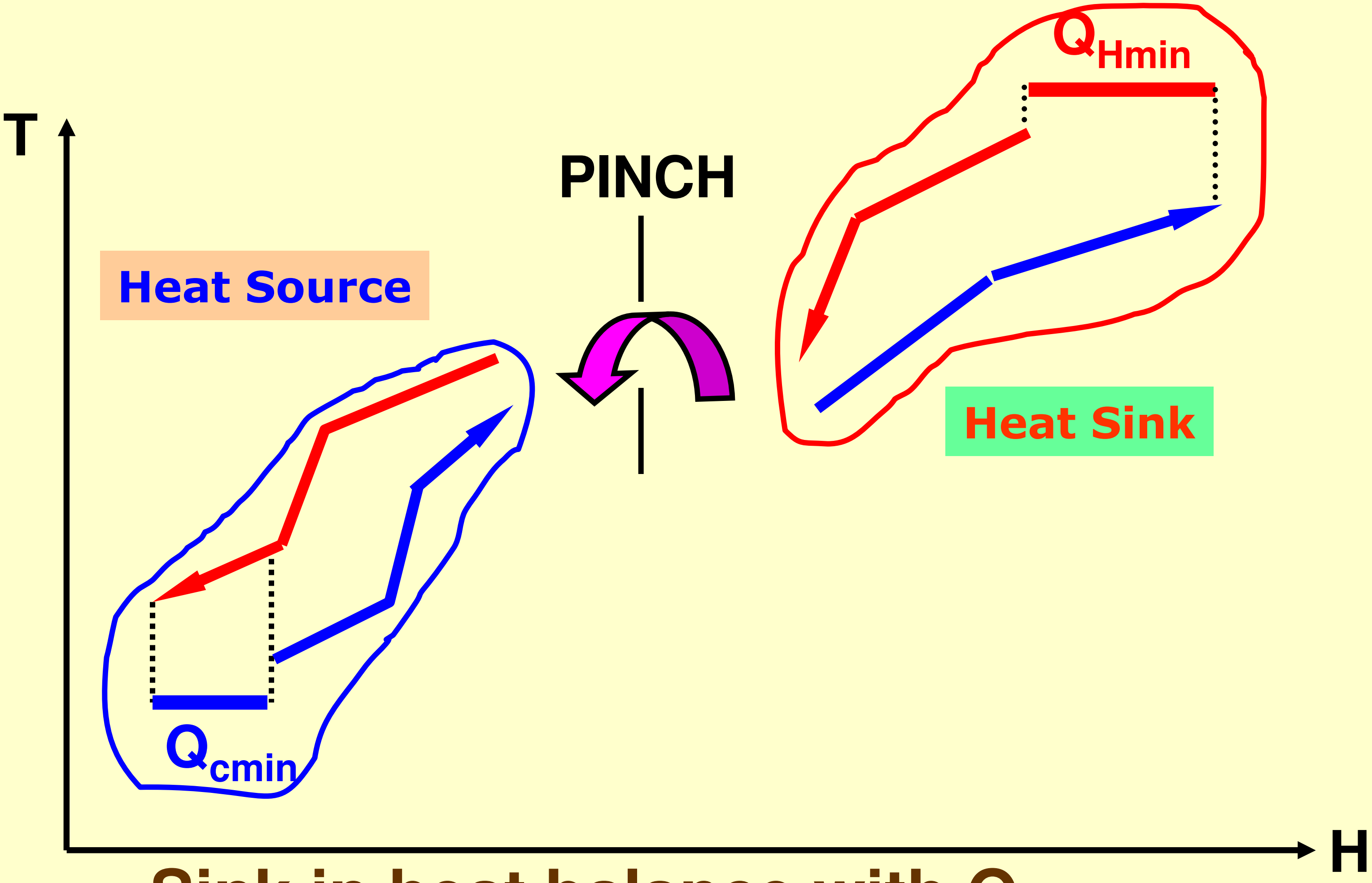
The Pinch Sets Absolute Limits for Process Heat Recovery



For a Practical ΔT_{min} $T_{HOT} \neq T_{COLD}$



The “pinch” divides the problem into a heat source and heat sink

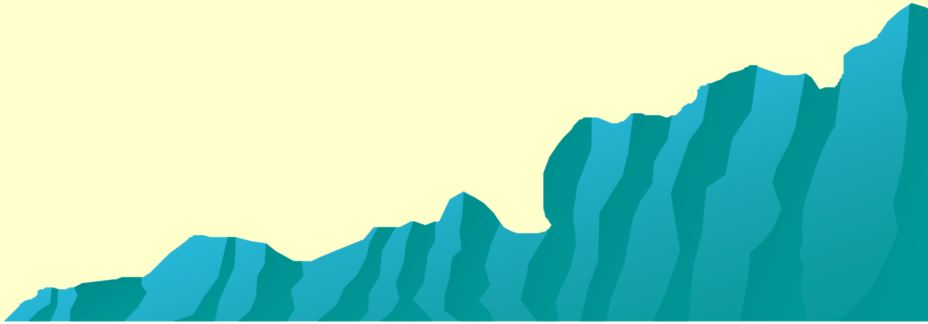


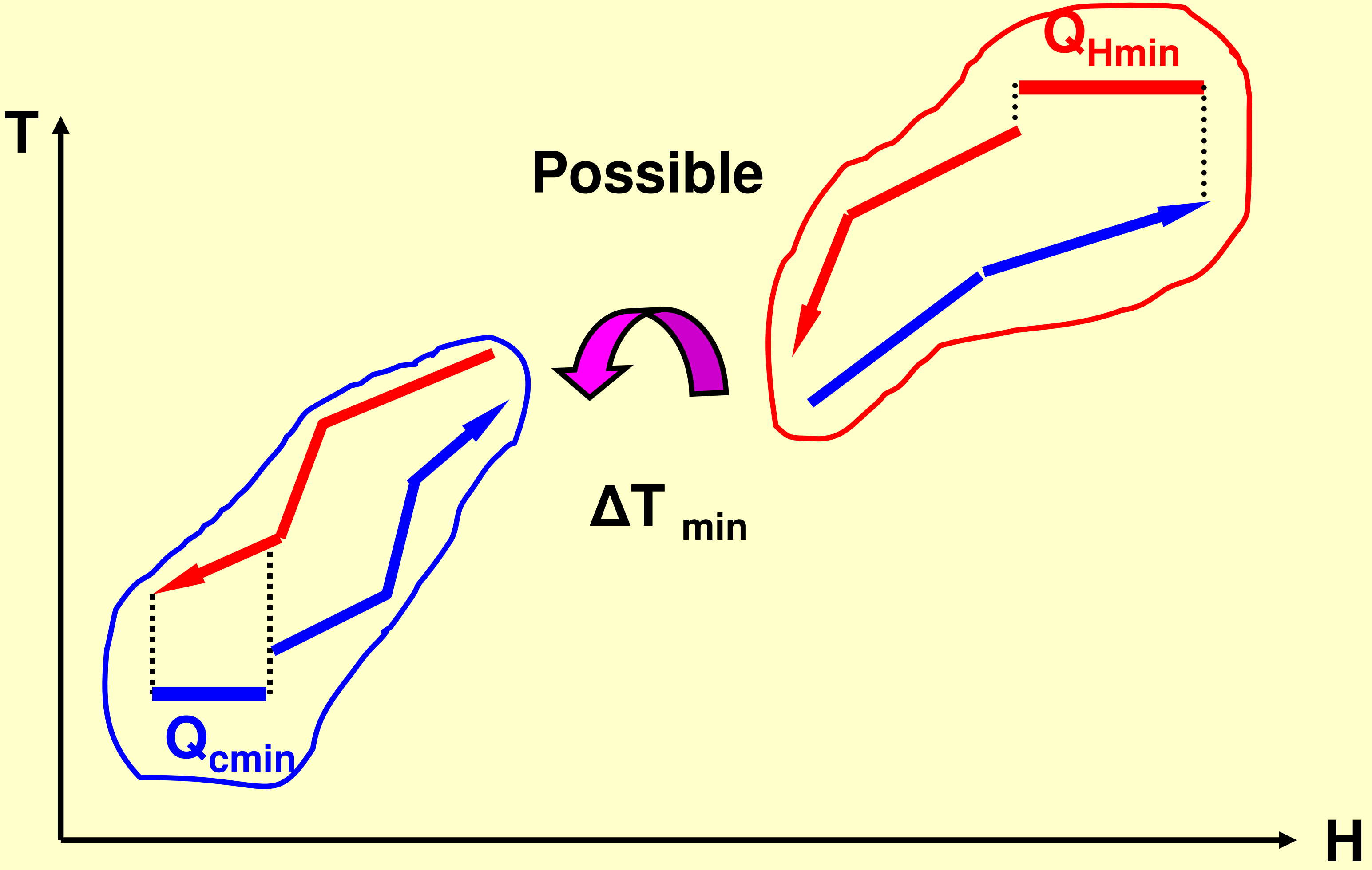
Sink in heat balance with Q_{Hmin}

Source in heat balance with Q_{cmin}

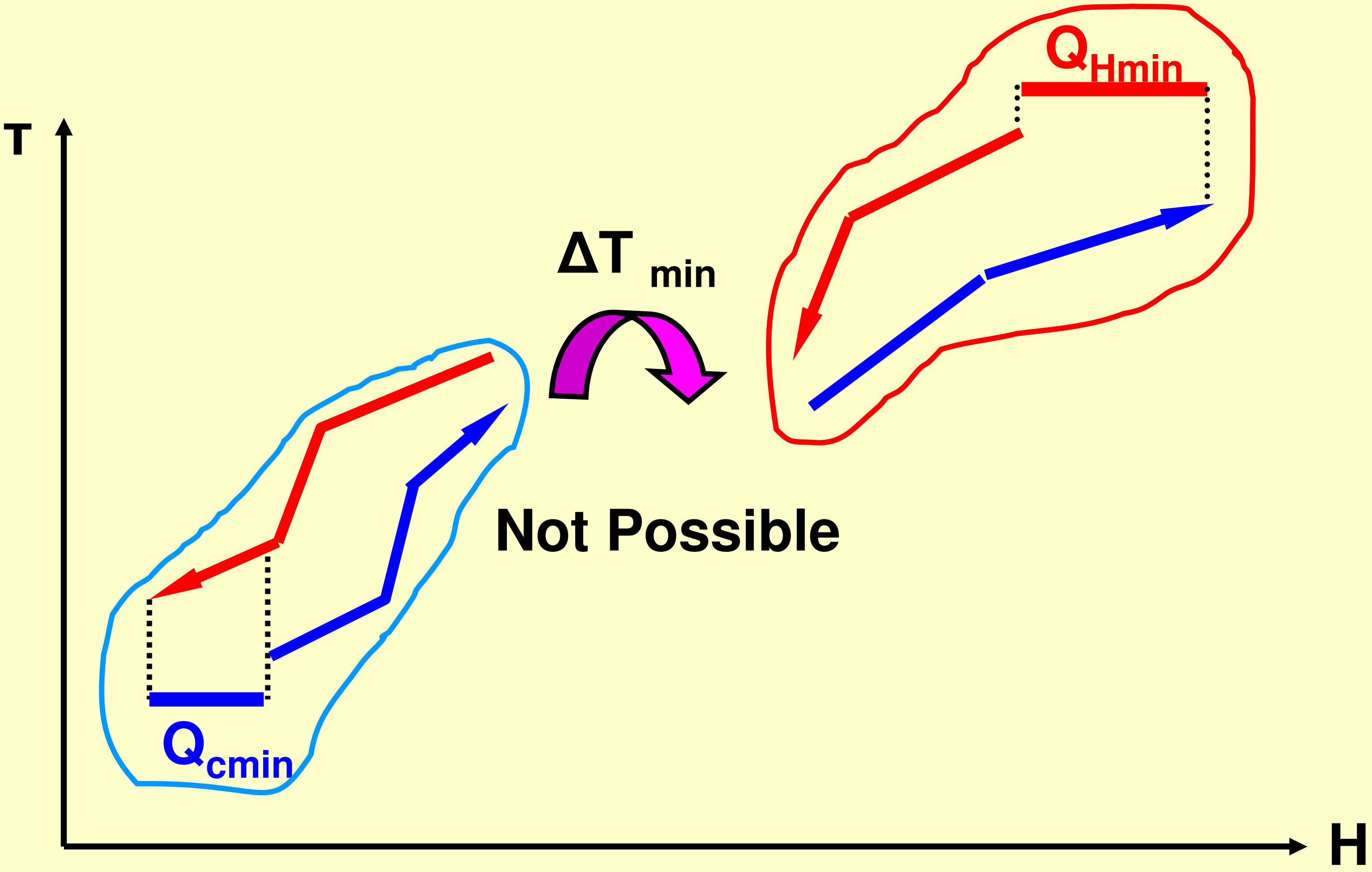
zero cross-pinch transfer

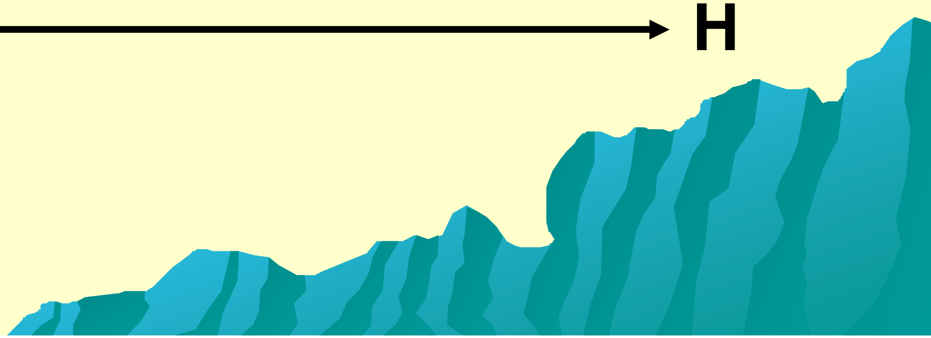
What happens if we transfer heat across the pinch?

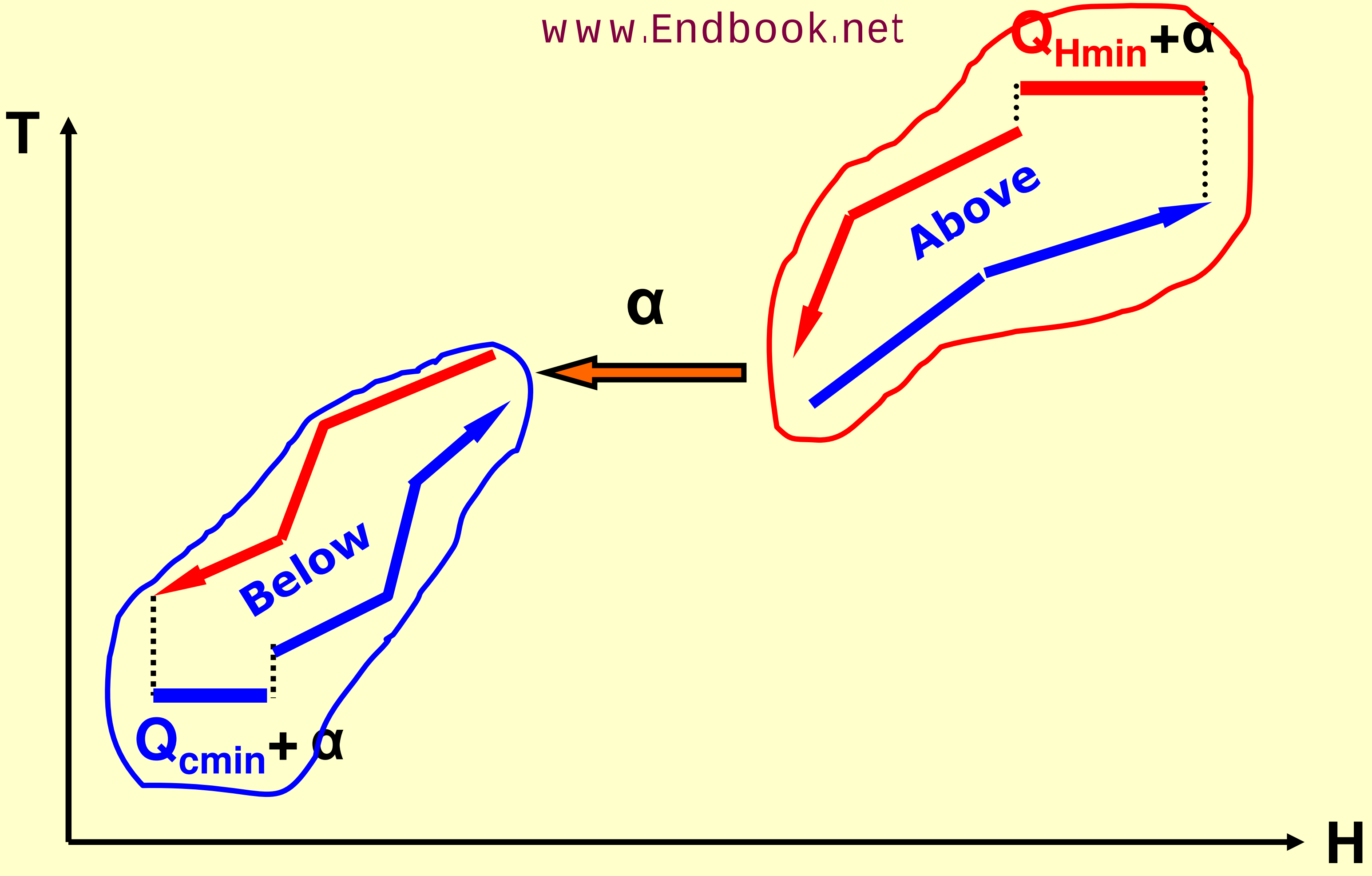




It is possible to transfer heat from above the pinch to below the pinch.


T
H
Q_{Hmin}
Q_{cmin}
ΔT_{min}
Not Possible





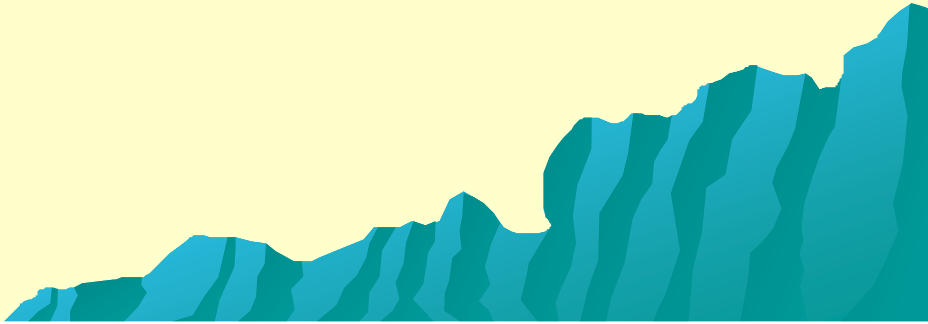
If we transfer α units of heat across the pinch

⬇

Q_{Hmin} and Q_{cmin} are both increased by α

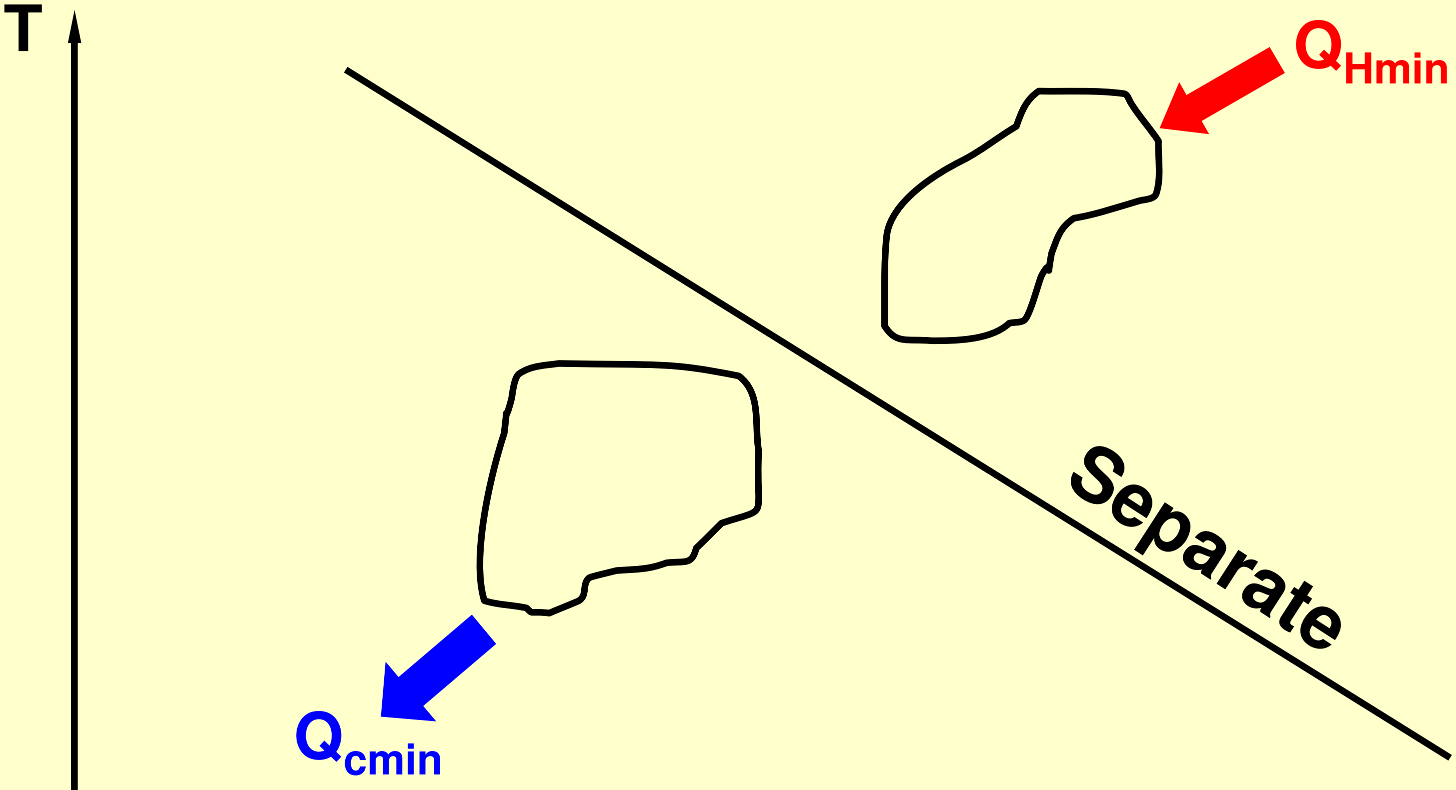
Design Rules

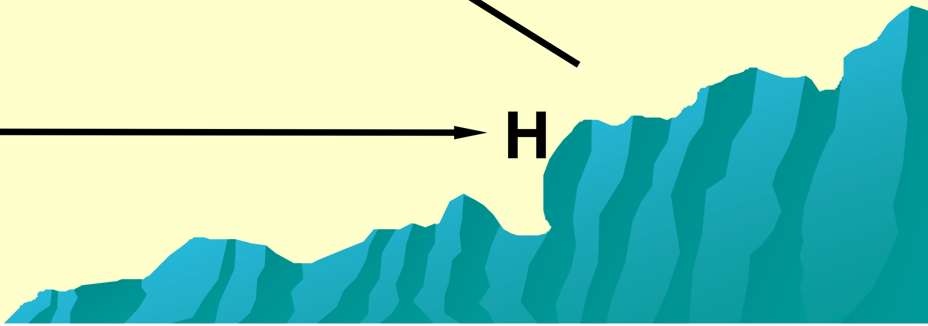
- ✓ Do not use hot utility below
- ✓ Do not recover process heat across
- ✓ Do not use cold utility above



OR:

- ✓ **Keep source (below) and sink (above) separate**
- ✓ **Use hot utility above and cold utility below**



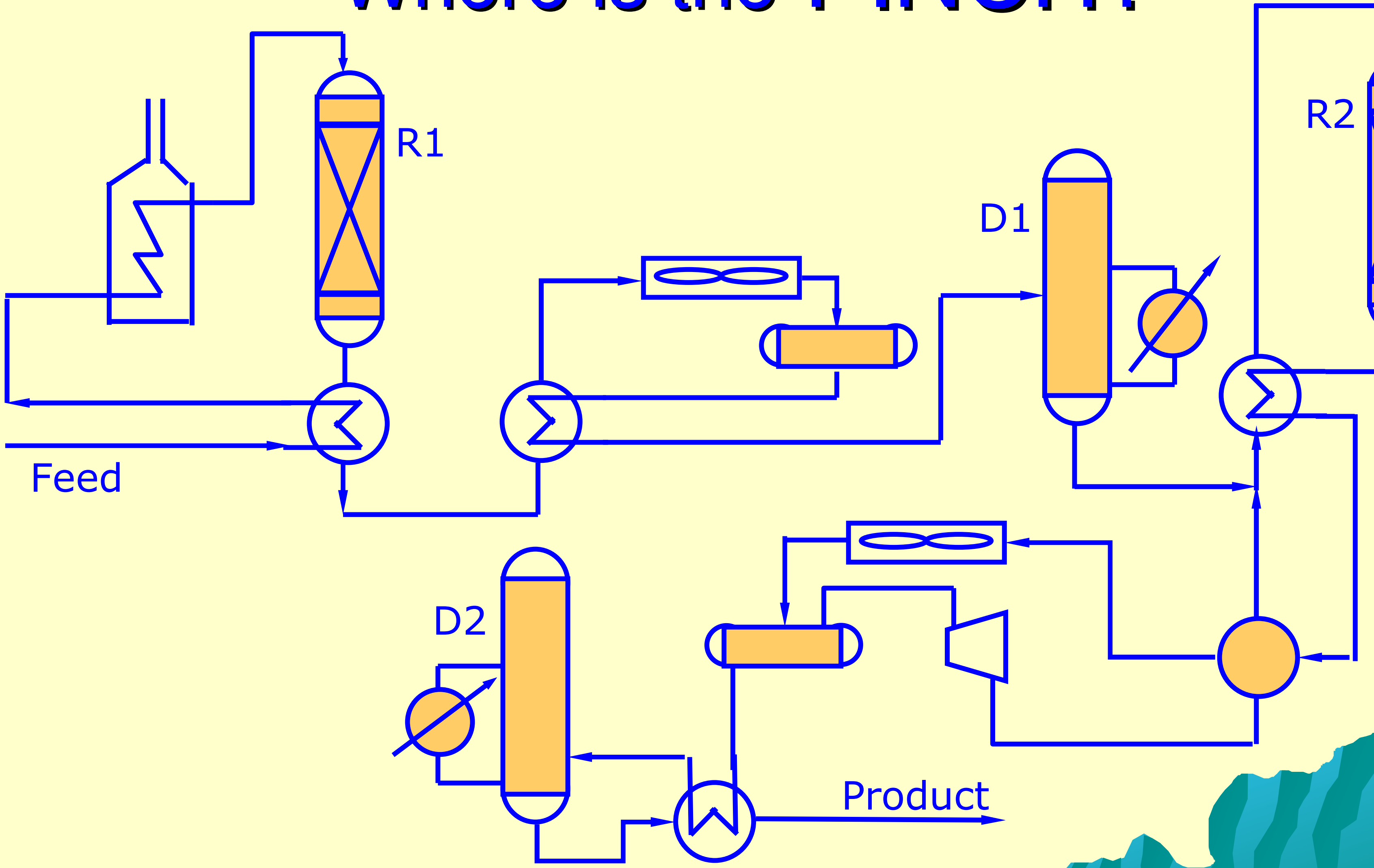


LECTURE 5

Heat Exchanger Network Representation

Conventional Flowsheet

Where is the PINCH?

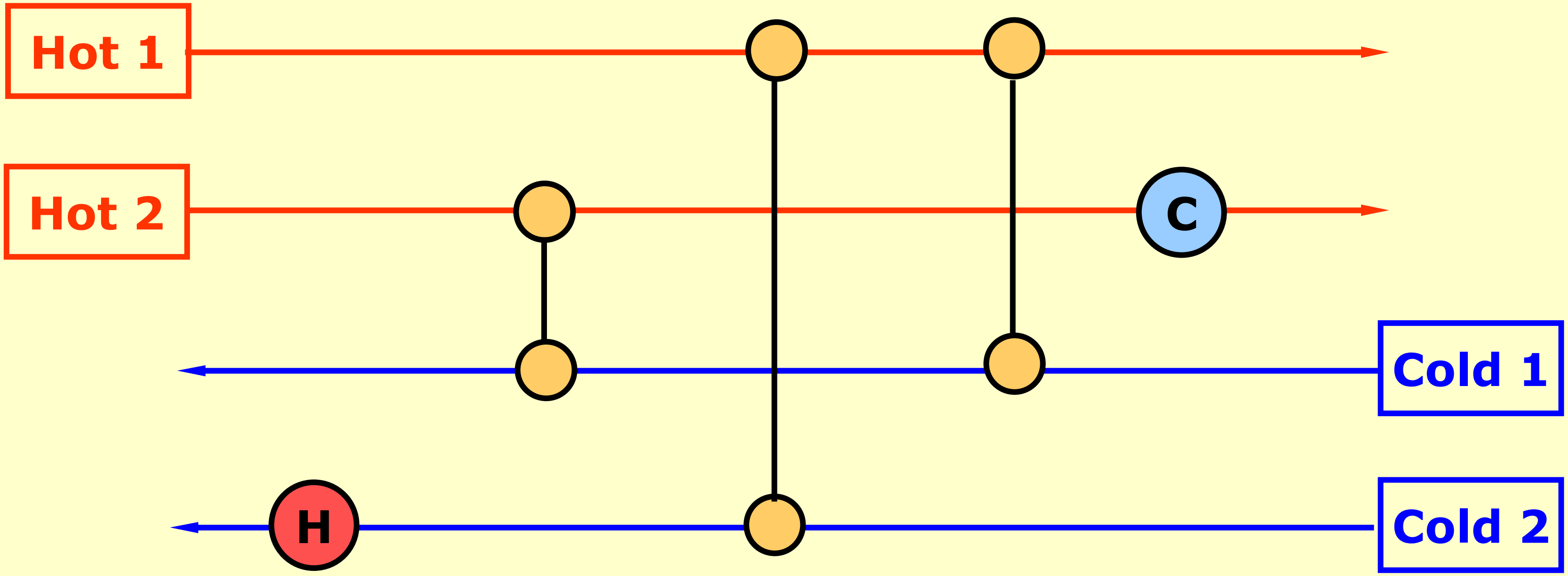


The pinch is much more clearly shown on:

"Grid Diagram"

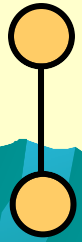
Which only shows heat transfer operations

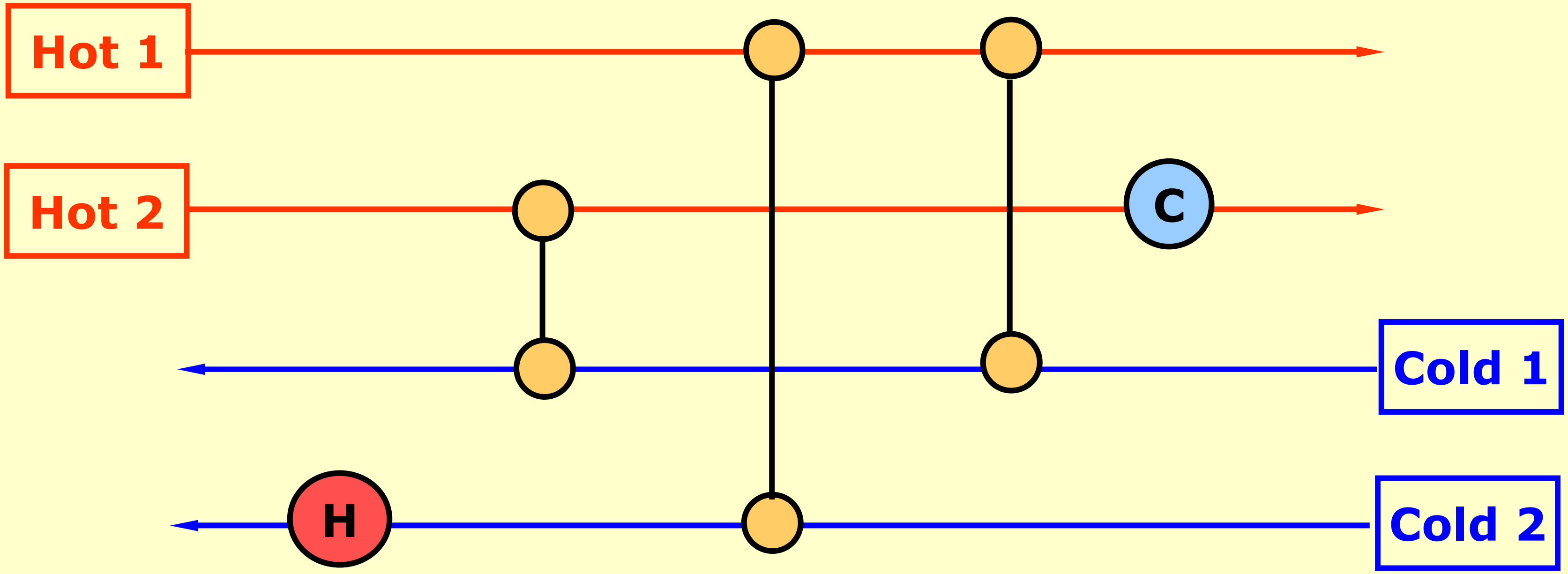
Typical Grid Diagram



Rules for construction

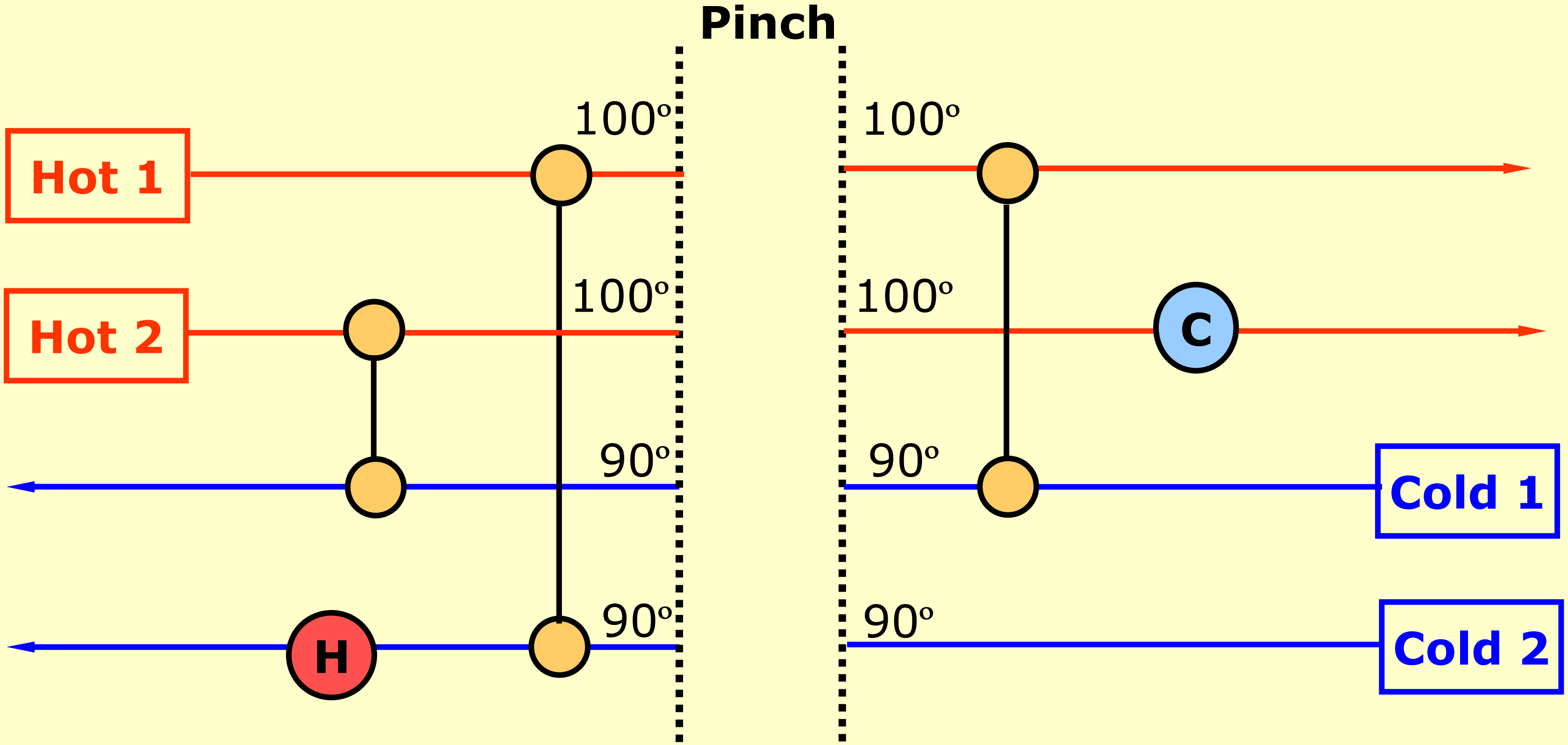
- ✓ Hot streams run left to right
- ✓ Cold streams run right to left
- ✓ Hot streams on top;cold streams on bottom
- ✓ Hot utility= H
- ✓ Cold utility= C
- ✓ Heat exchanger between streams=

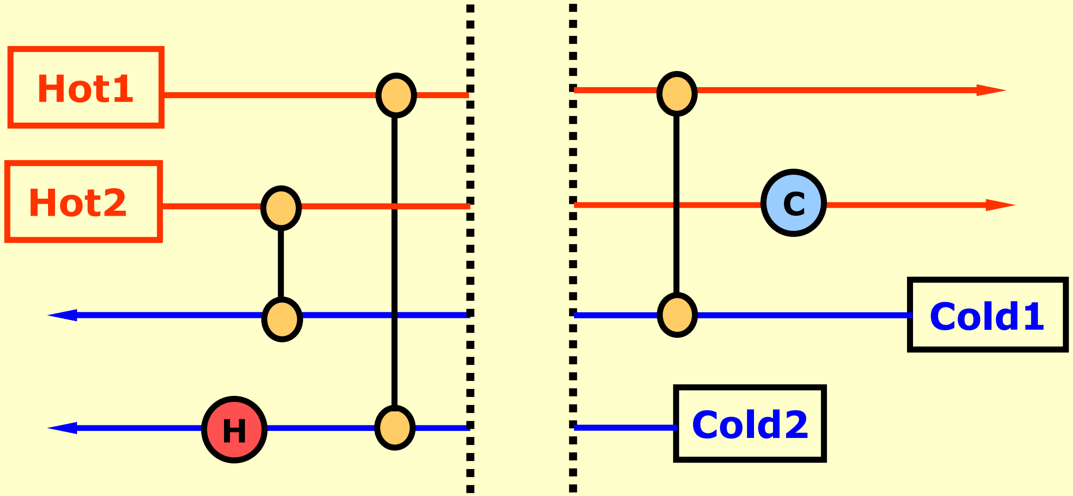




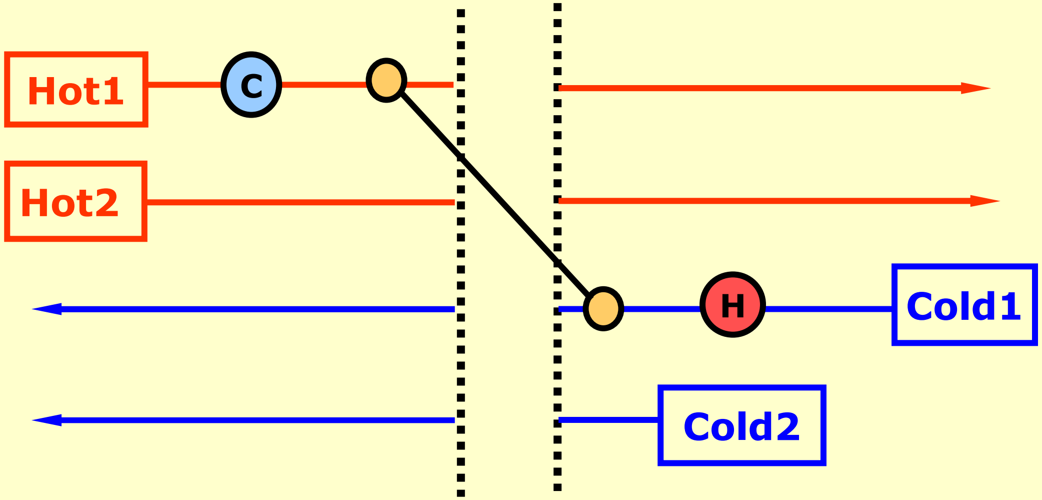
Where is the pinch?

Pinch is easily shown:





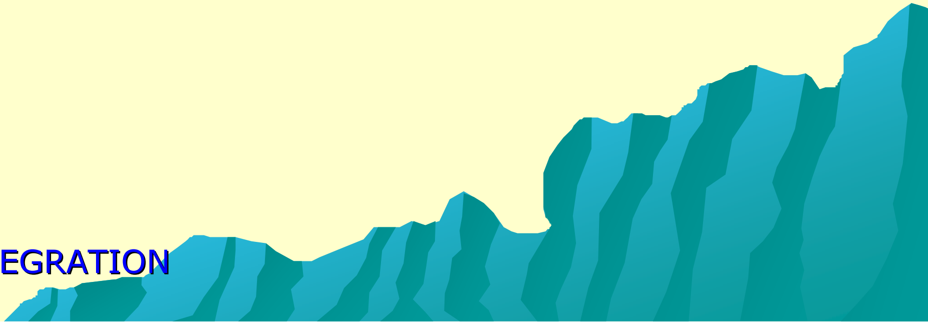
“Allowed”



“Forbidden”

LECTURE 6

Minimum Number of Units

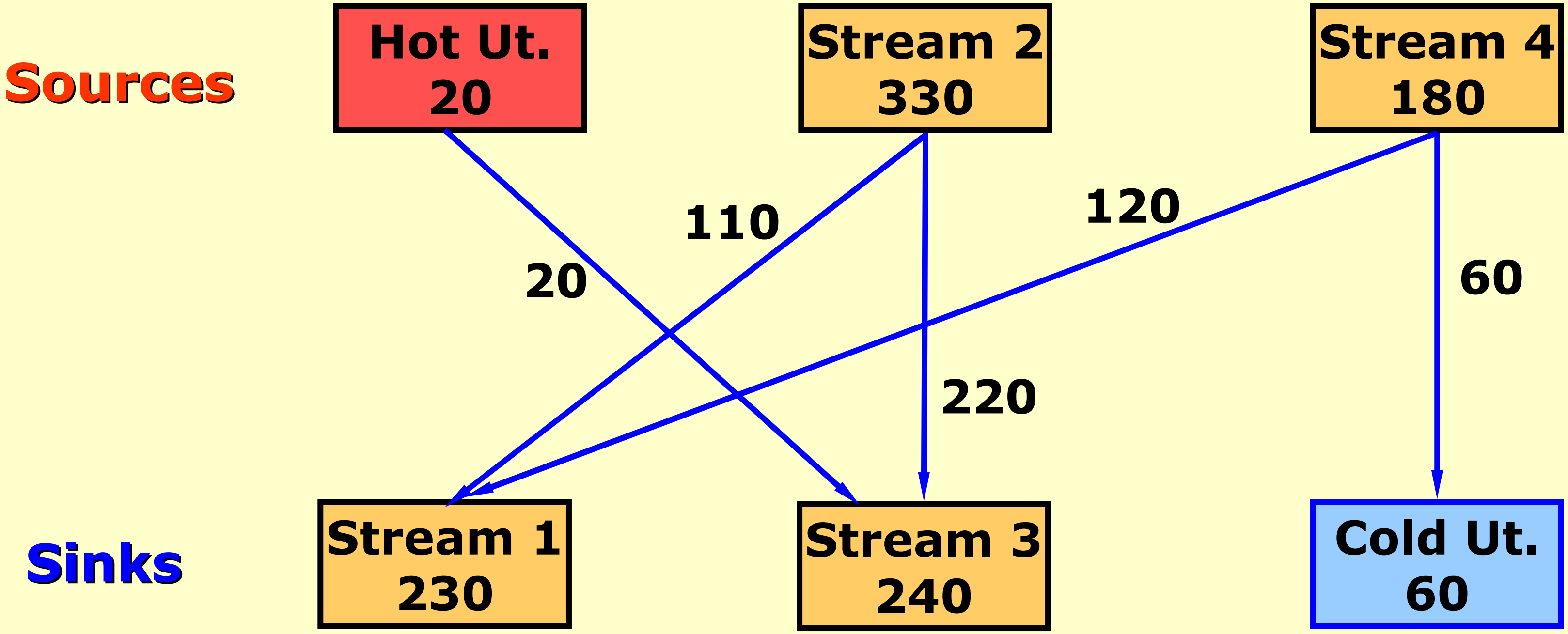


Back to Example Problem 2

Stream	Type	Supply Temp. T_s(°C)	Target Temp T_T(°C)	CP	ΔH
1	Cold	20	135	2	230
2	Hot	170	60	3	330
3	Cold	80	140	4	240
4	Hot	150	30	1.5	180

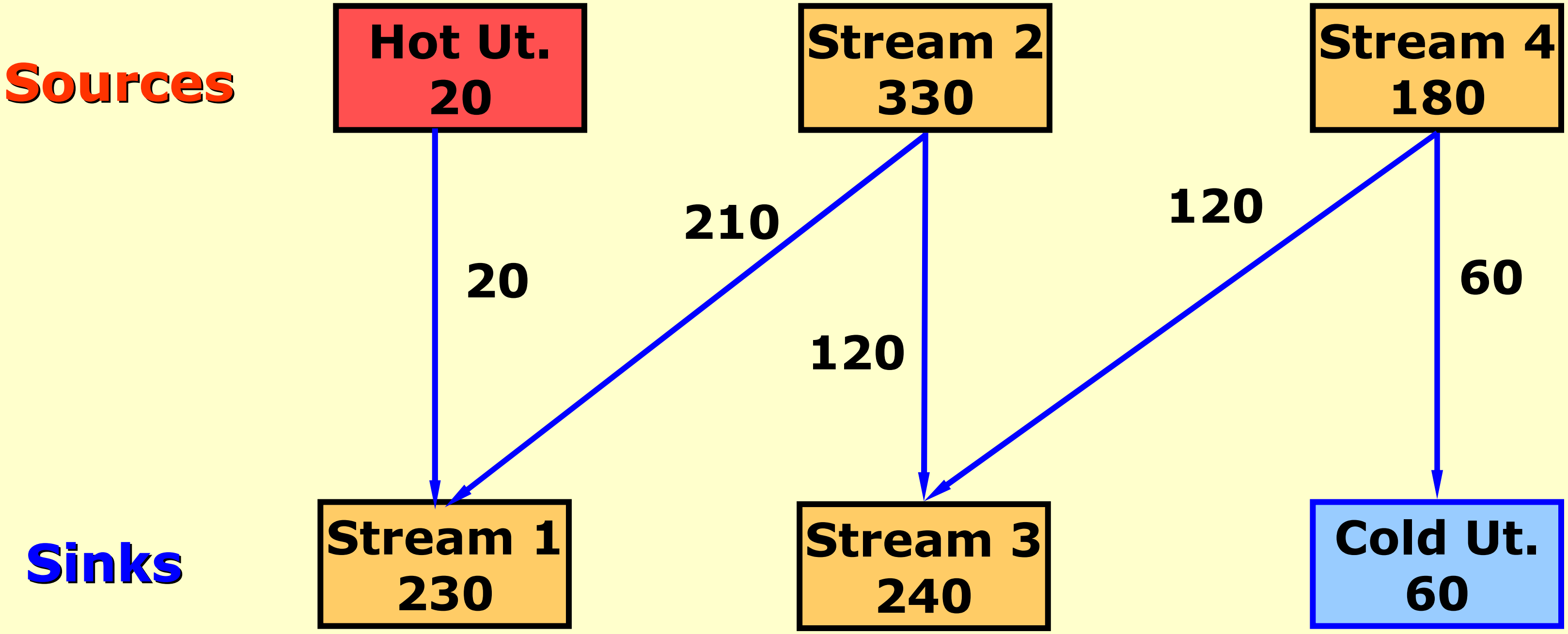
$Q_{cmin} = 60$

$Q_{Hmin} = 20$



No. of Exchangers = No. of Streams + No. of Utilities - 1

5 = 4 + 2 - 1



Sources

Hot Ut.
20

Stream 2
330

Stream 4
180

20

210

120

120

60

Sinks

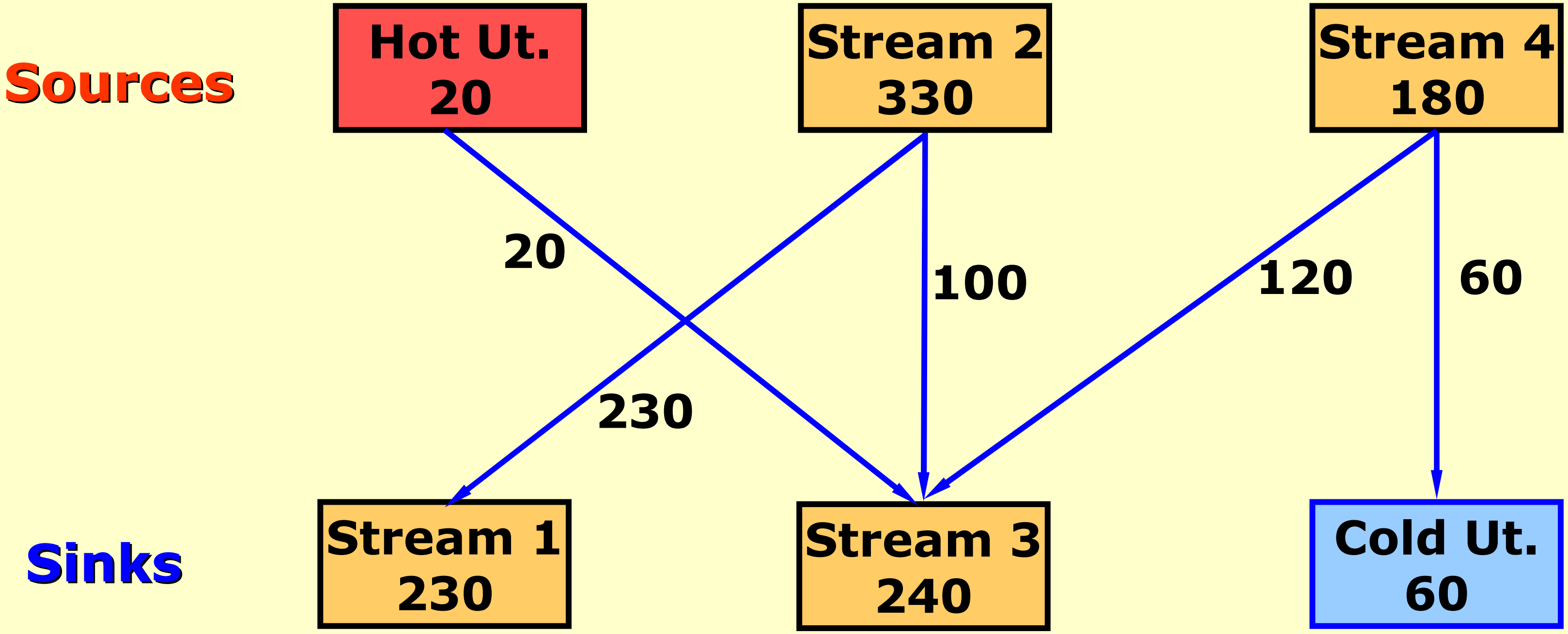
Stream 1
230

Stream 3
240

Cold Ut.
60

No. of Exchangers = No. of Streams + No. of Utilities - 1

5 = 4 + 2 - 1



Sources

Hot Ut.
20

Stream 2
330

Stream 4
180

Sinks

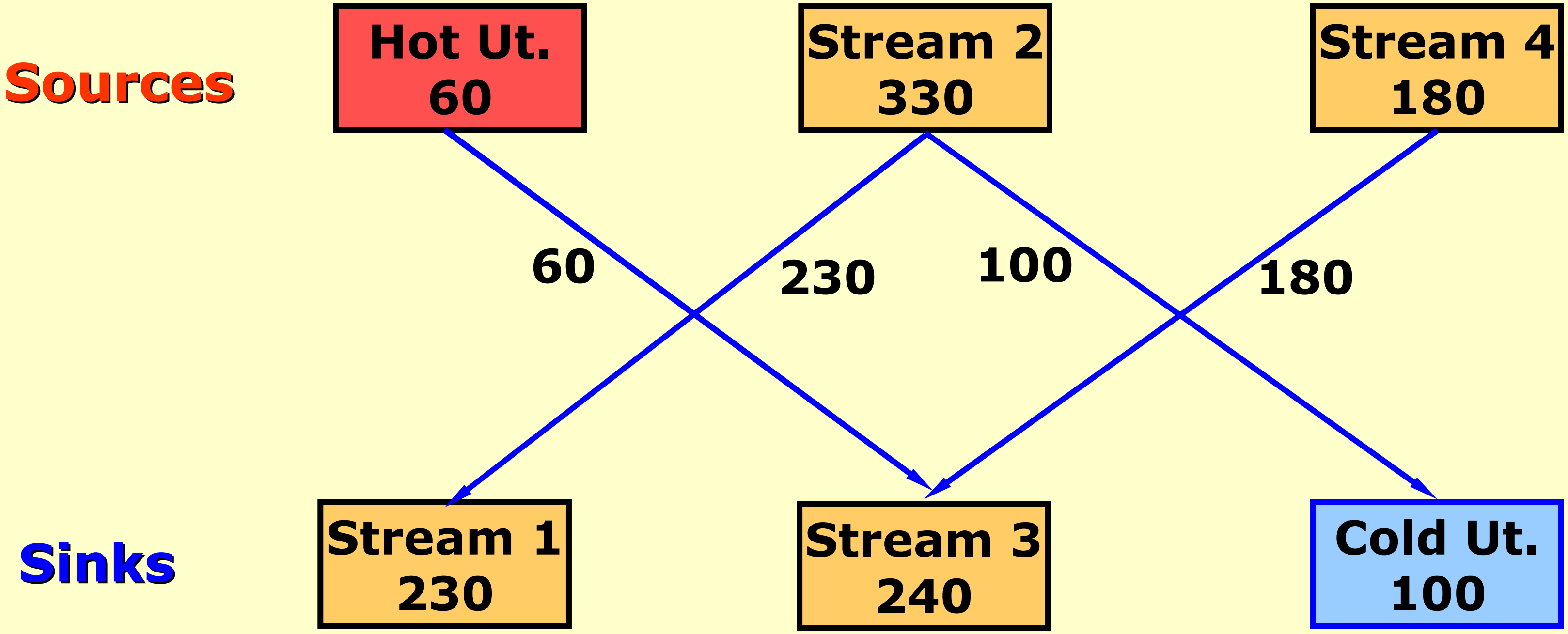
Stream 1
230

Stream 3
240

Cold Ut.
60

No. of Exchangers= No. of Streams + N0. of Utilities - 1

5 = 4 + 2 - 1



Sources

Hot Ut.
60

Stream 2
330

Stream 4
180

60

230

100

180

Sinks

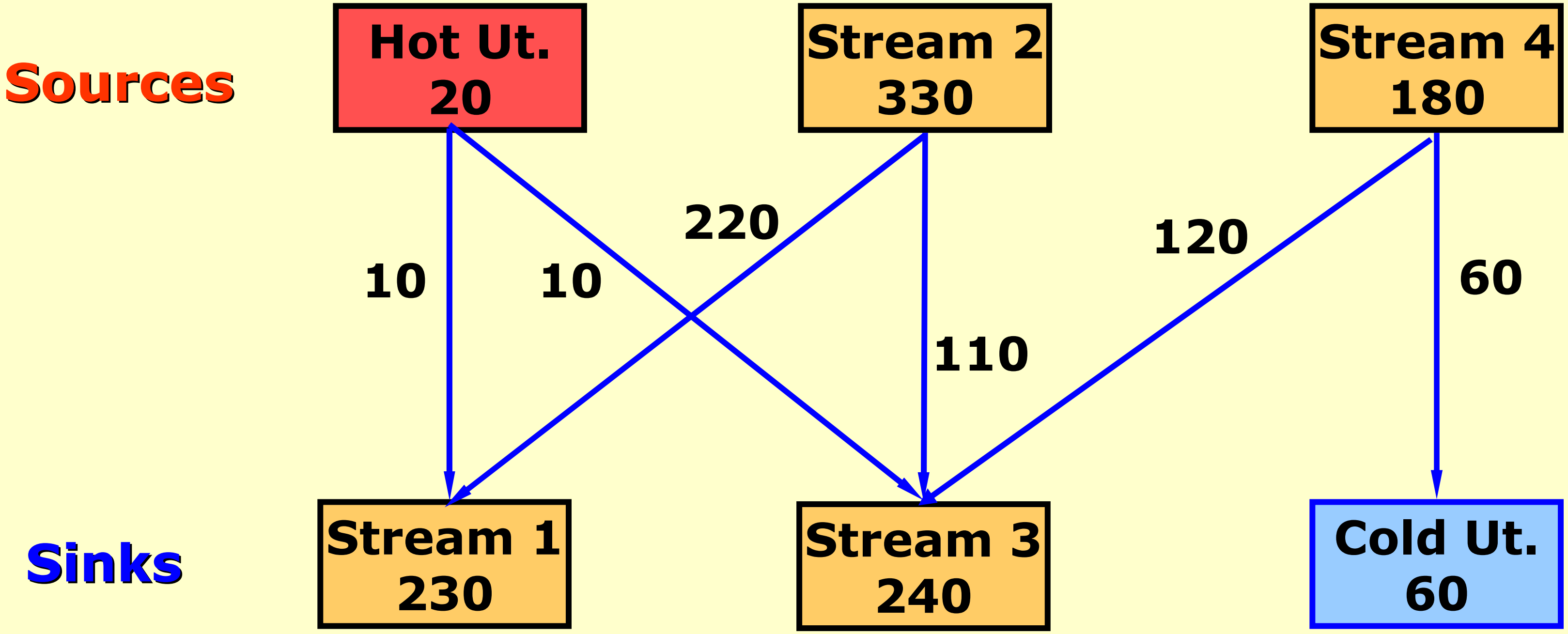
Stream 1
230

Stream 3
240

Cold Ut.
100

No. of Exchangers= No. of Streams + No. of Utilities - Independent Systems

4 = 4 + 2 - 2



No. of Exchangers = No. of Streams + No. of Utilities + No. of Loops - Independent Systems

6 = 4 + 2 + 1 - 1

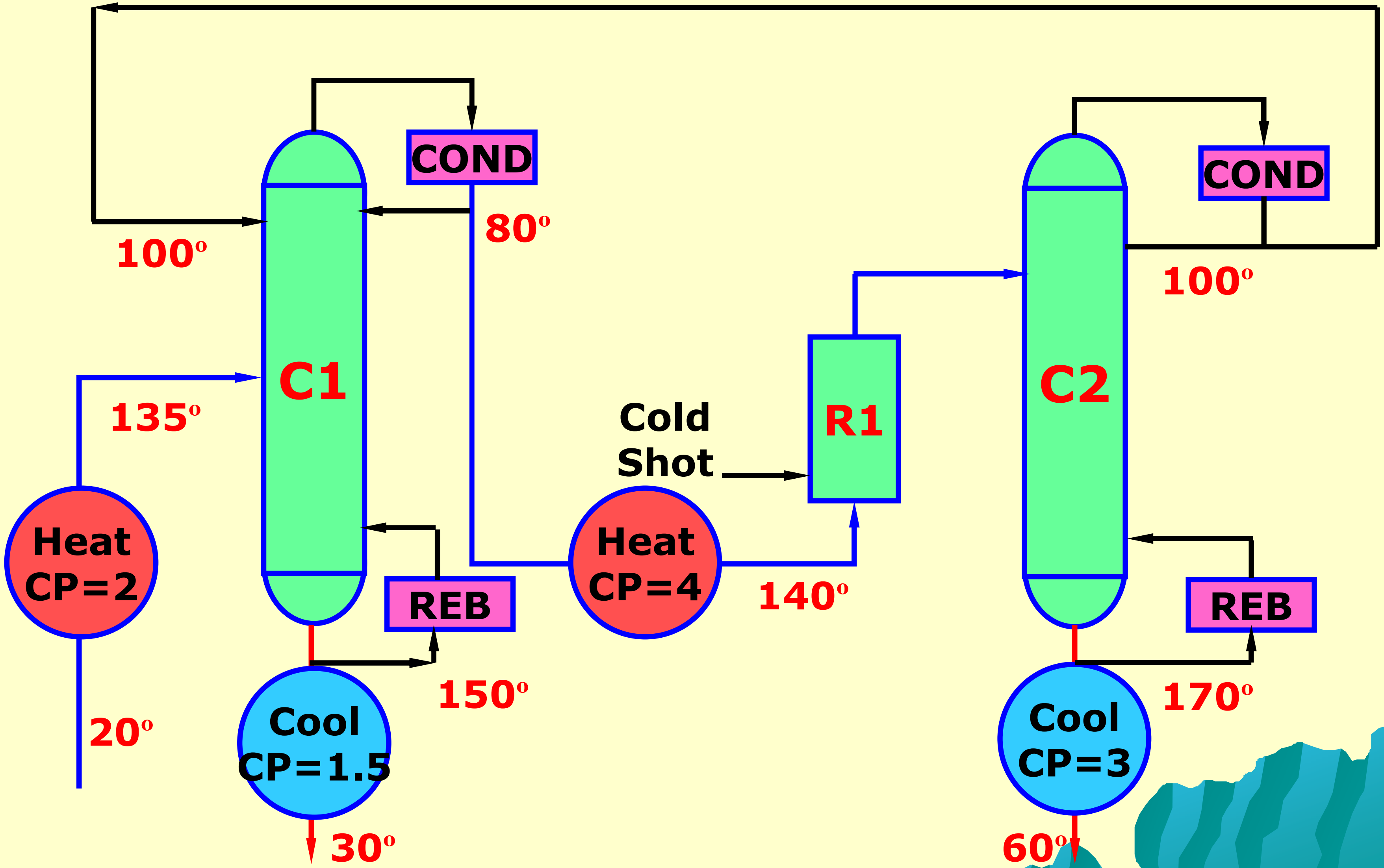
LECTURE 7

Heat Exchanger Network Design for Maximum Energy Recovery

Rules so far:

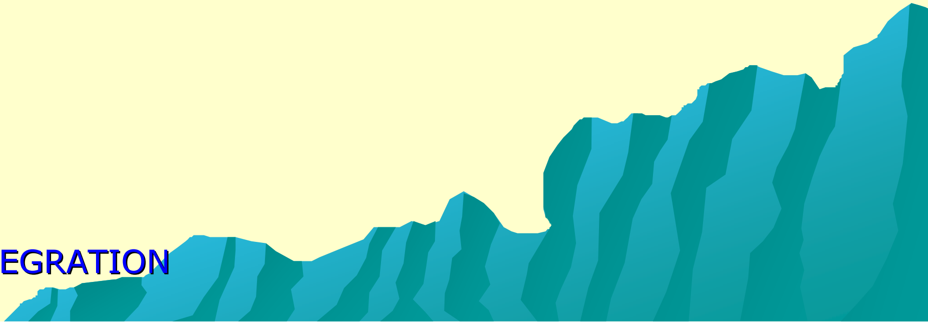
- No exchanger has a temperature difference < $\Delta T_{min.}$
- No process to process heat transfer across the pinch
- No heat transfer across the pinch by inappropriate use of utilities

Example Problem 2

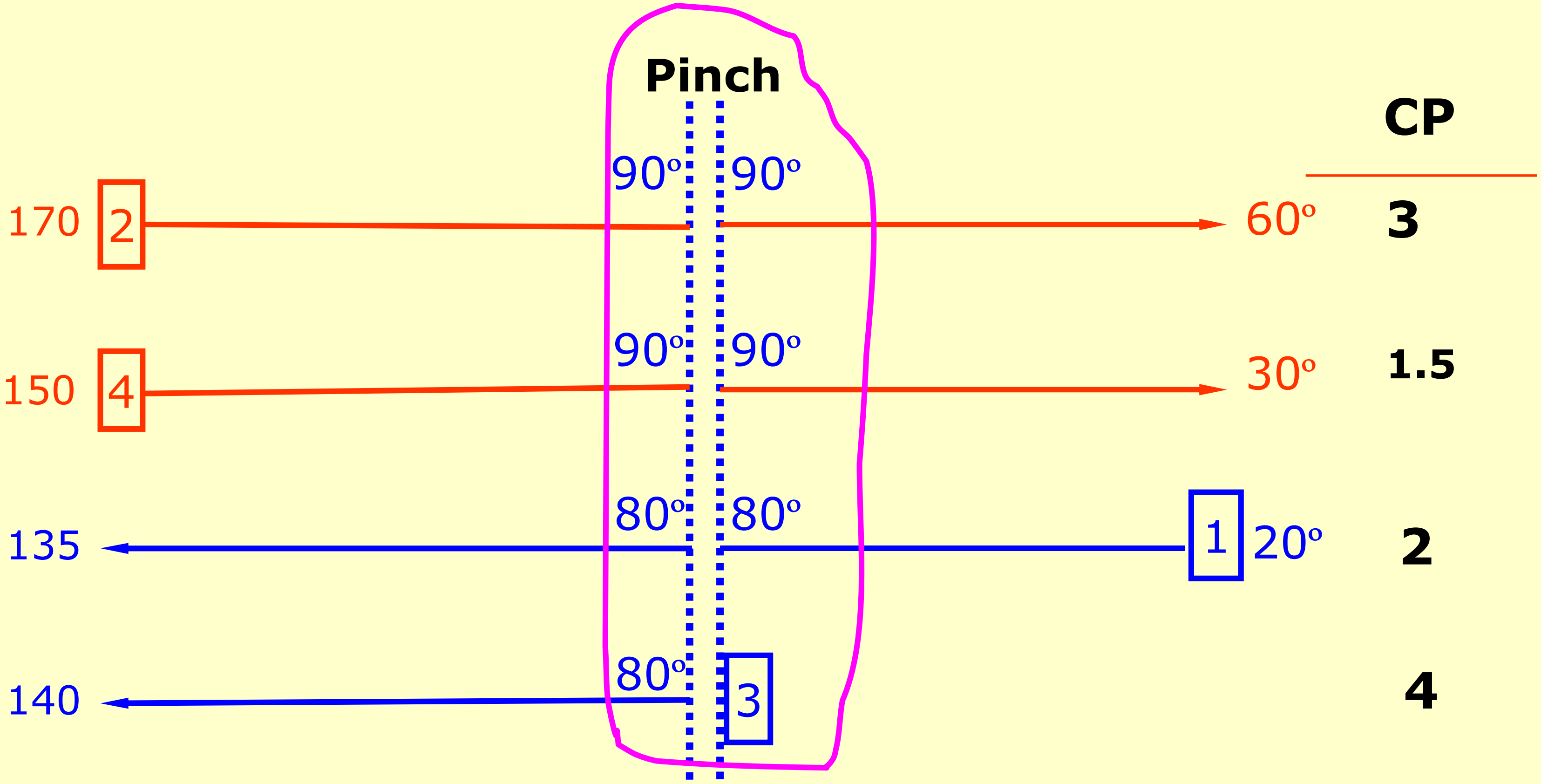


Example Problem 2

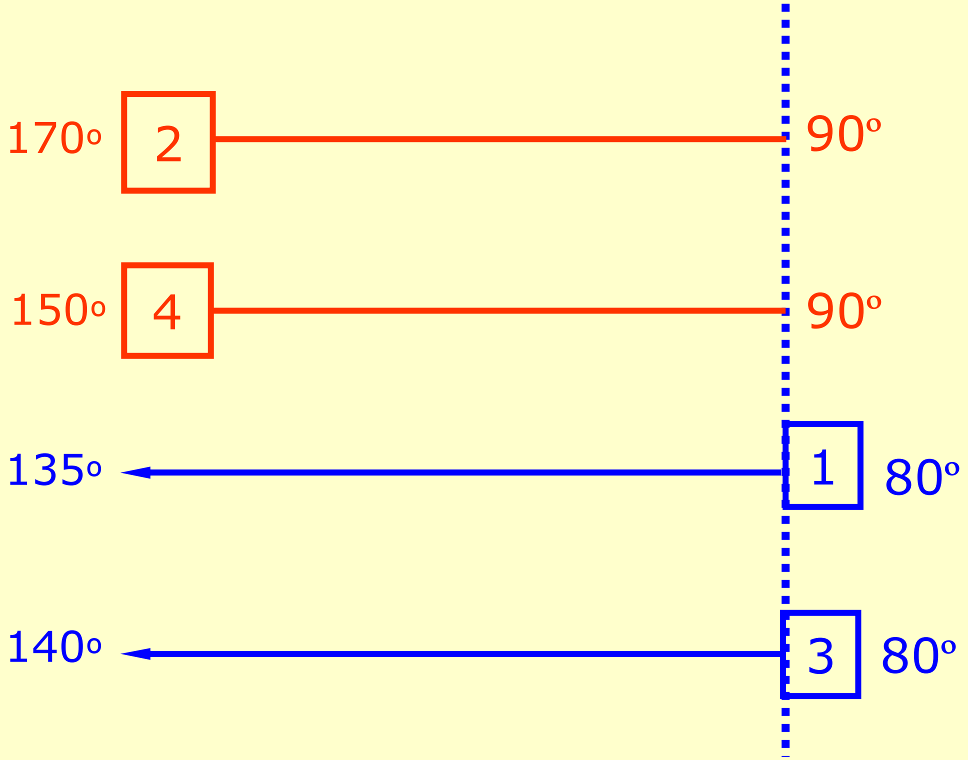
Stream	Type	Supply Temp. T_s(°C)	Target Temp. T_T(°C)	Heat capacity flowrate CP(MW/°C)
1	Cold	20	135	2
2	Hot	170	60	3
3	Cold	80	140	4
4	Hot	150	30	1.5



Grid Presentation



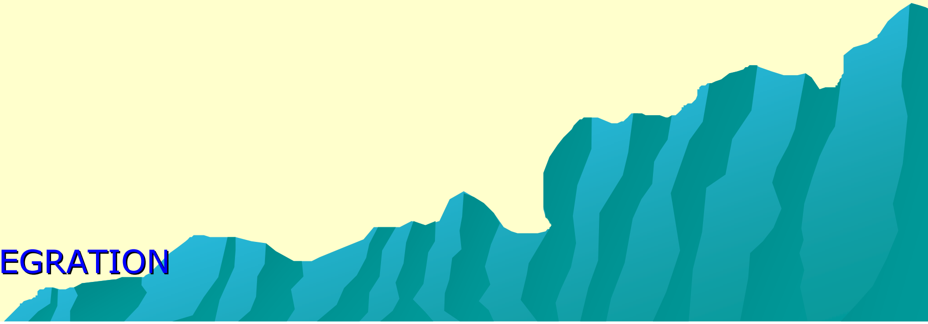
Above the Pinch Design



Which match?

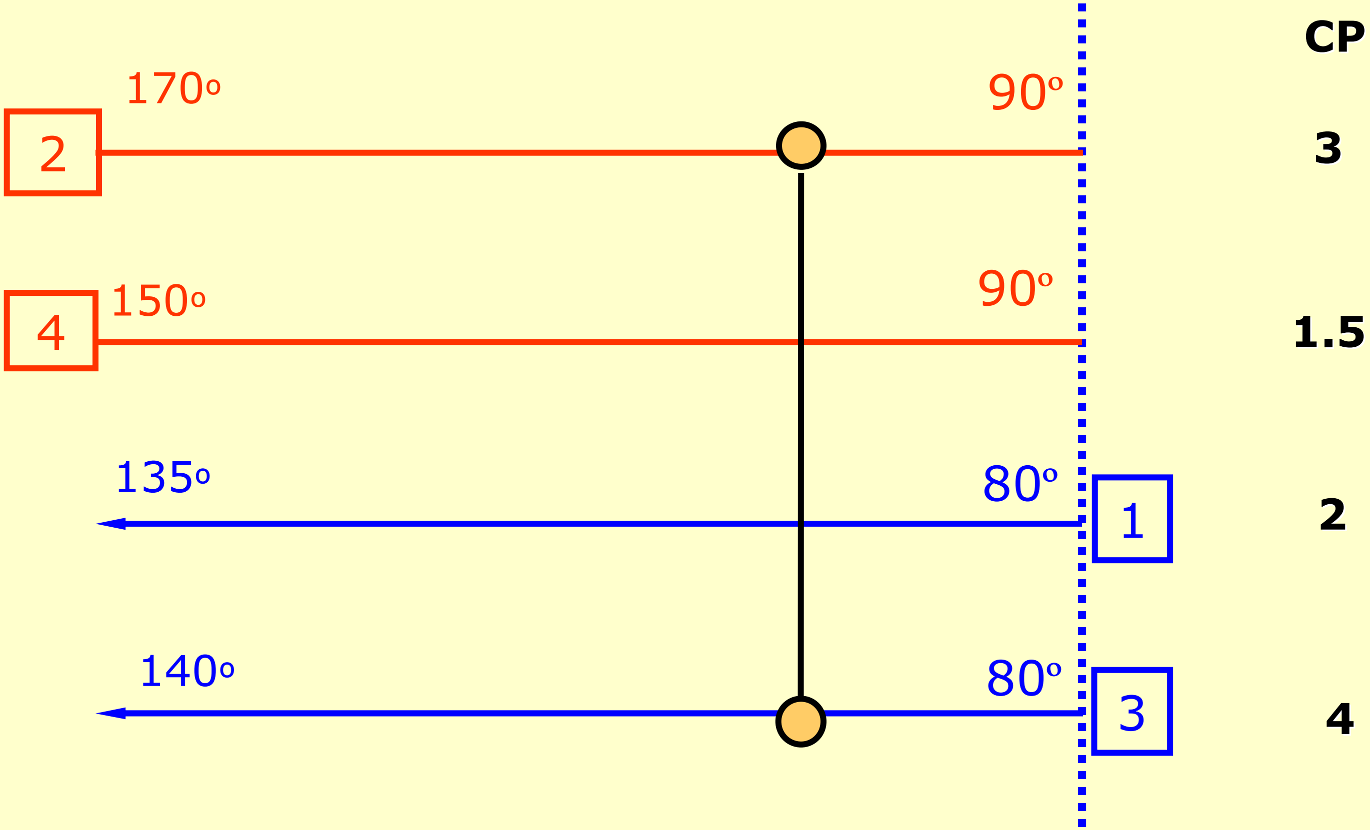
Design Rules

- **Start from pinch and move away**
- **Observe $FCp_{out} \geq FCp_{in}$ for every pinch match**
- **Tick off at least one stream with each match**



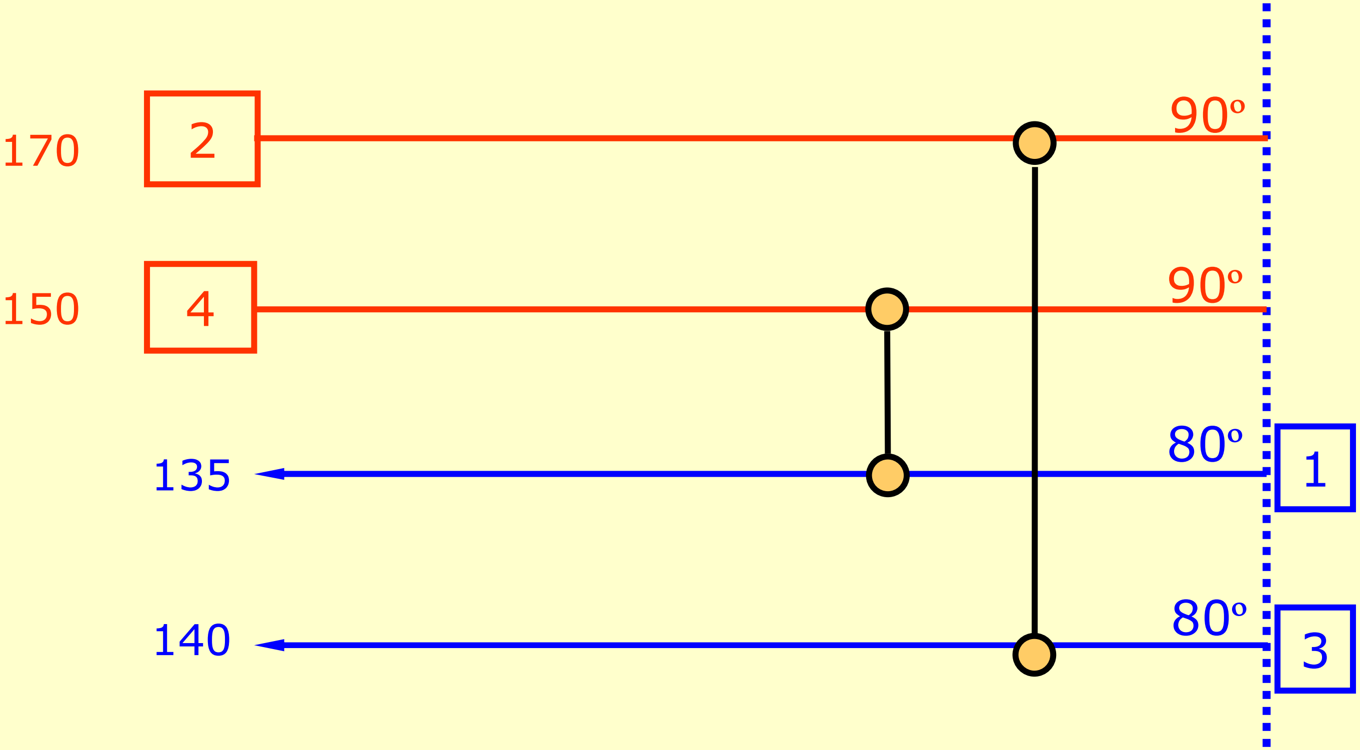
Generally

Start with the biggest stream "In"



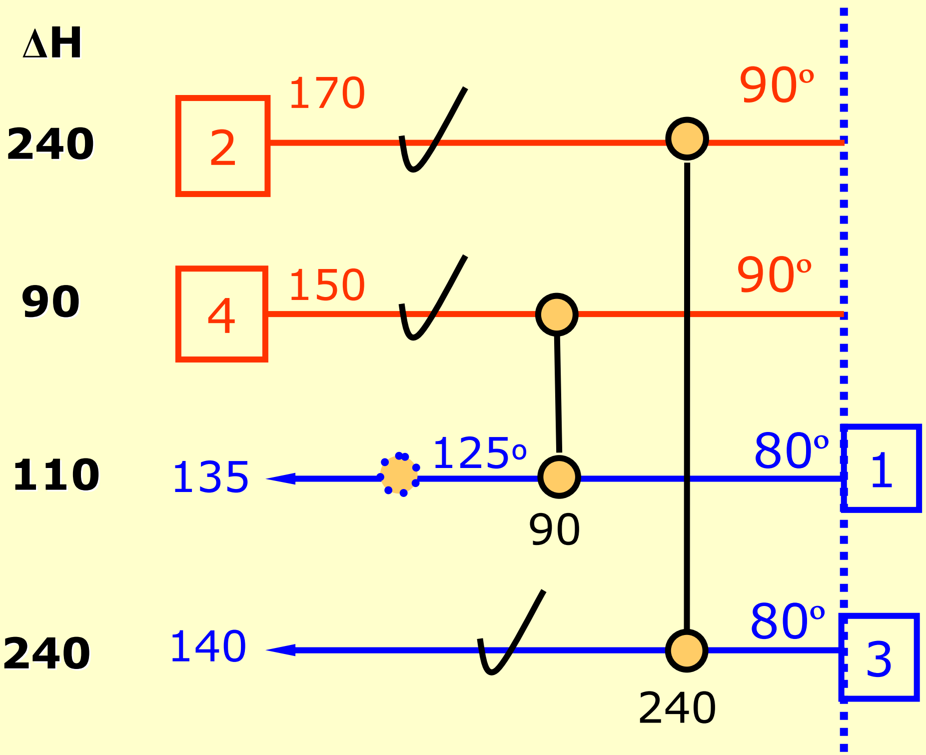
This leaves one more pinch match to place

Two Matches

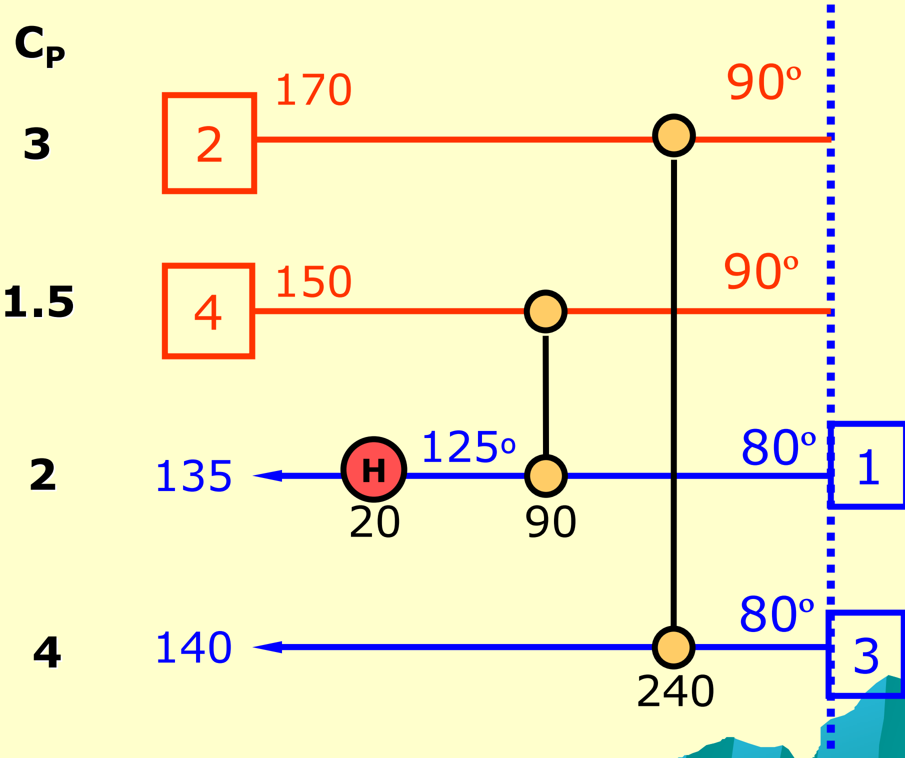


Now, how much heat should these matches transfer?

Maximise loads to “Tick Off” streams (Keeps capital costs down)

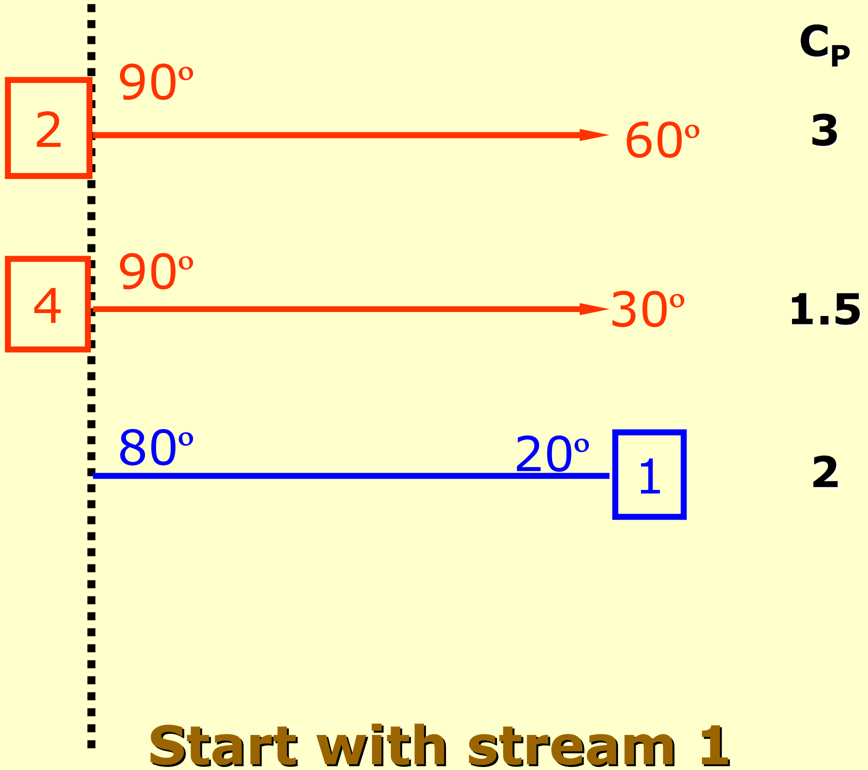


Next step: ”Fill in the rest”



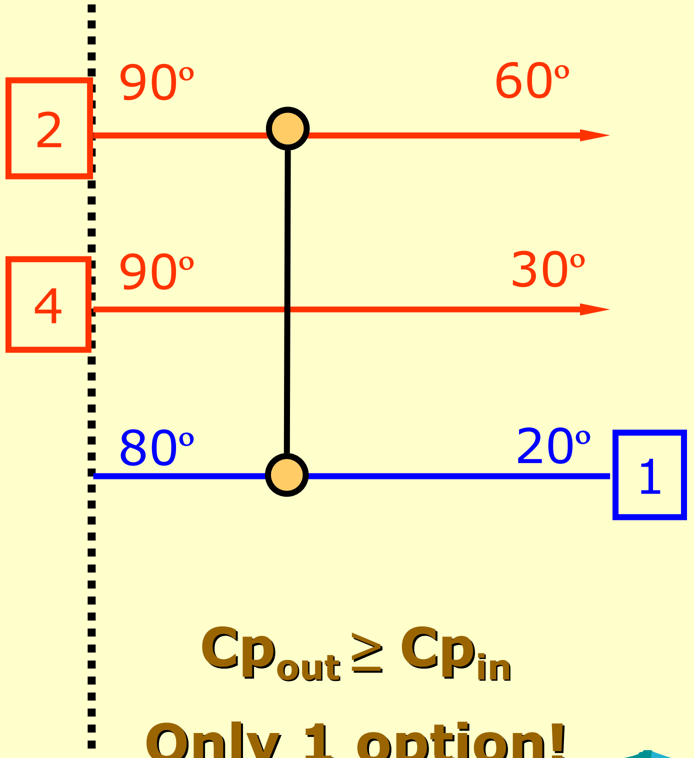
$Q_{Hmin}=20$

Below the Pinch Design



Start with stream 1

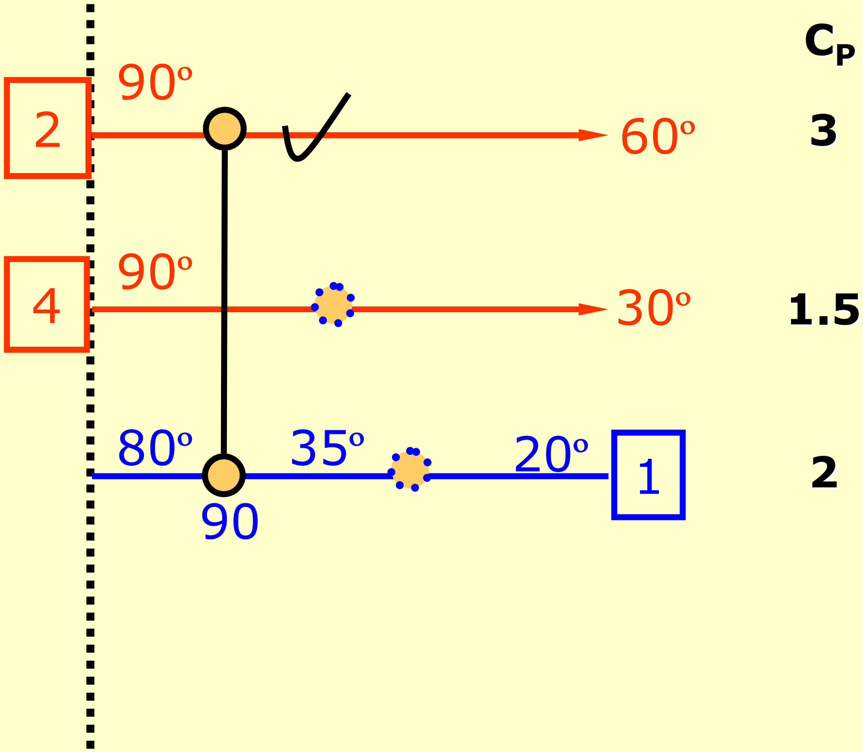
Place Pinch Match



$$Cp_{out} \geq Cp_{in}$$

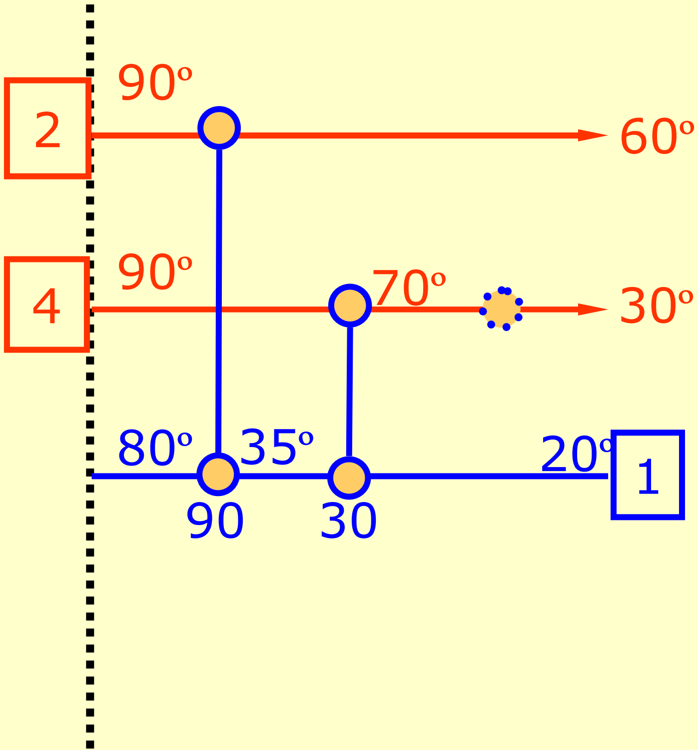
Only 1 option!

Maximise load to “Tick off” stream

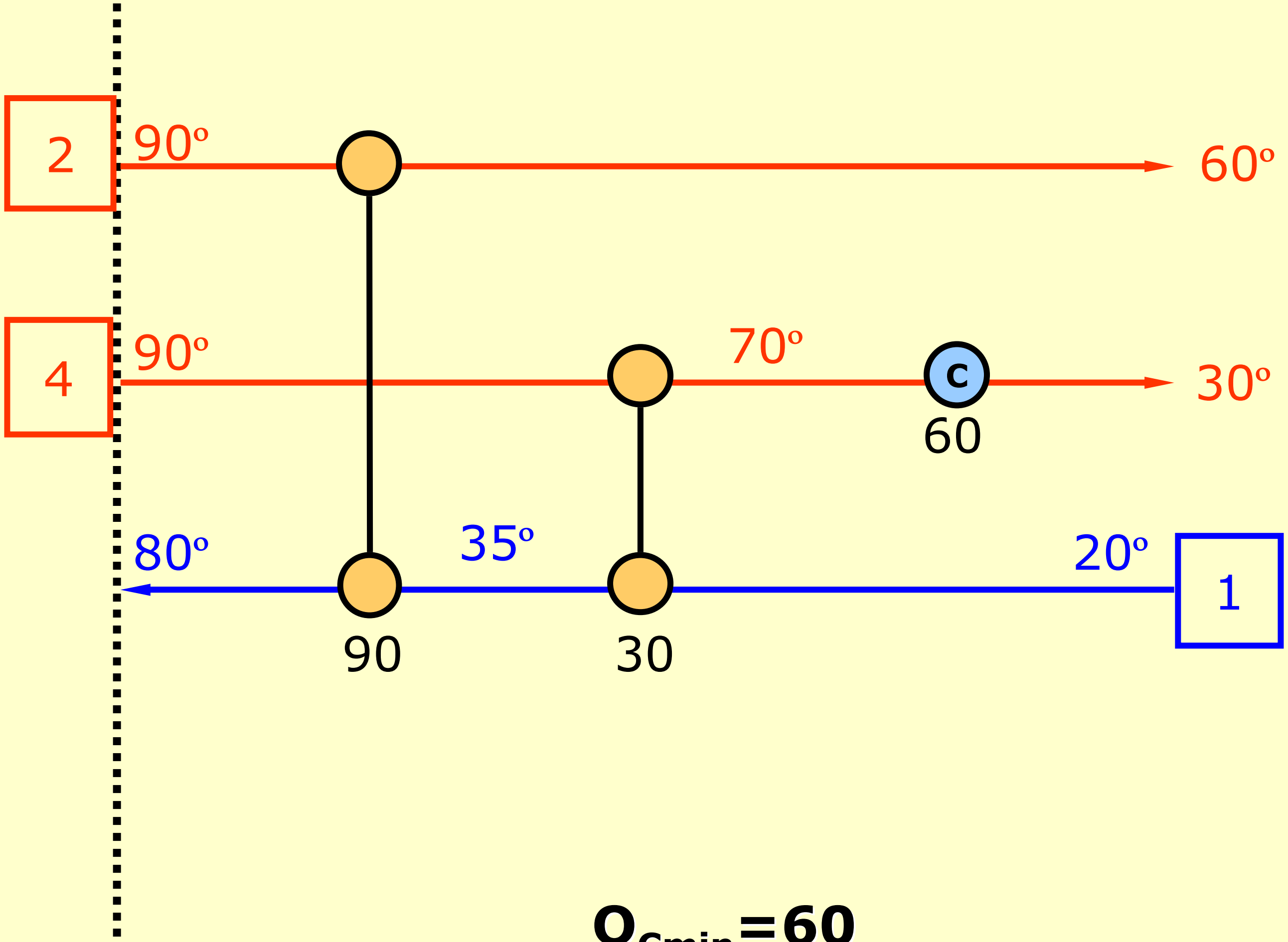


What next?

Fill in the rest(1)

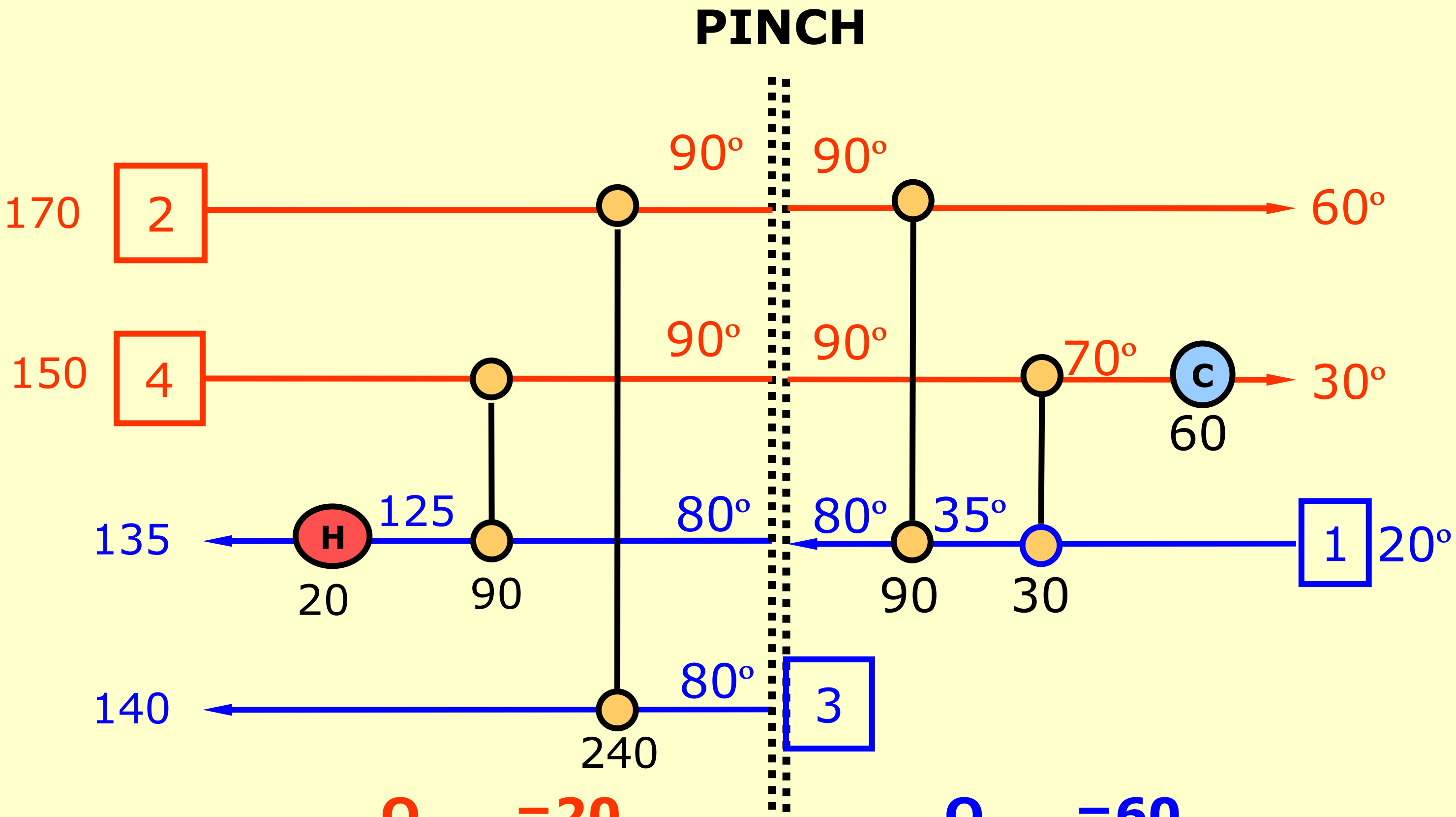


Fill in the rest



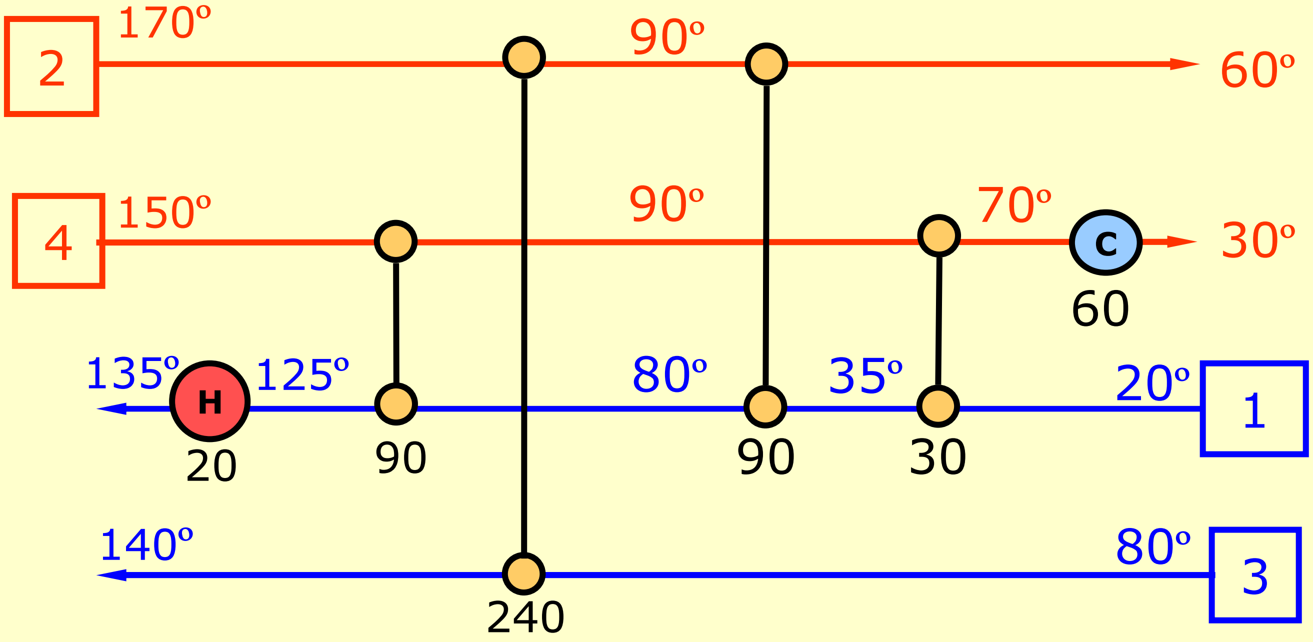
Q_{Cmin}=60

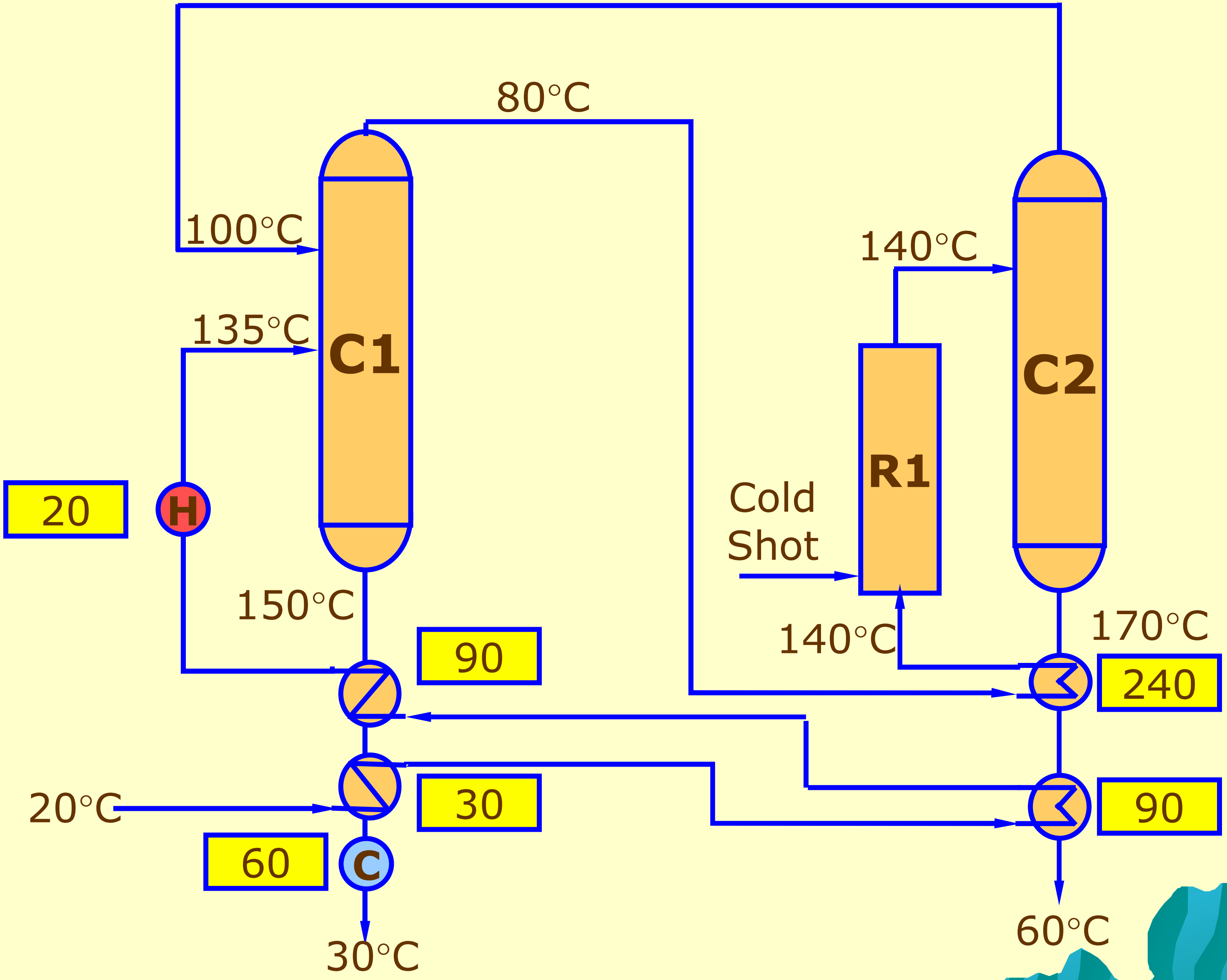
Above **Below**



$Q_{Hmin}=20$ $Q_{Cmin}=60$

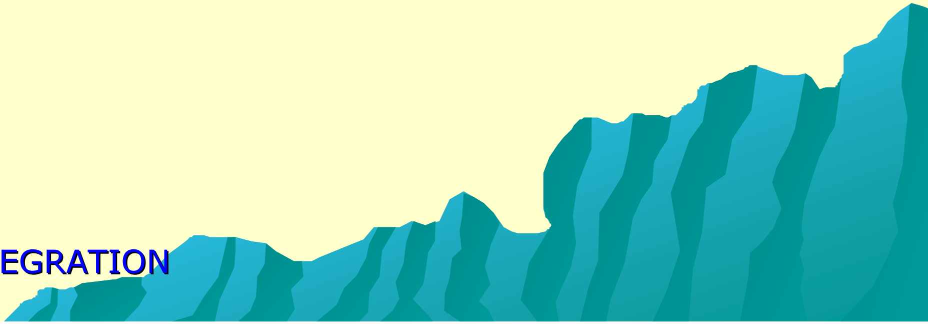
Completed design

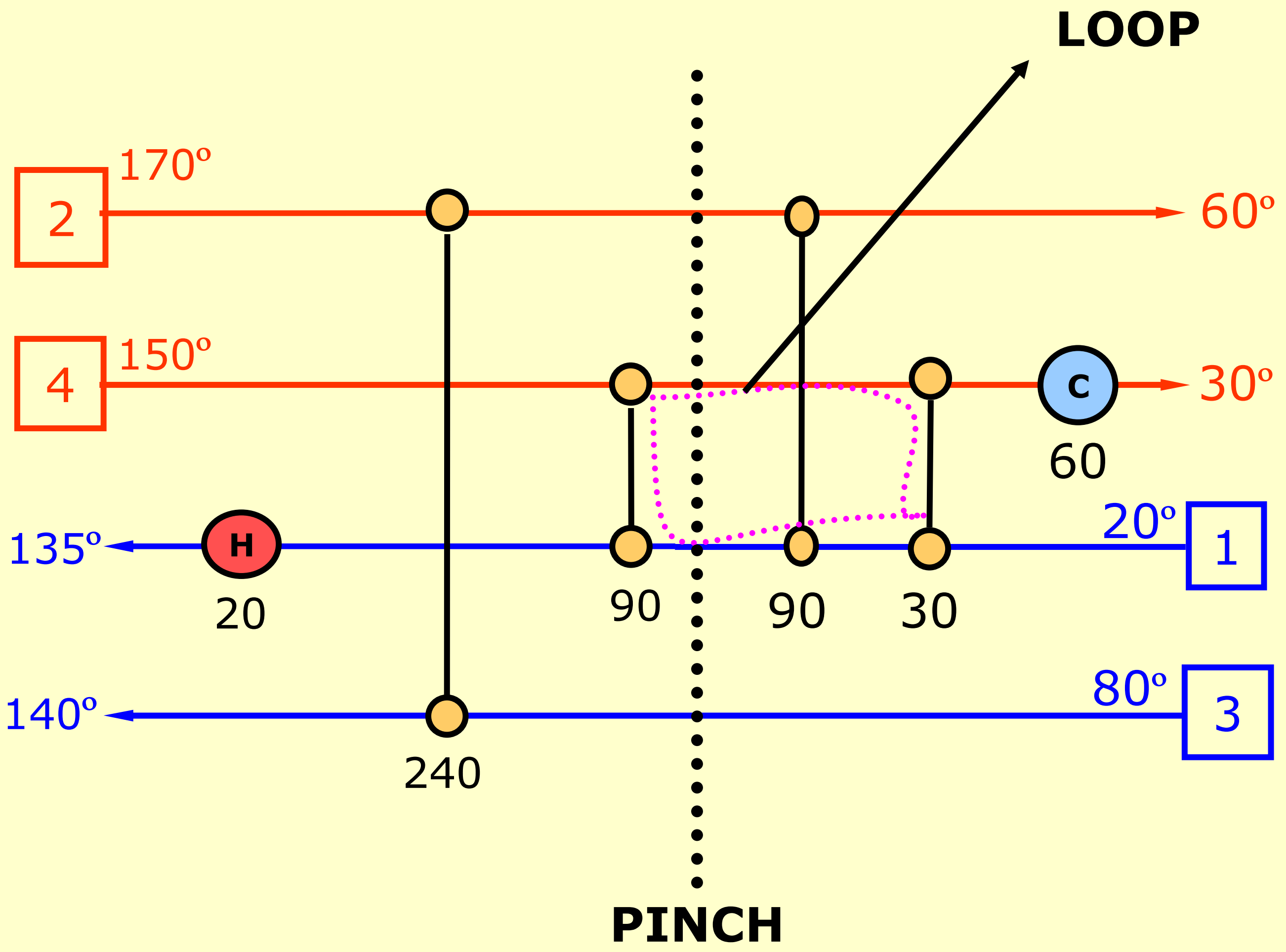



80°C
100°C
135°C
C1
C2
140°C
R1
Cold
Shot
20
H
150°C
90
140°C
170°C
240
20°C
30
90
60
C
30°C
60°C

Design for Maximum Energy Recovery

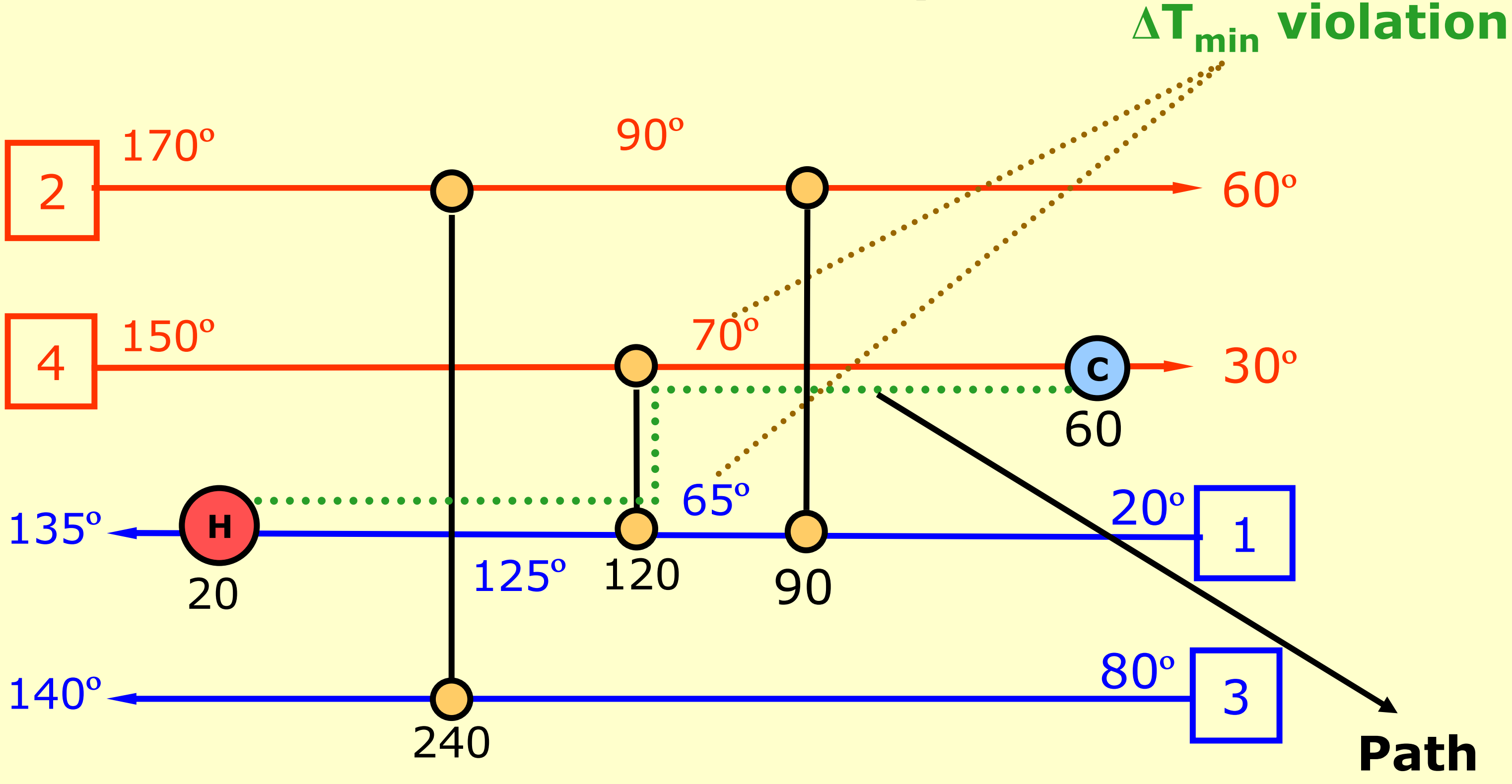
- Divide problem at the pinch
- Start at the pinch and move away
- Start with biggest streams “IN”
- Observe $CP_{out} \geq CP_{in}$ for all pinch matches
- Maximize loads on each match
- Fill in the rest



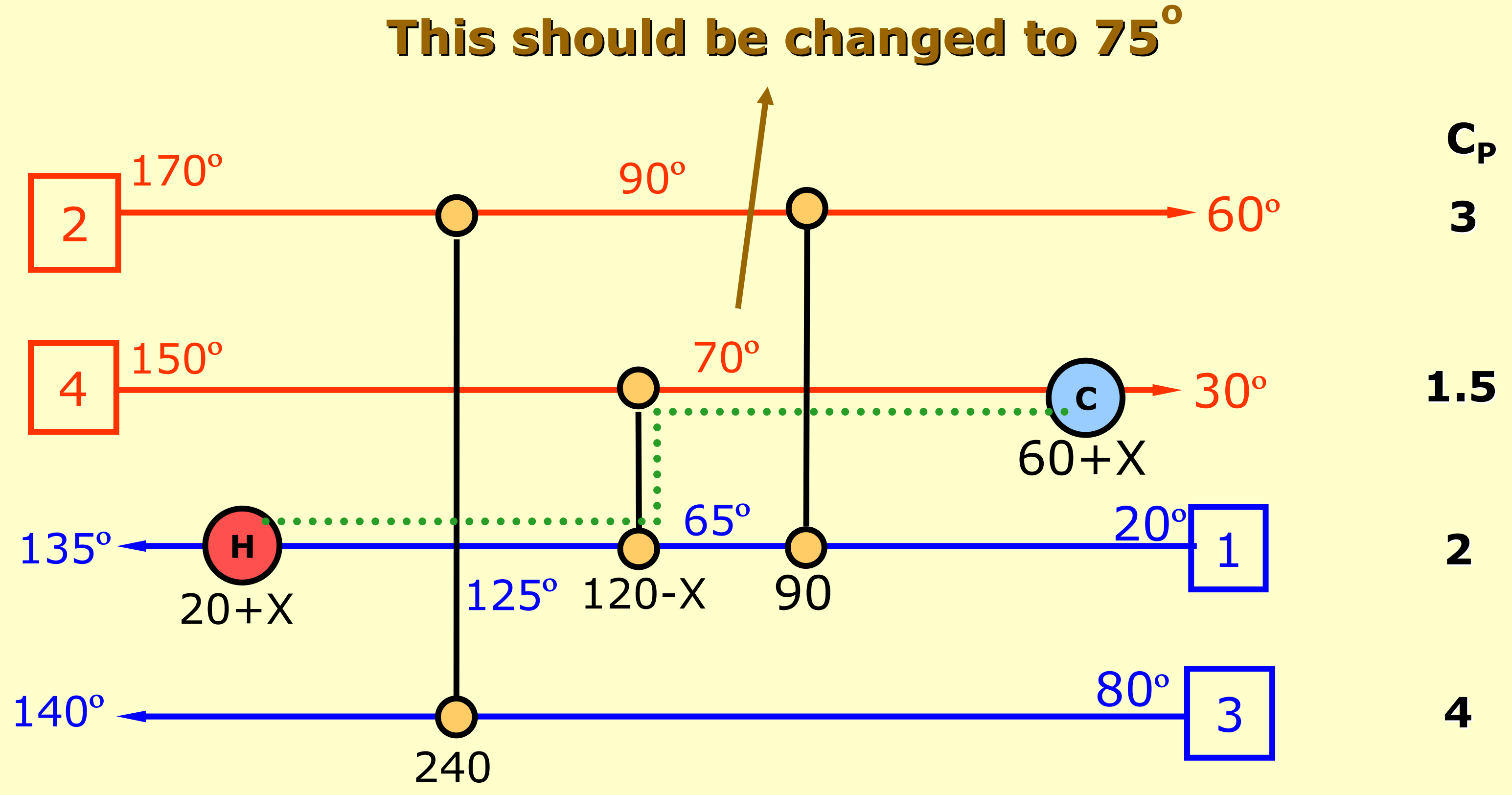


Each loop means you can reduce one exchanger.

In order to break the loop and reduce the number of exchangers remove the exchanger with the smallest heat load in loop.



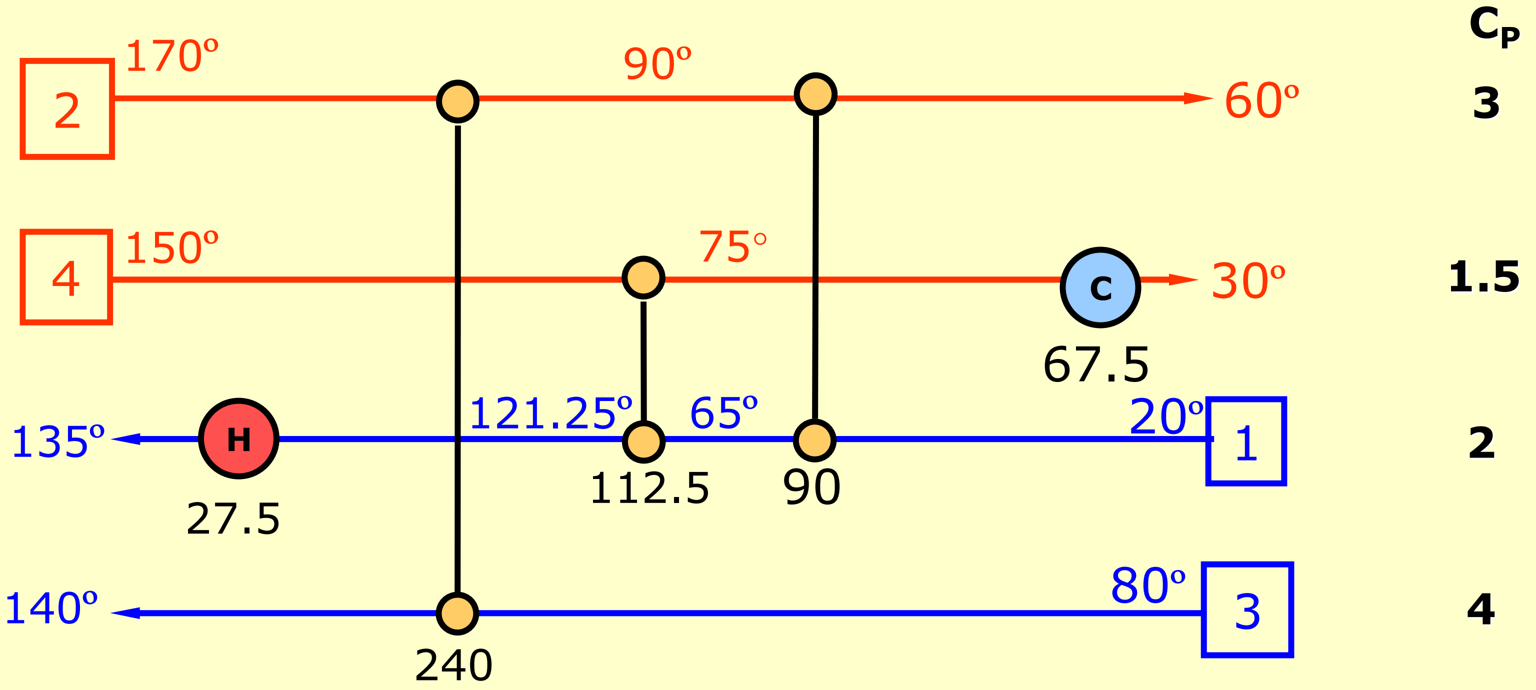
Path ia a connection between hot and cold utilities which passes from or near the exchanger with violation



$$150 - (120 - X)/1.5 = 75$$

$$X = 7.5$$

Final design with 5 exchanger



7.5 unit of hot and cold utilities are sacrificed in order to reduce one exchanger

WORKING SESSION 7

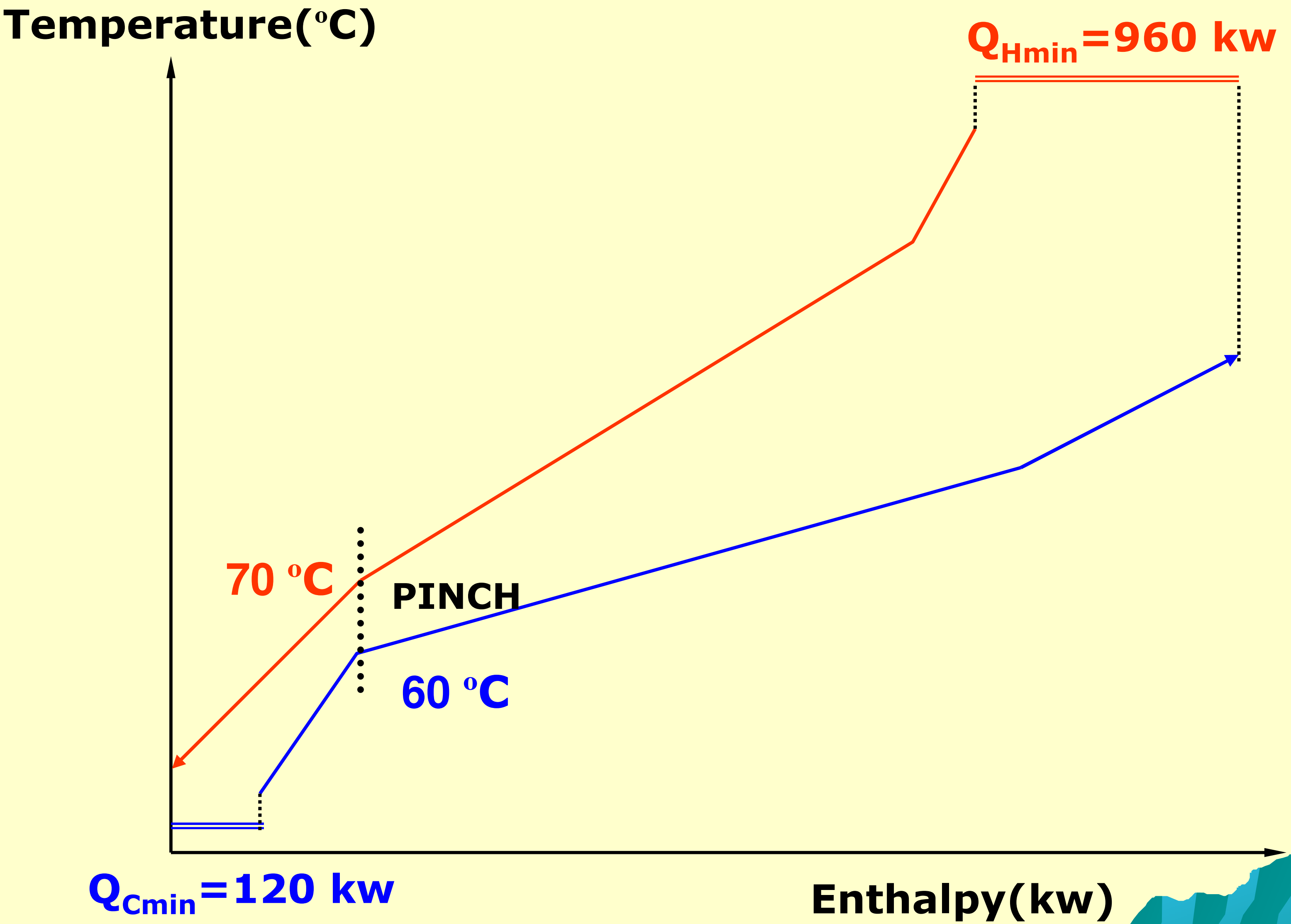
Exercise 1

Stream	Type	Supply Temp. T_s(°C)	Target Temp. T_T(°C)	Heat capacity flowrate CP(MW/°C)
1	Hot	180	80	20
2	Hot	130	40	40
3	Cold	60	100	80
4	Cold	30	120	36

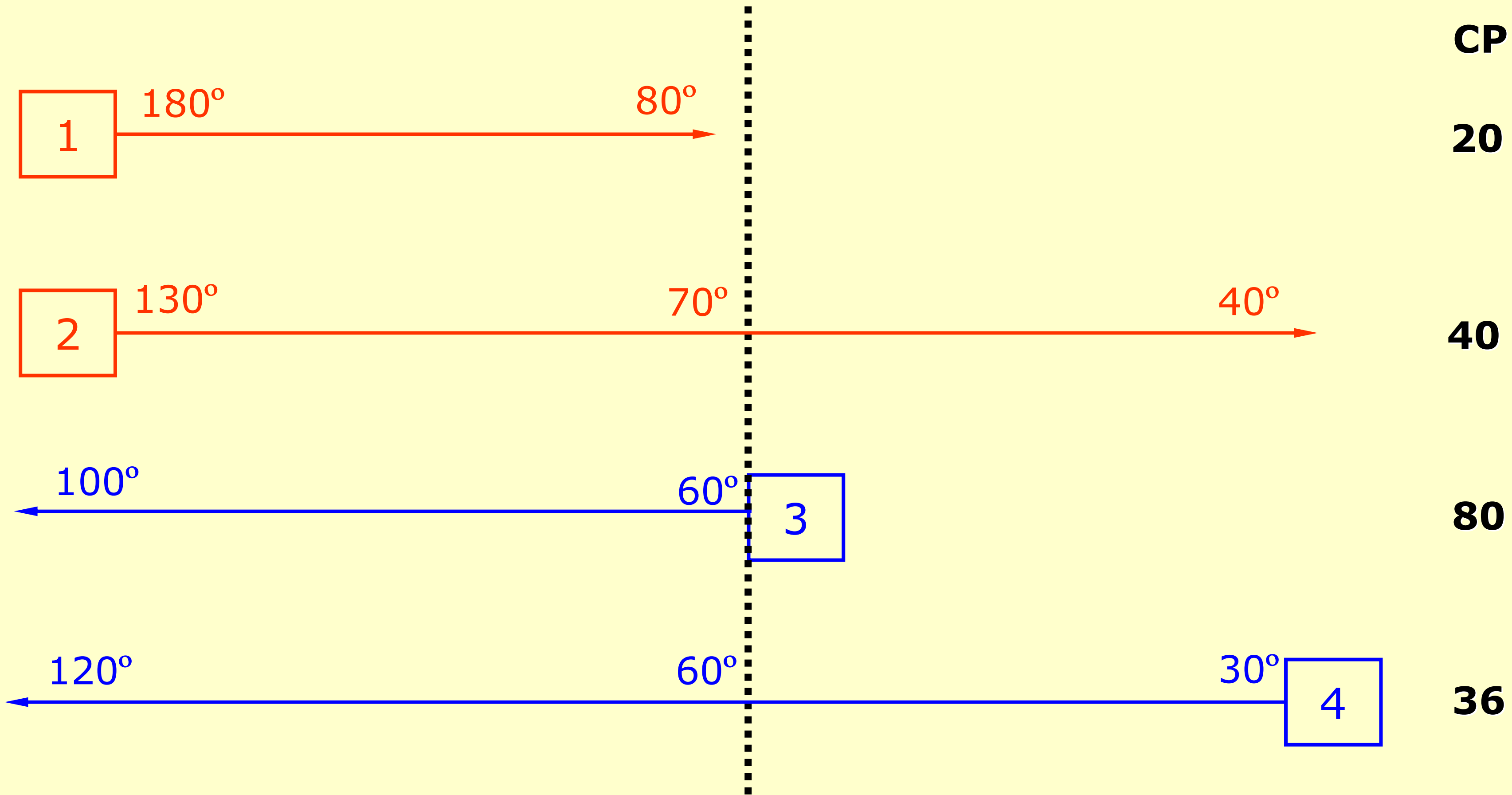
$\Delta T_{min}=10^oC$

Utilities:Steam at 200°C, C.W. at 25°C

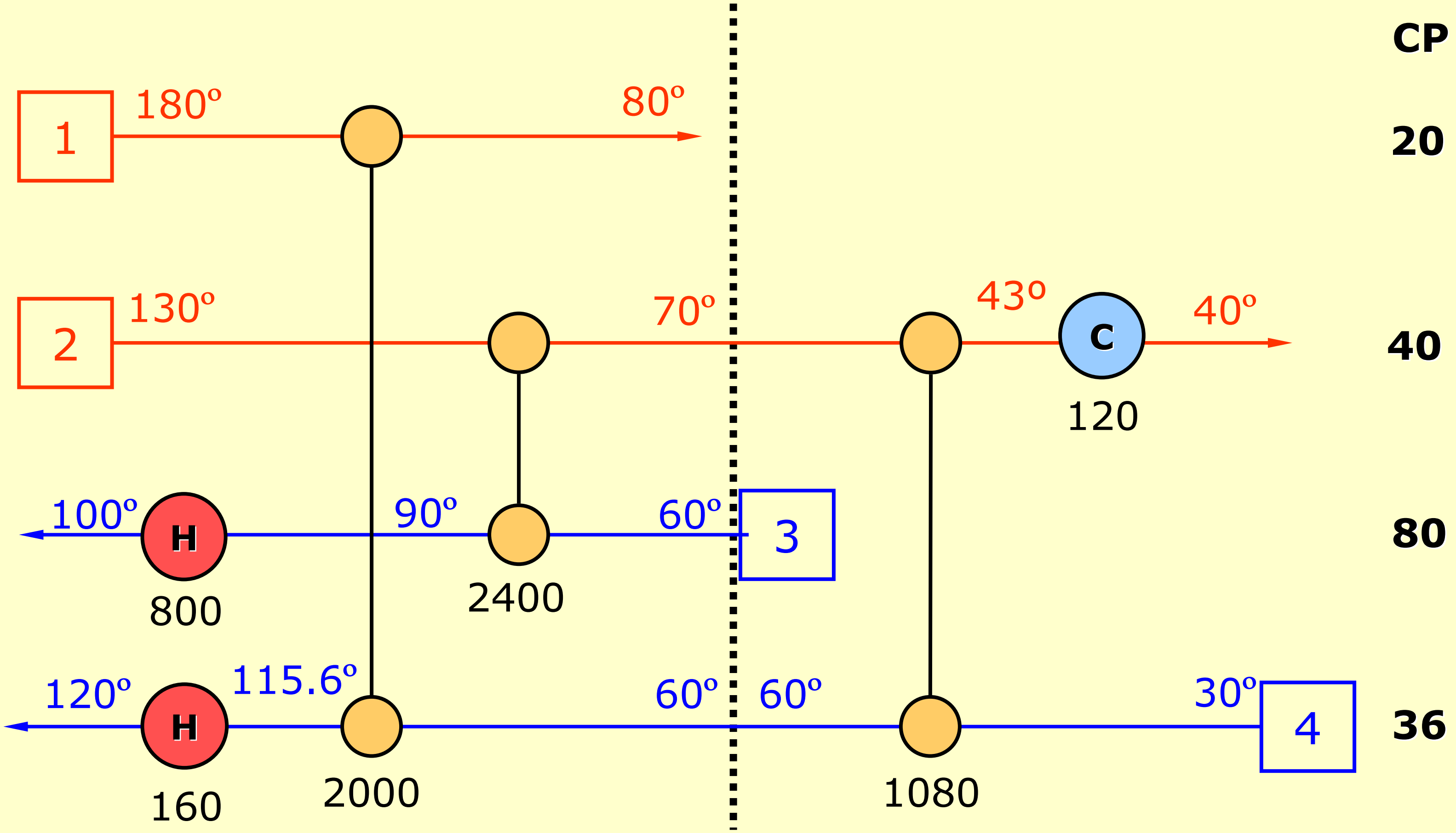
Design a network for Maximum Energy Recovery


Temperature(°C)
Q_{Hmin}=960 kw
70 °C
PINCH
60 °C
Q_{Cmin}=120 kw
Enthalpy(kw)

Solution 7



Q_{Hmin}=960 kw **Q_{Cmin}=120kw**



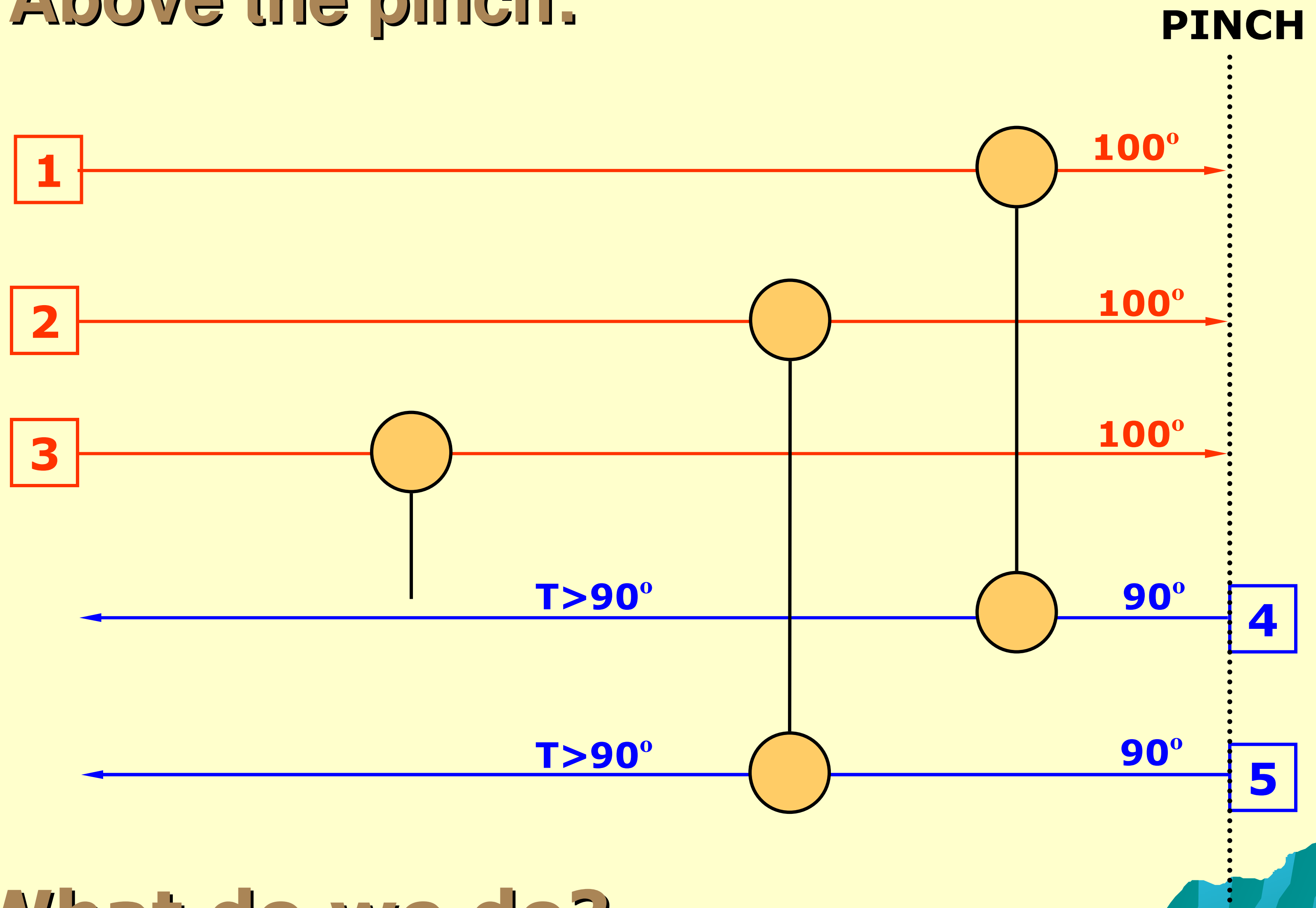
$Q_{Hmin}=960$ kw

$Q_{Cmin}=120$kw

LECTURE 8

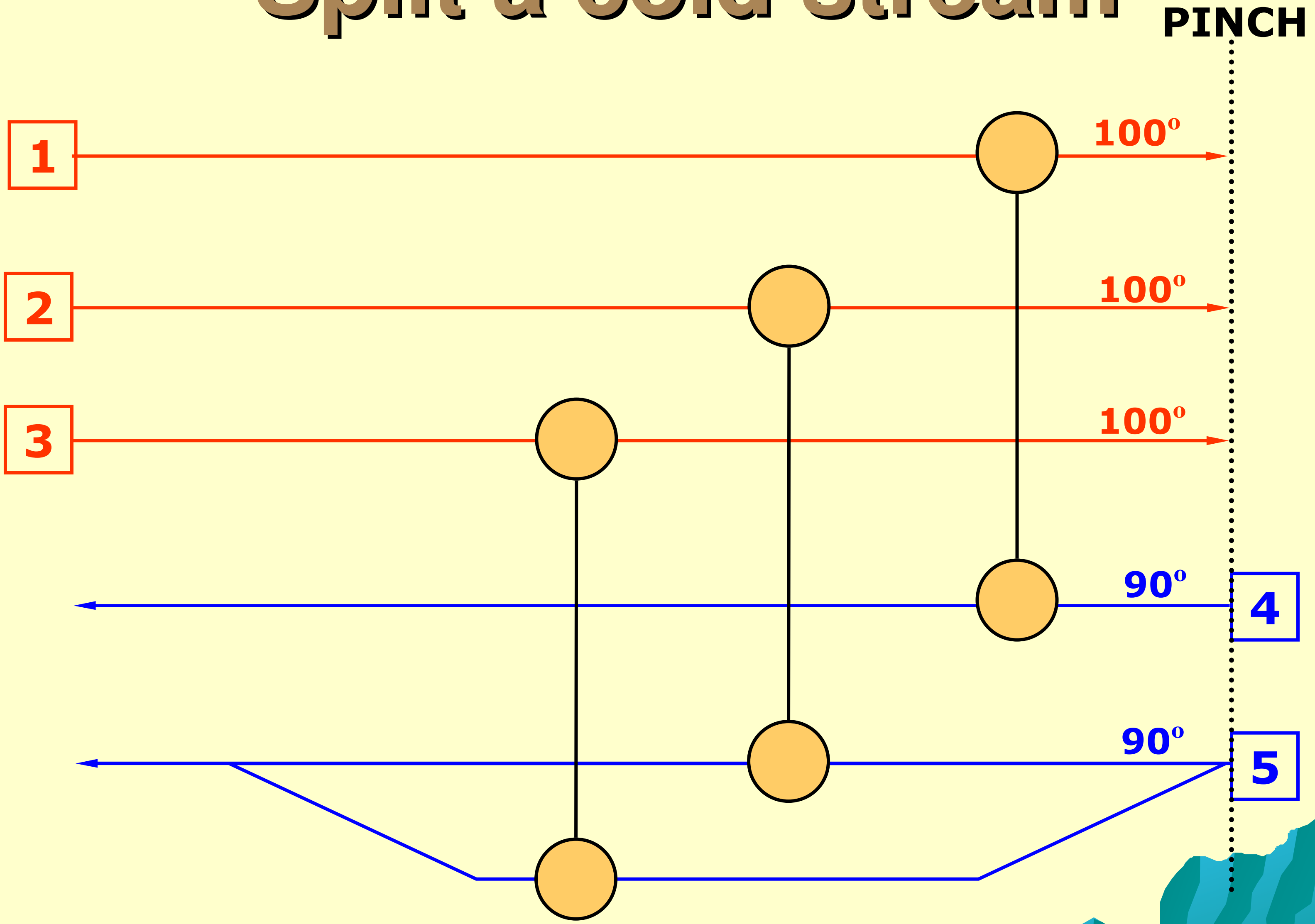
Stream Splitting

Above the pinch:



What do we do?

Split a cold stream

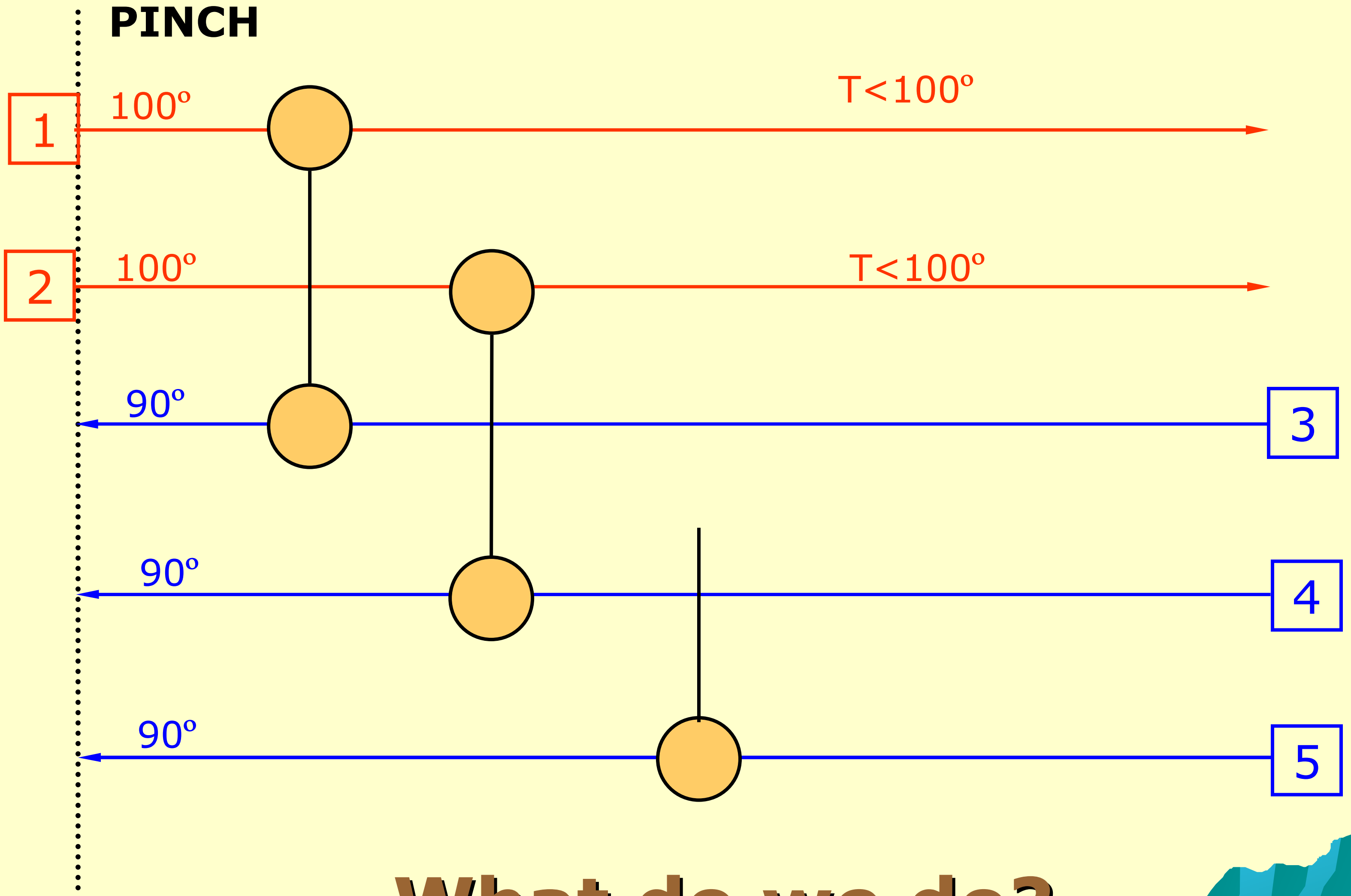


Rule:

Above the pinch, $N_H \le N_C$

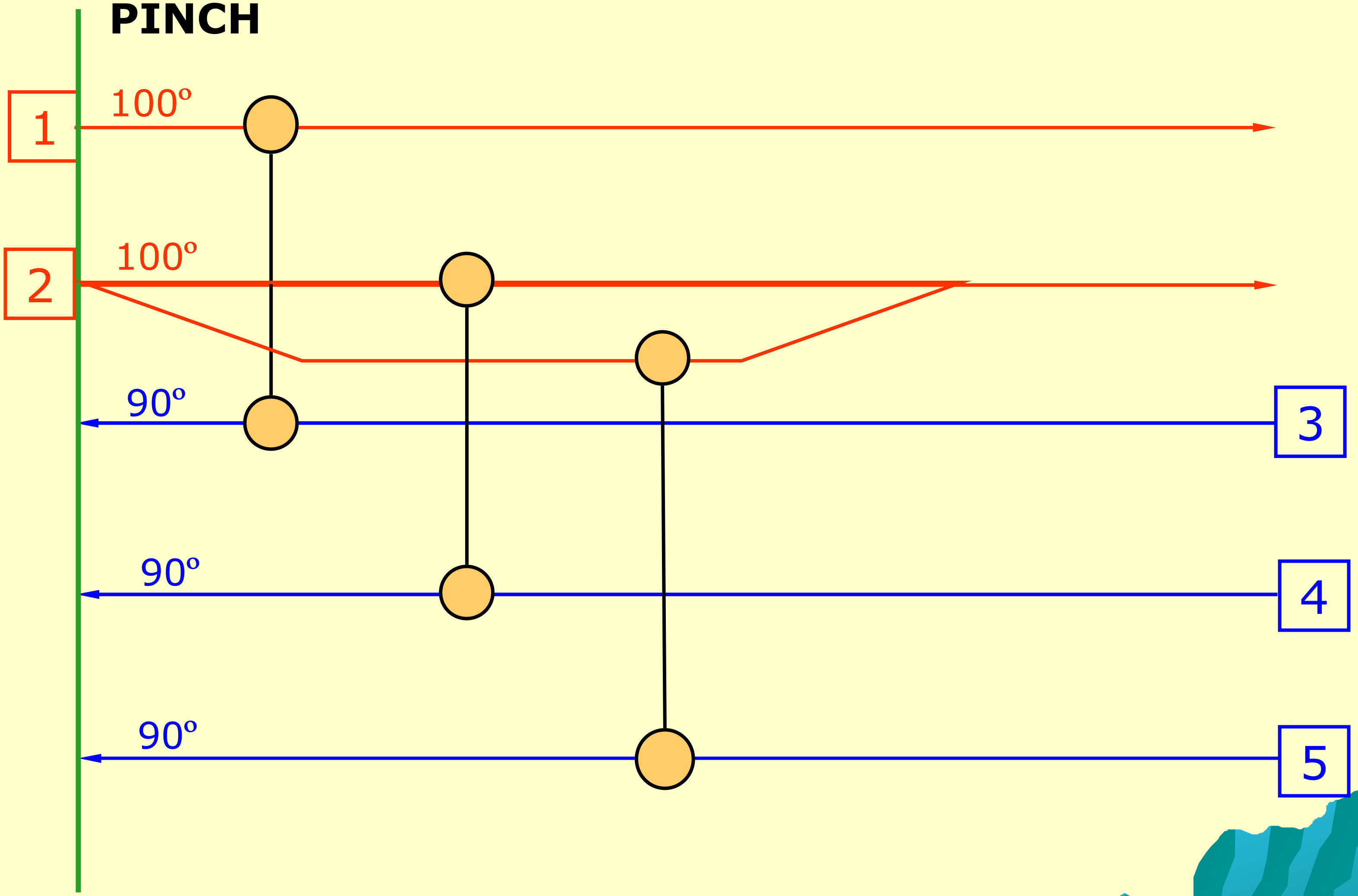
- **N_H=Number of hot streams**
- **N_C=Number of cold streams**

Below the pinch:



What do we do?

Split a hot stream:



Rule:

Below the pinch, $N_H \geq N_C$

- **N_H=Number of hot streams**
- **N_C=Number of cold streams**

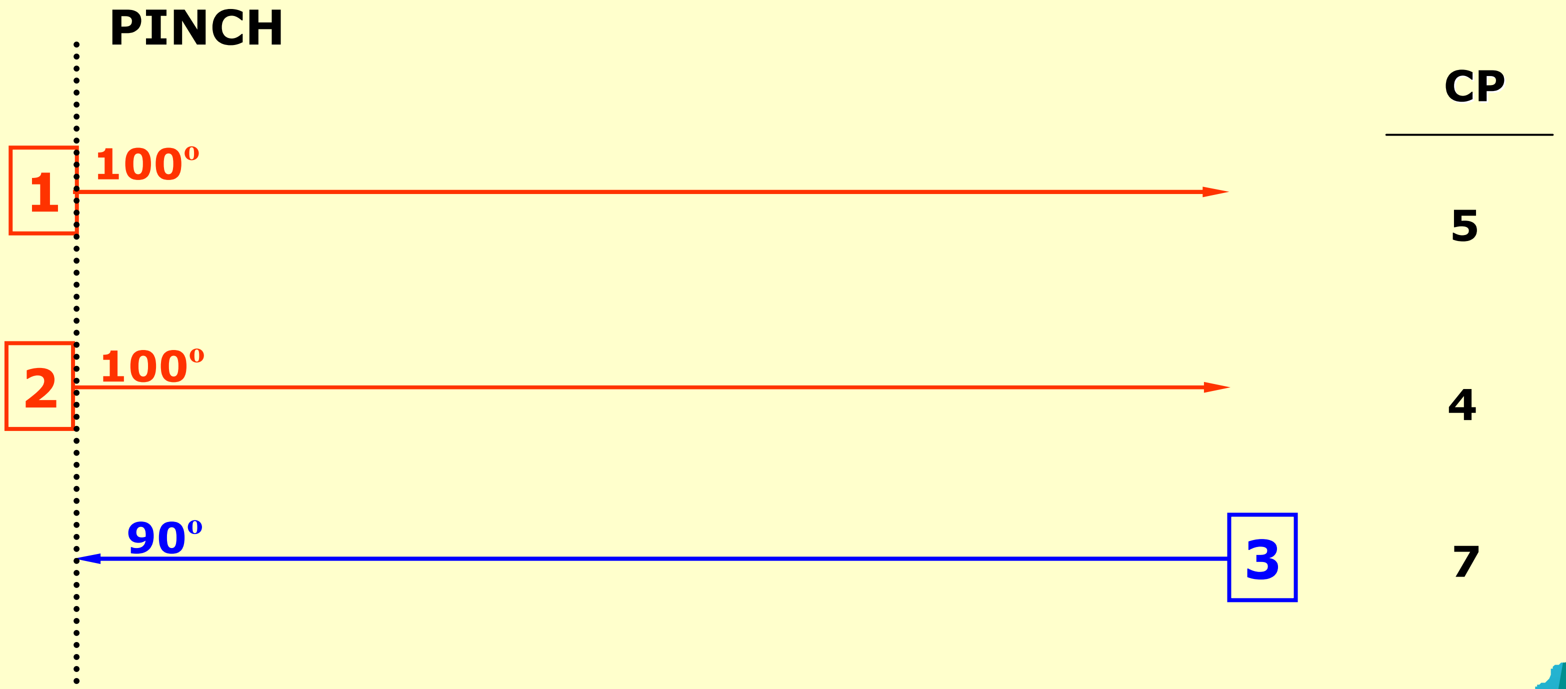
General Rule:

always observe $N_{out} \geq N_{in}$

Example problem:

$$N_H \geq N_C$$

But no appropriate CP match



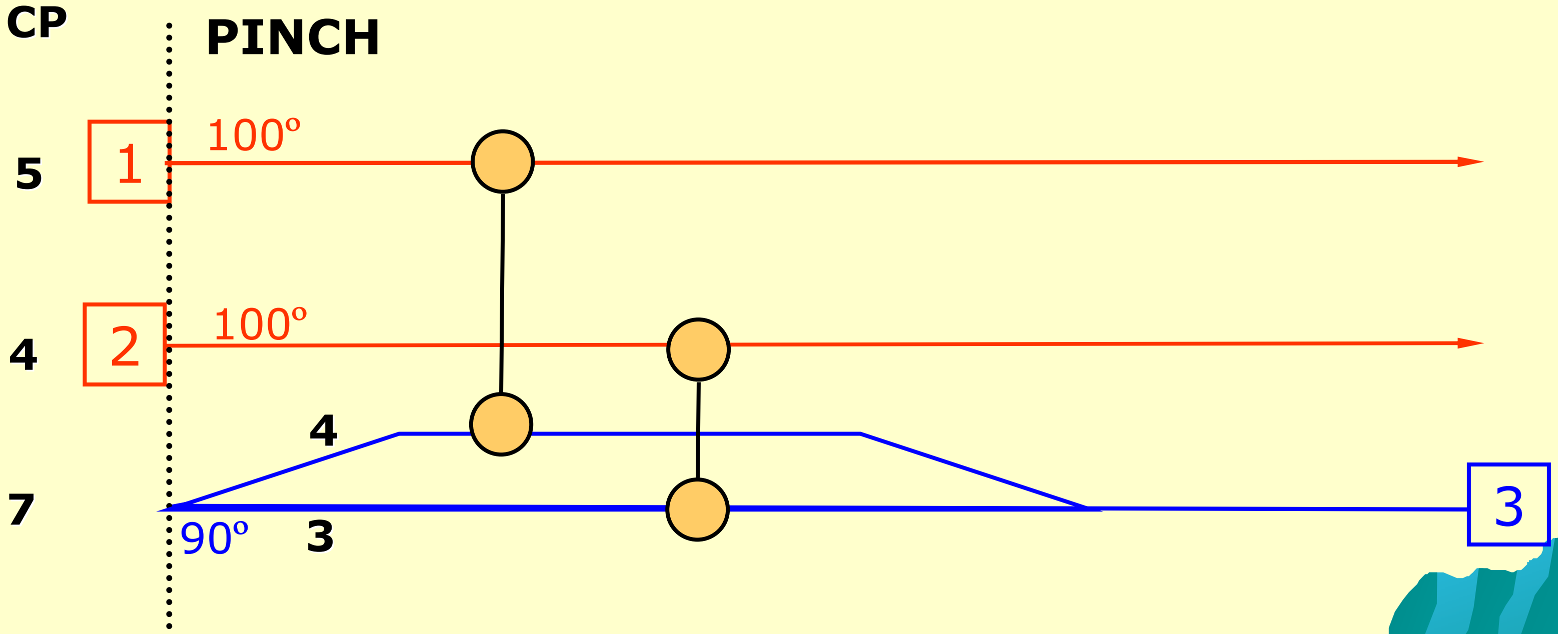
No feasible match!

Solution:

$CP_H \geq CP_C$

$N_H \geq N_C$

$$\left.\begin{matrix}5 & 4\\ 4 & 3\end{matrix}\right\} 7$$



What about?

$$CP_H \geq CP_C$$

$$N_H \geq N_C$$

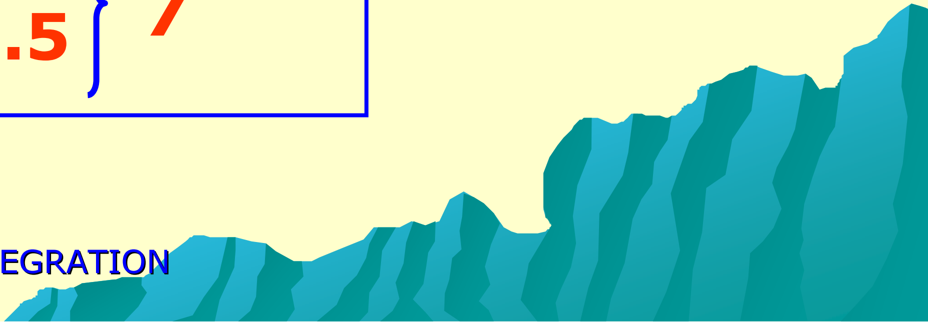
$$\left.\begin{array}{cc} 5 & 3.5 \\ 4 & 3.5 \end{array}\right\} 7$$

Or:

$$CP_H \geq CP_C$$

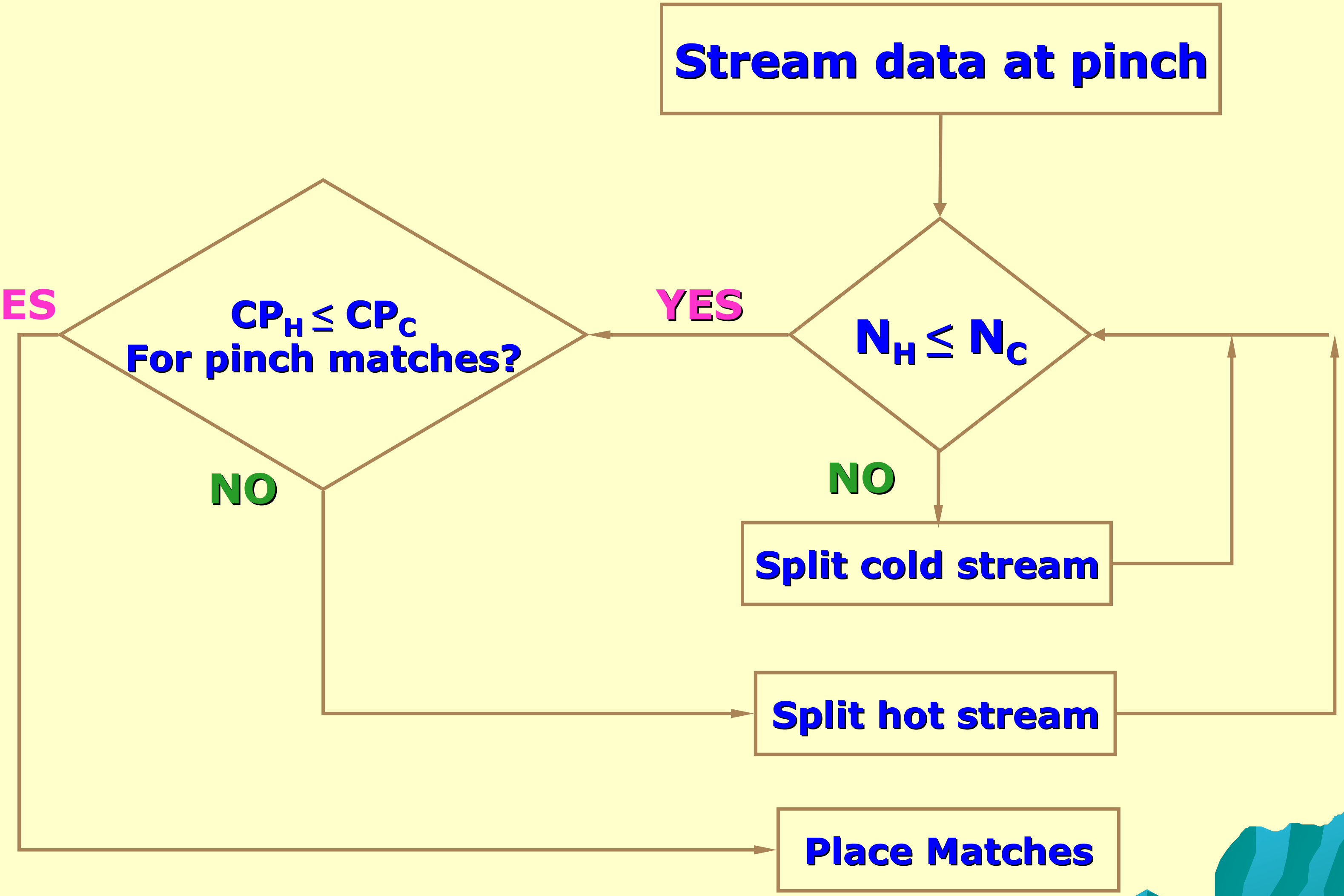
$$N_H \geq N_C$$

$$\left.\begin{array}{cc} 5 & 4.5 \\ 4 & 2.5 \end{array}\right\} 7$$



- Branch flow rates =degree of freedom in design
- Finding the best choice= optimization problem

Summary Above the pinch:



Stream data at pinch

$N_H \leq N_C$

YES

$CP_H \leq CP_C$
For pinch matches?

YES

NO

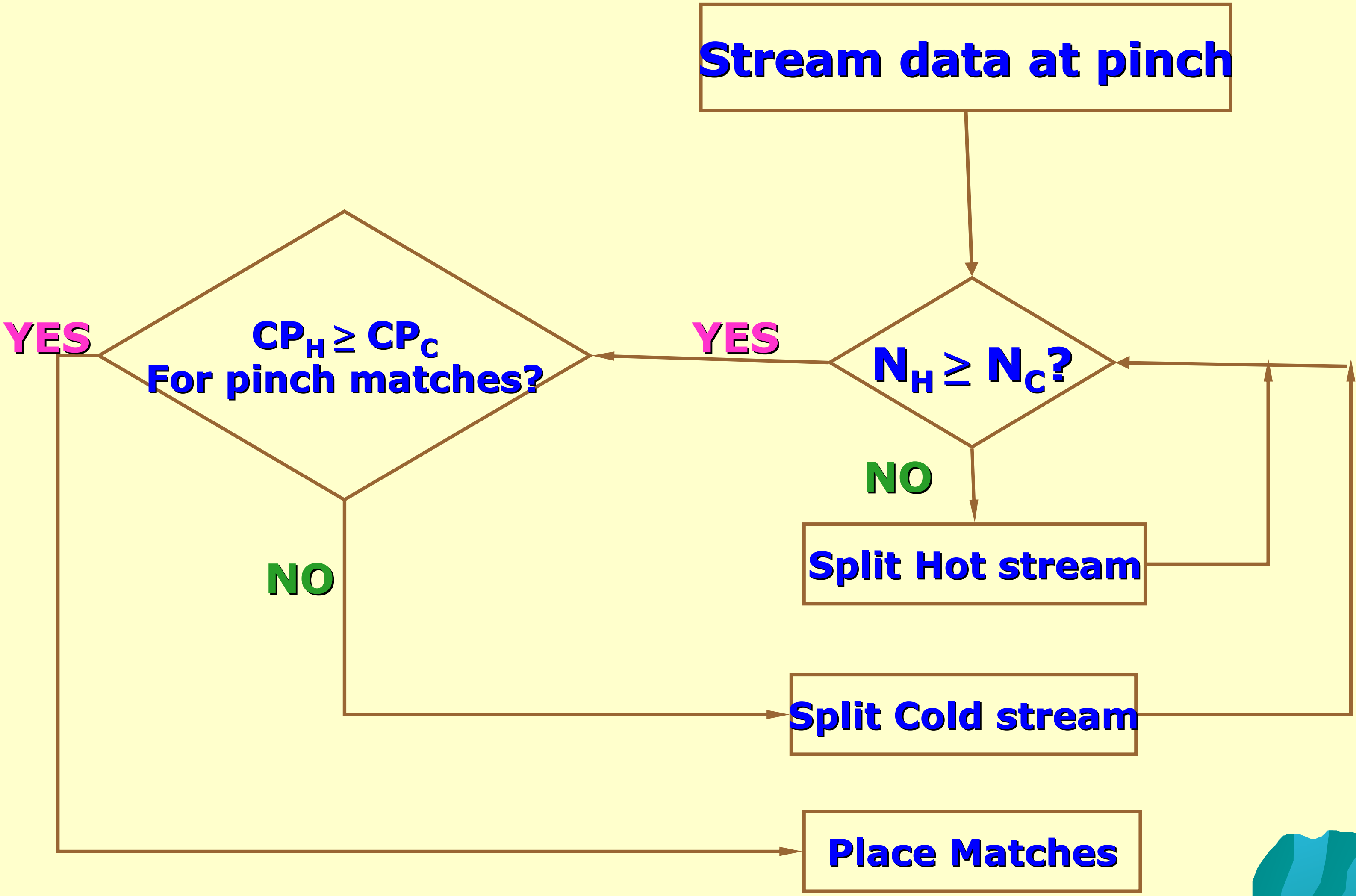
NO

Split cold stream

Split hot stream

Place Matches

Summary Below the pinch:



Stream data at pinch

$N_H \geq N_C$?

YES

$CP_H \geq CP_C$
For pinch matches?

YES

NO

Split Hot stream

NO

Split Cold stream

Place Matches

Working session 8

Working session 8

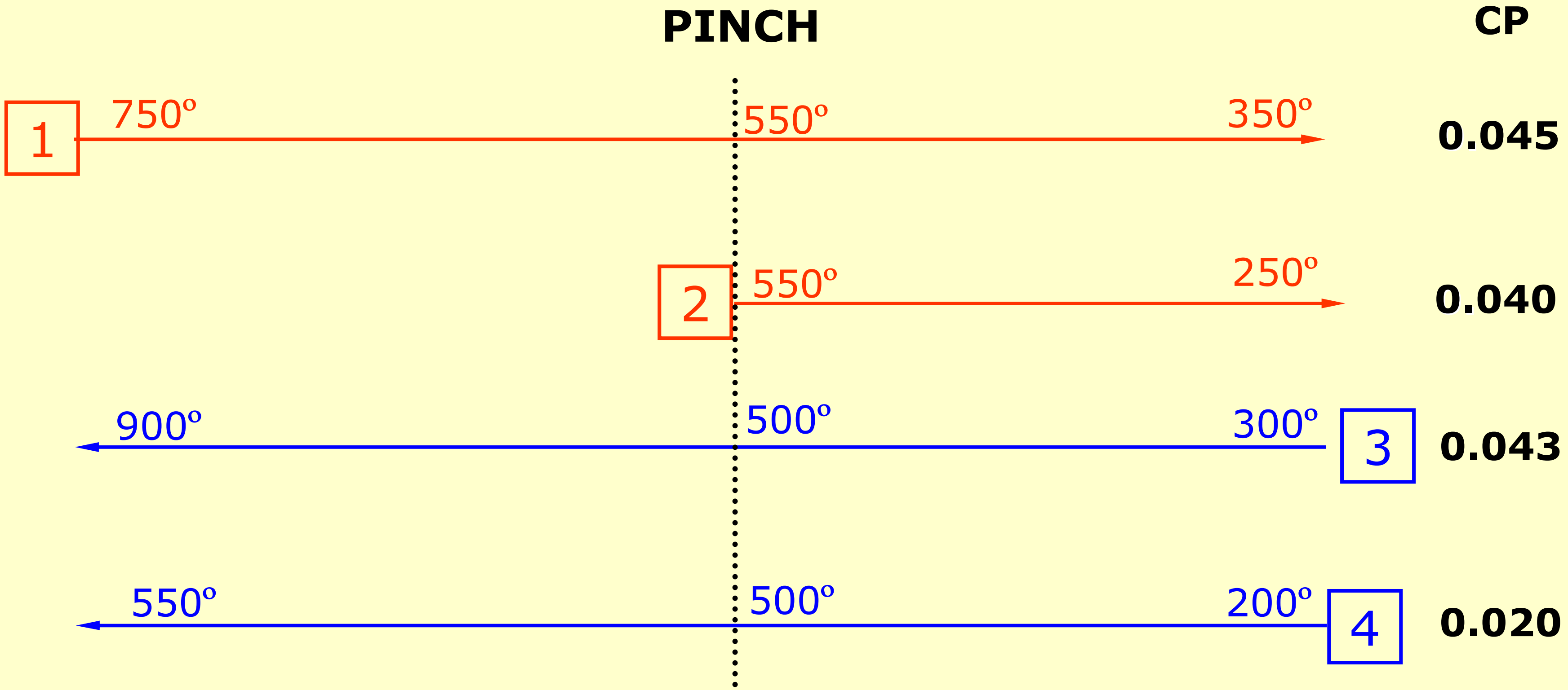
Stream	Type	Supply Temp. T_s(°C)	Target Temp. T_T(°C)	Heat capacity flowrate CP(MW^oC^{-1})
1	HOT	750	350	0.045
2	HOT	550	250	0.04
3	COLD	300	900	0.043
4	COLD	200	550	0.02

ΔT_{min}=50 °C

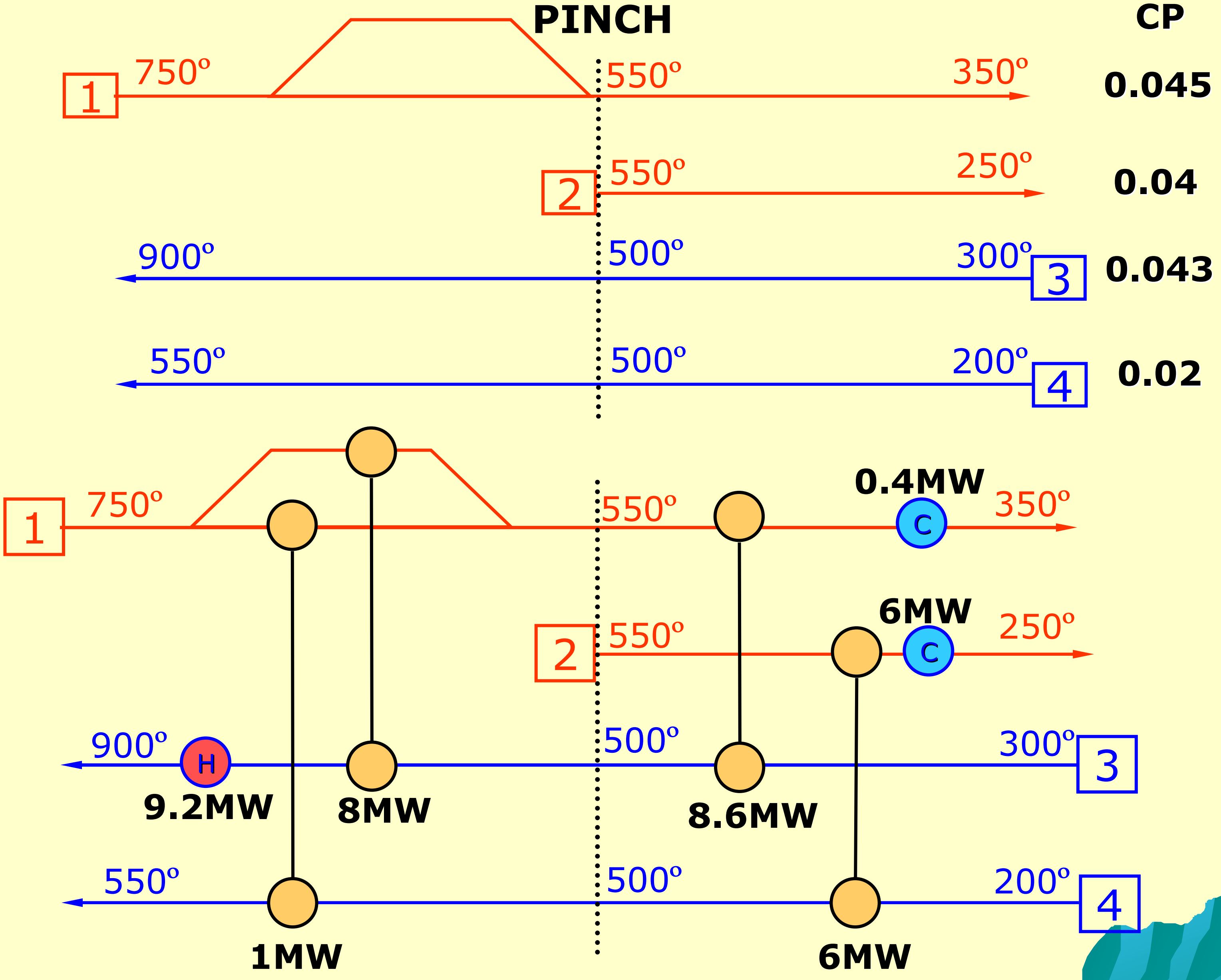
Q_{Hmin}=9.2 Mw

Q_{Cmin}=6.4 Mw

Grid diagram:

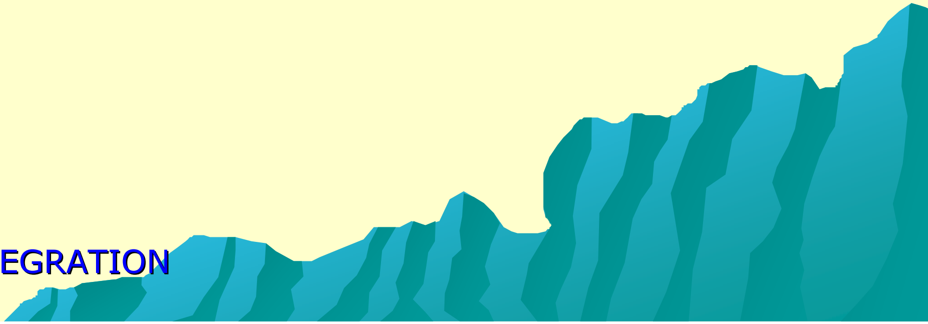


Solution 8

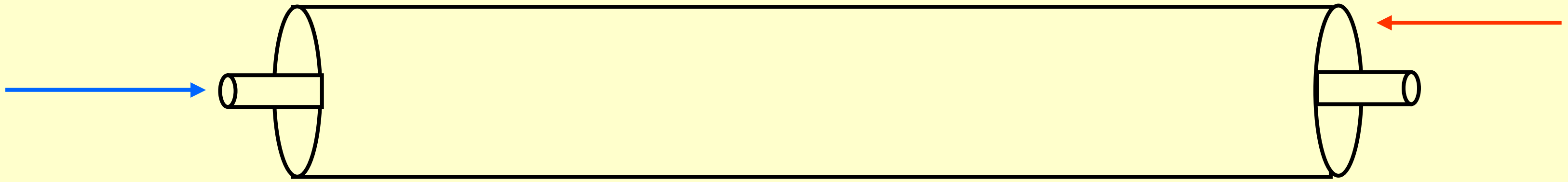

PINCH
CP
1
750°
550°
350°
0.045
2
550°
250°
0.04
900°
500°
300°
3
0.043
550°
500°
200°
4
0.02
1
750°
550°
0.4MW
C
350°
2
550°
6MW
C
250°
900°
H
500°
300°
3
9.2MW
8MW
8.6MW
550°
500°
200°
4
1MW
6MW

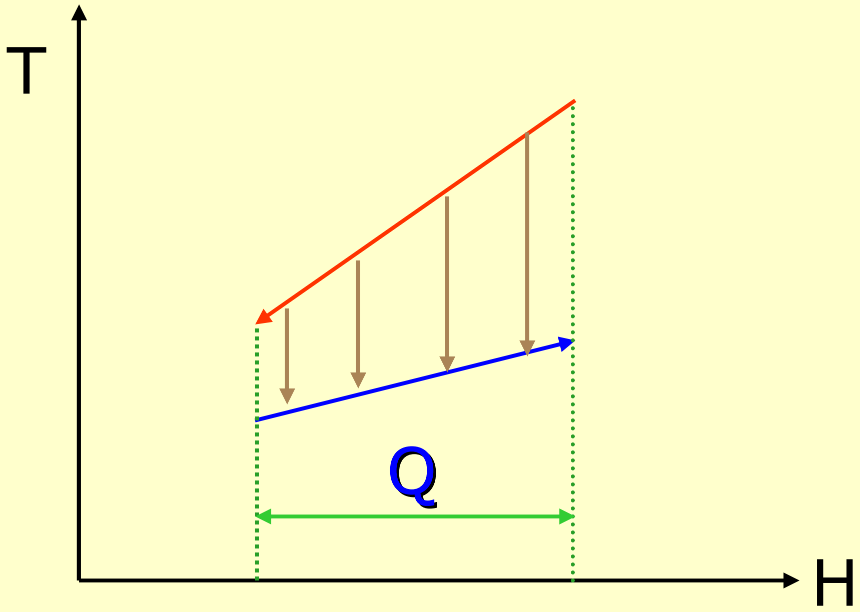
LECTURE 9

Area Targeting



Ideal Exchanger: Counter-Current





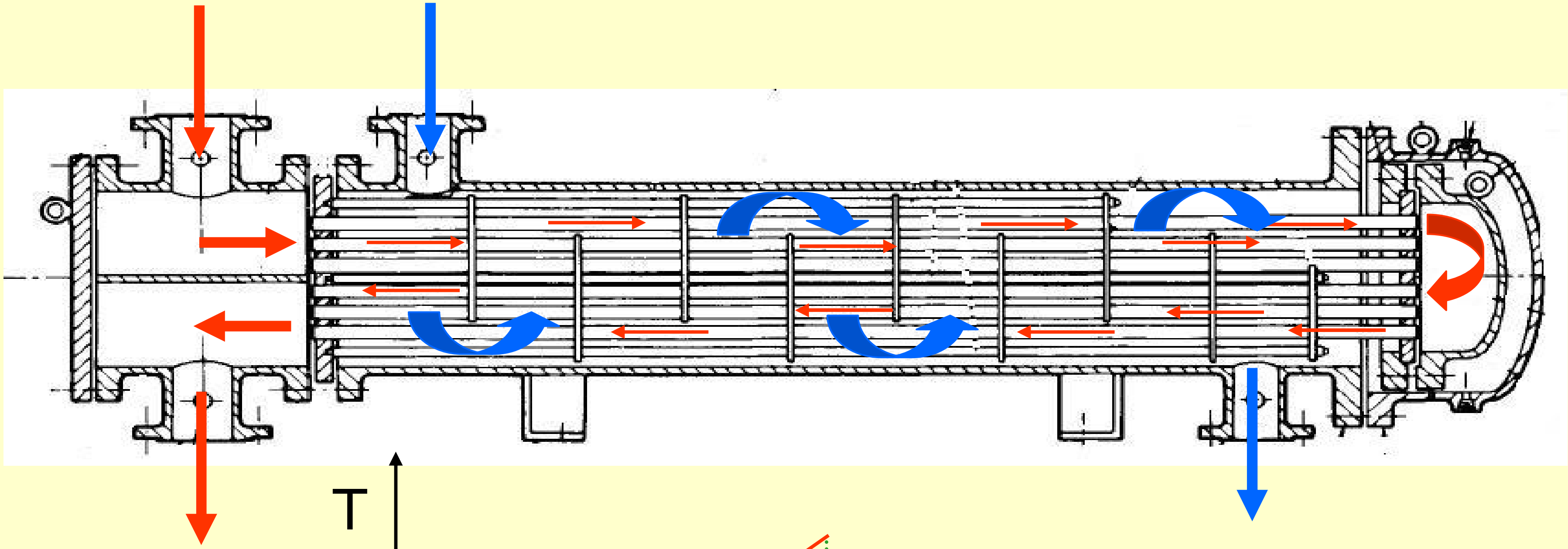
Heat load

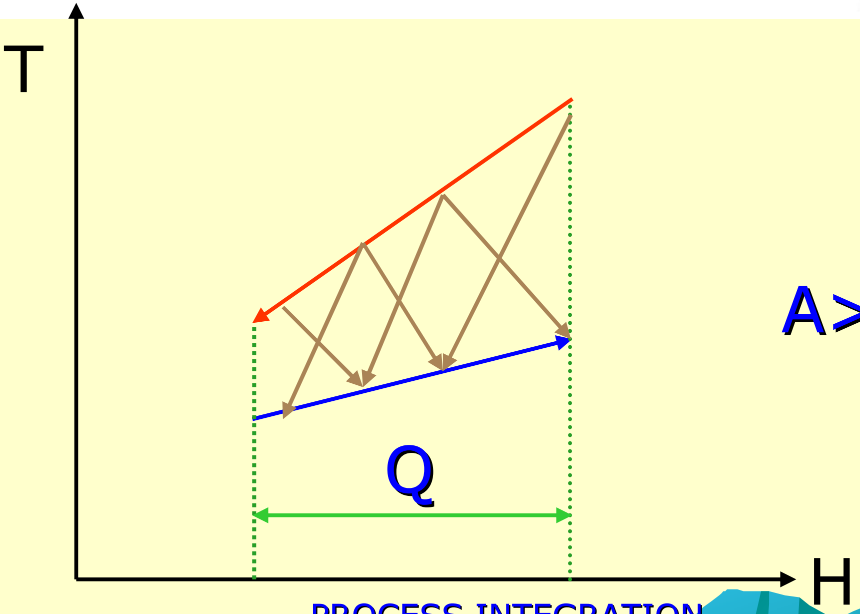
$$A = \frac{1}{U} \times \frac{Q}{\Delta T_{LM}}$$

Resistance

Driving Force

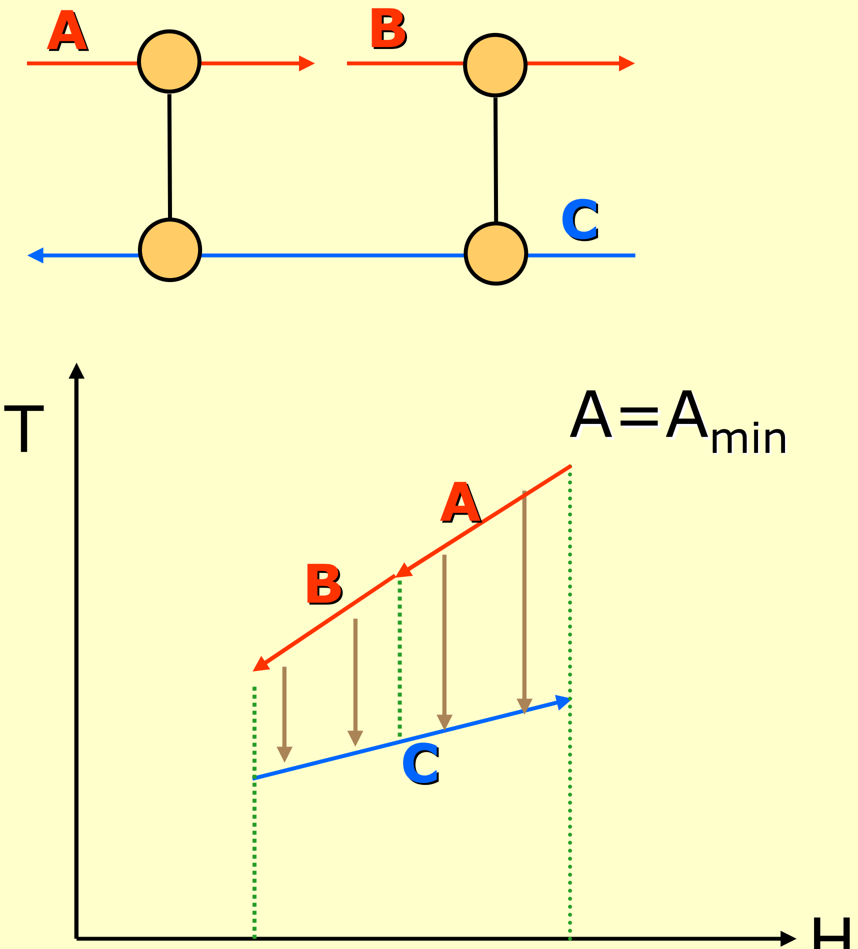
Real Exchanger:Not Counter-Current



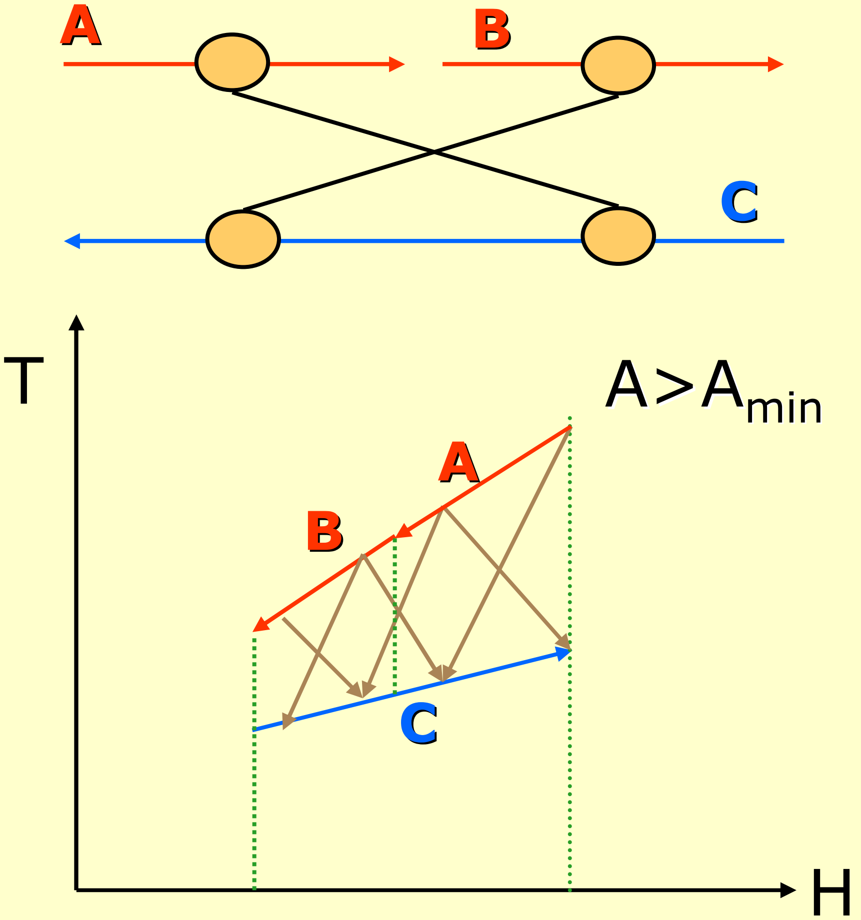


$A > A_{min}$

Likewise

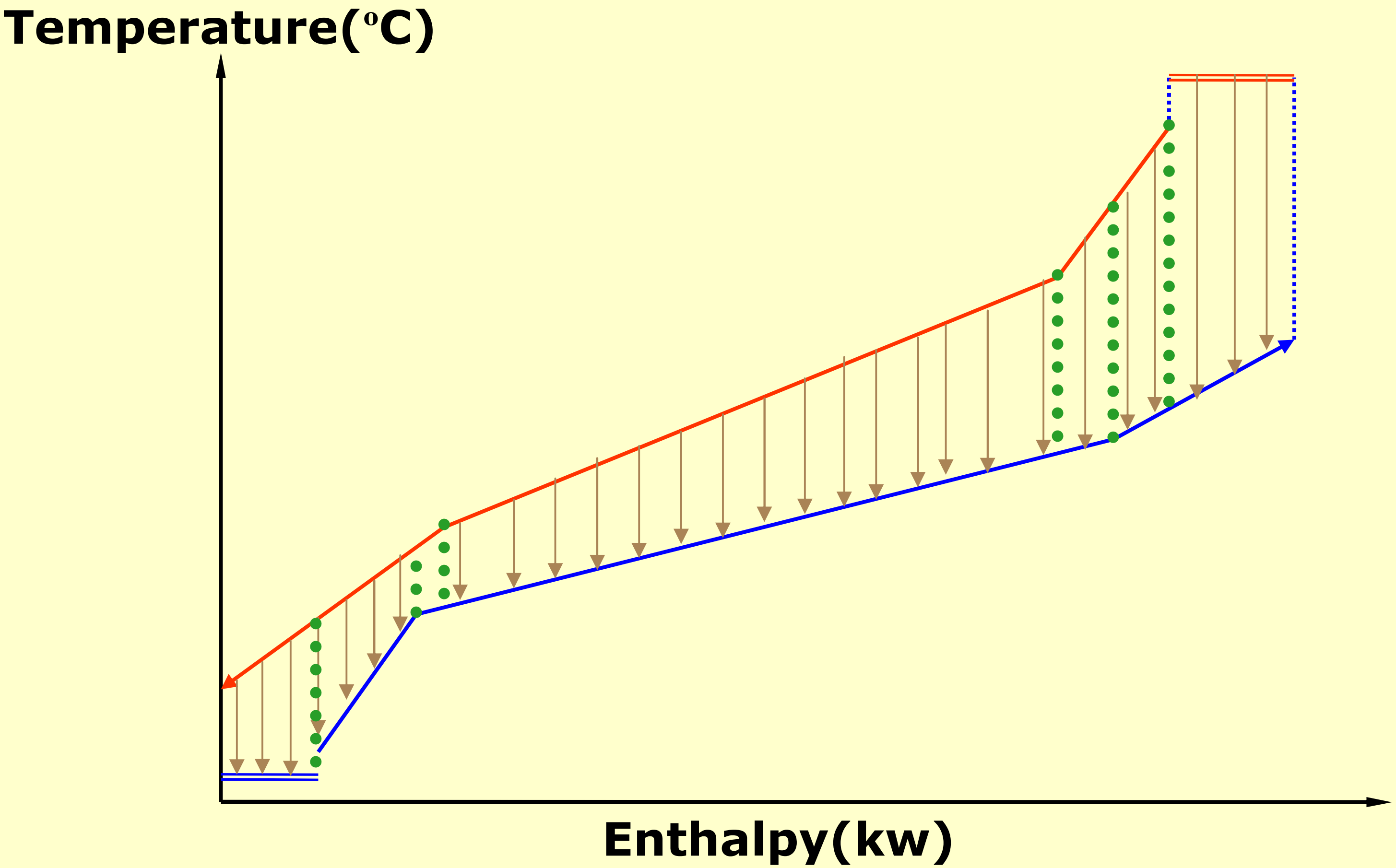


Counter-Current(Vertical)



Non-Counter Current (Criss-Cross)

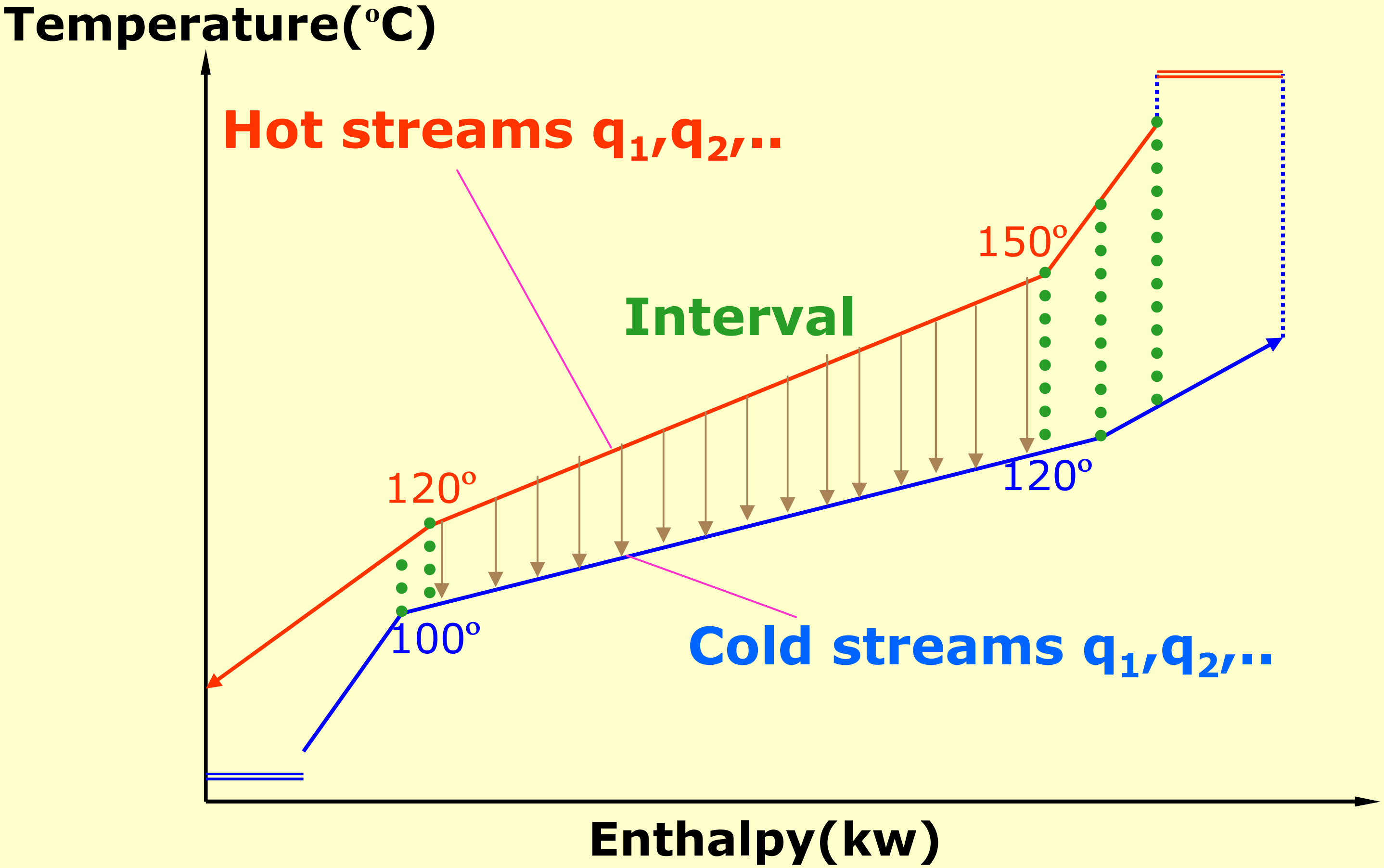
For uniform h-values



The vertical model guarantees

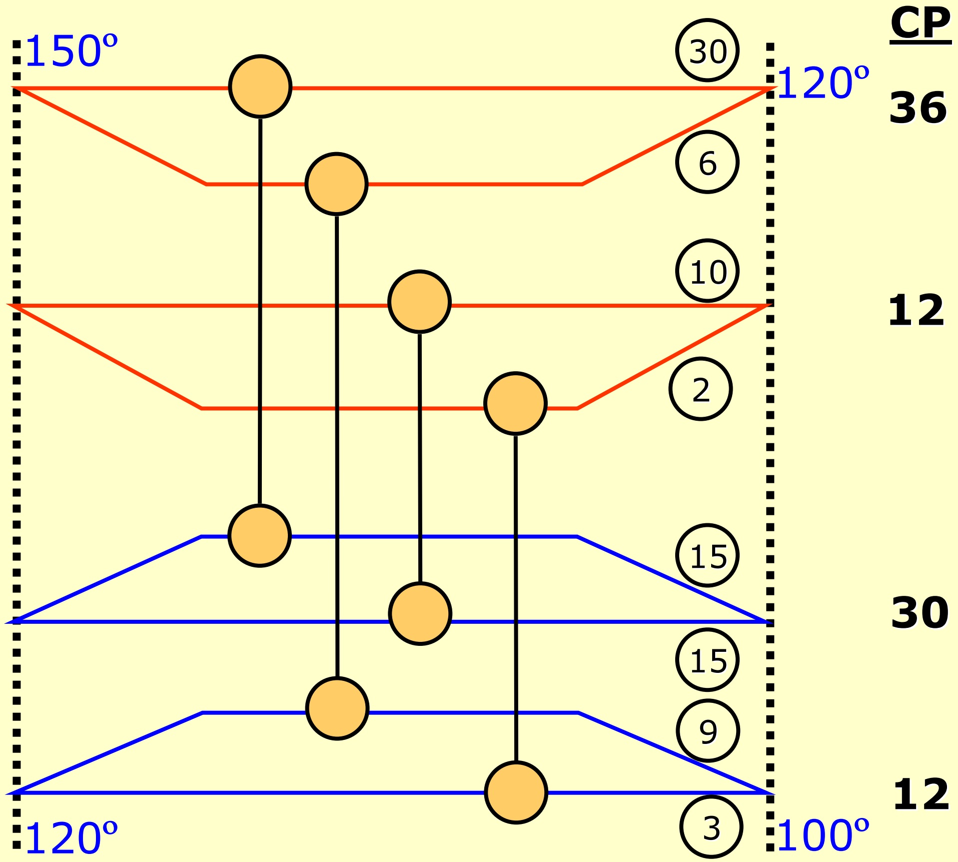
$A=A_{min}$

Counter current heat transfer in interval

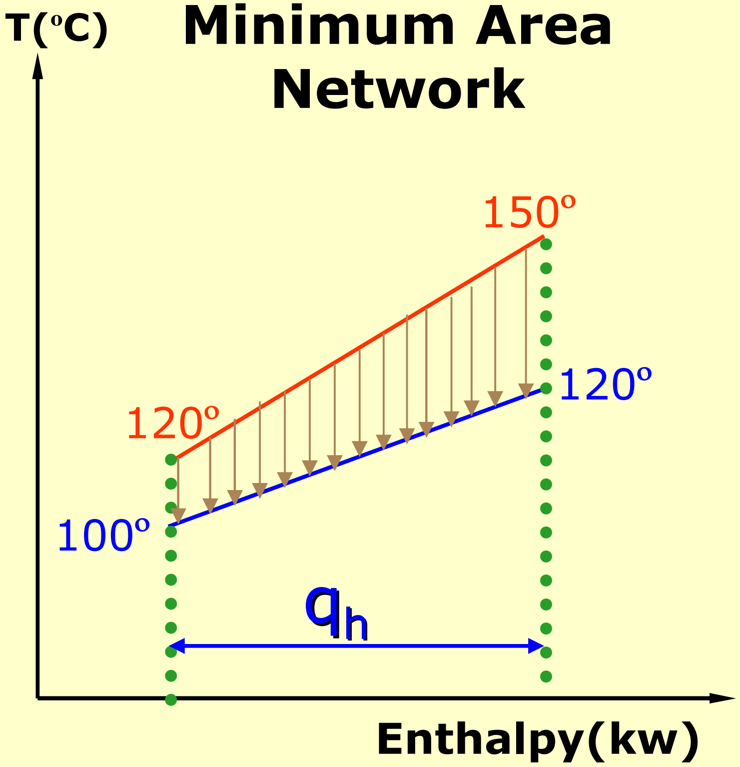


Hot stream in each interval only matches with **Cold** Stream in the same interval

Spaghetti Design

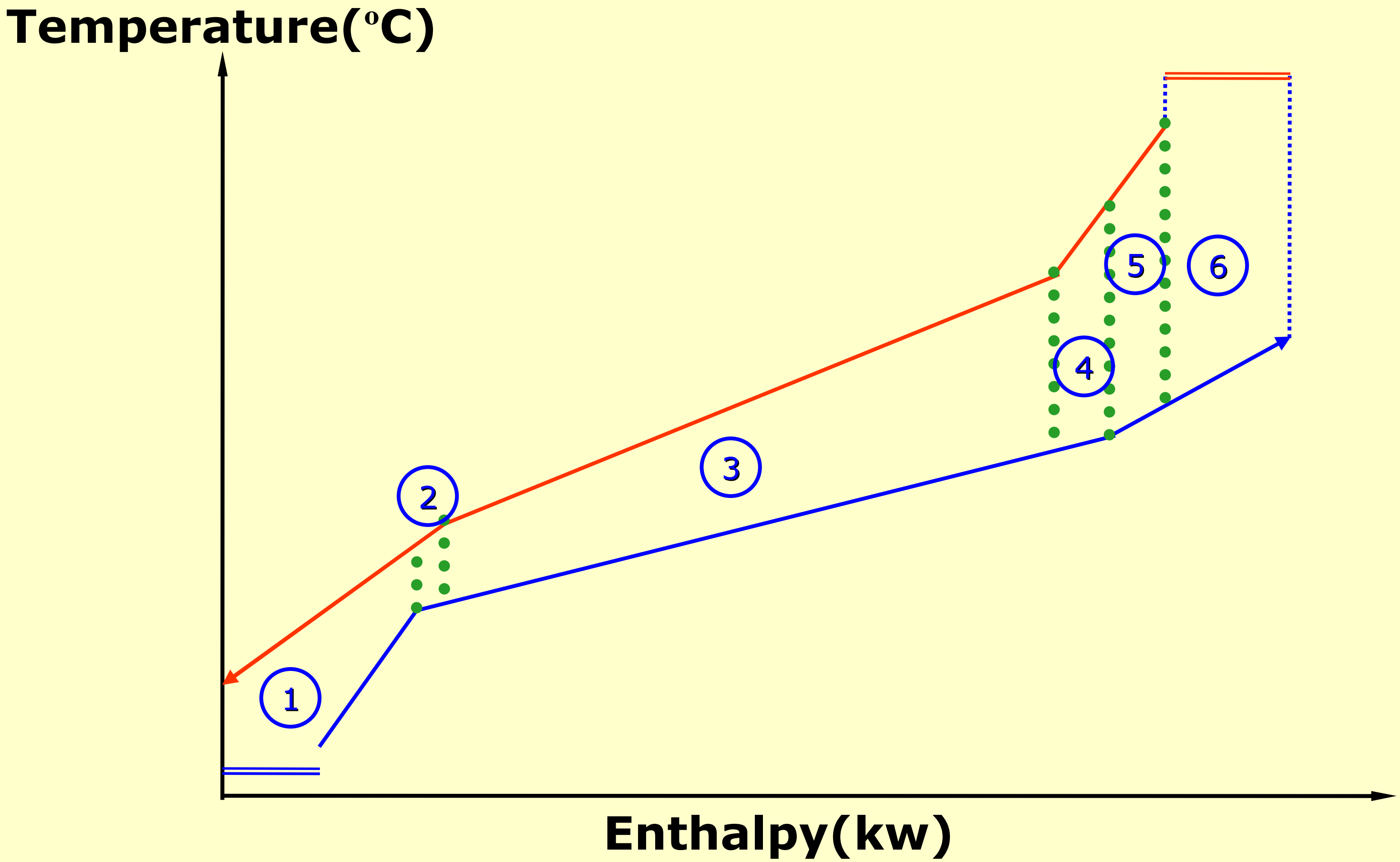


Minimum Area Network



$$A_i = \frac{1}{(\Delta T_{LM})_i} \sum_{Stream}^{j} \left(\frac{q}{h}\right)$$

Temperature profile is the same for every match And corresponds to that of the composite curves.



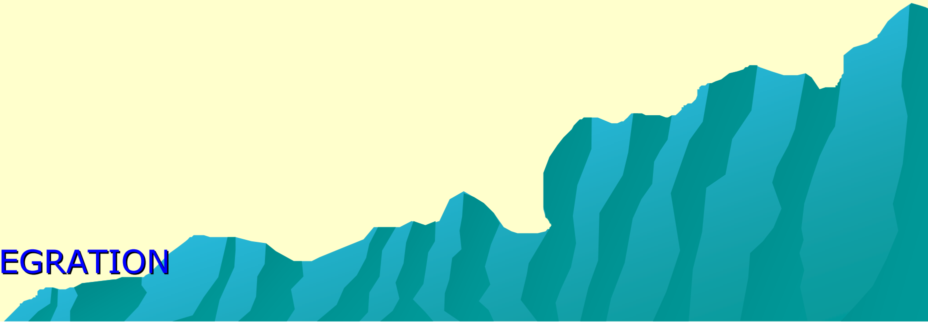
Network Area:

$$A_{Min} = \Sigma(A_i) = \sum_{interval}^{6}\left[\frac{1}{\Delta T_{LM}} \times \sum_{Stream}^{j}\left(\frac{q}{h}\right)\right]$$

Experience:

Good practical designs are within 10% of the area target

This also accounts for the h-value approximation



Having area target,
how do we estimate capital cost of the network?

Let’s start with a single exchanger

An exchanger cost model can be presented as:

$$\text{Ex. cost} = a + bA^{c}$$

$$a = \text{cost constant due to installation}$$

$$b = \text{cost constant due to material of construction}$$

$$c = \text{cost constant due to type or pressure}$$

What about capital cost of the network?

If there is N_{min} exchangers in the network and the total minimum area of the whole network is A_{min} then the cost can be found as:

$$\text{Network cost} = N_{\min} \times \left[a + b \left(\frac{A_{\min}}{N_{\min}} \right)^{c} \right]$$

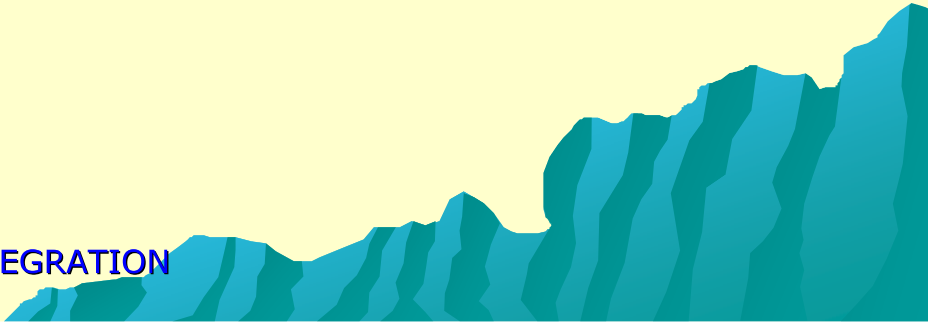
What are the assumptions used in this cost model?

Homework 1

Following assignment (including four problems) is due to be returned in three weeks.

LECTURE 10

Shell targeting



Bowman et al.(1940):

$Q = UA\Delta T_{LM} F_T \qquad 0 < F_T < 1$

$F_T = f(R,P)$

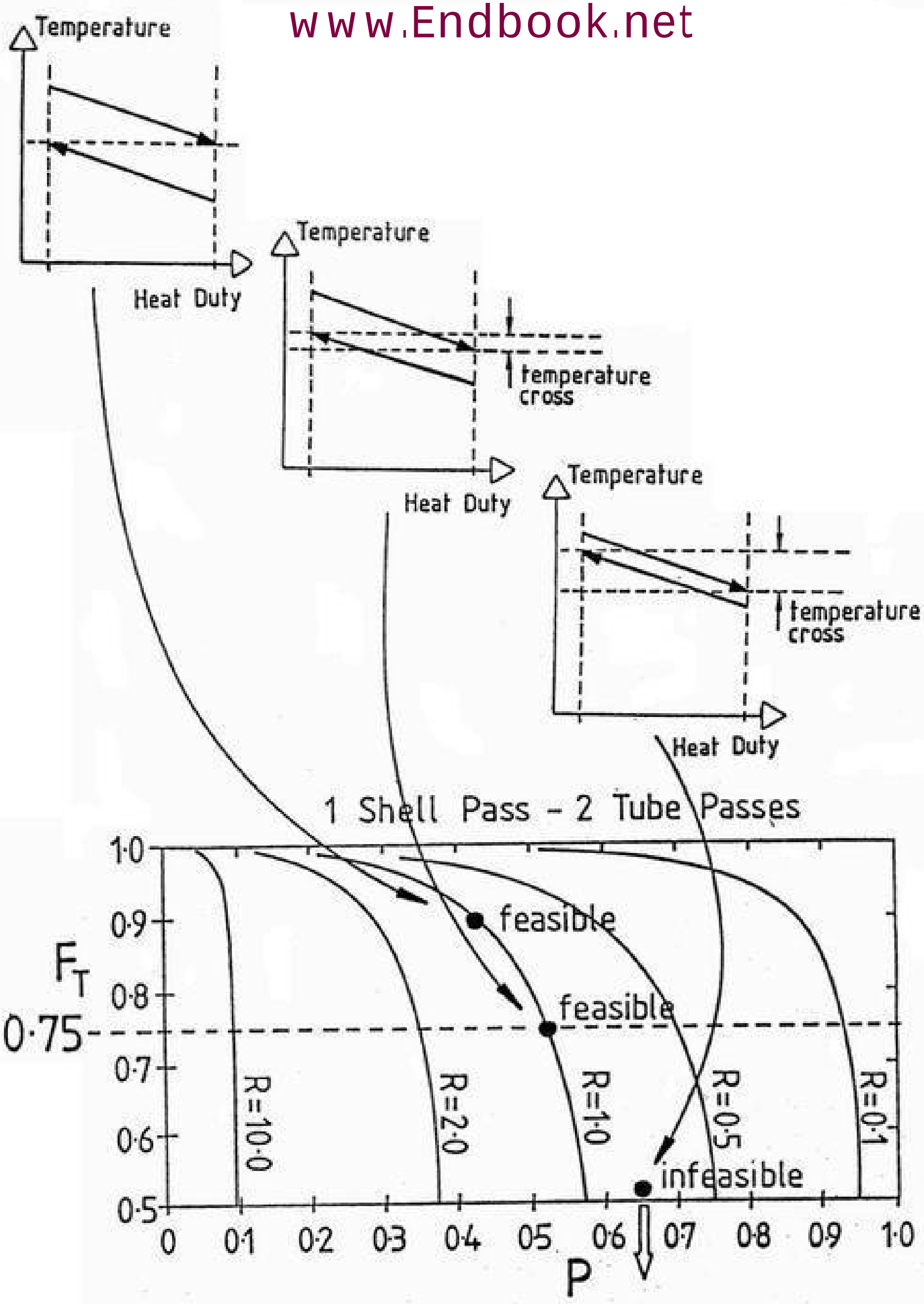
P ≡ Thermal effectiveness

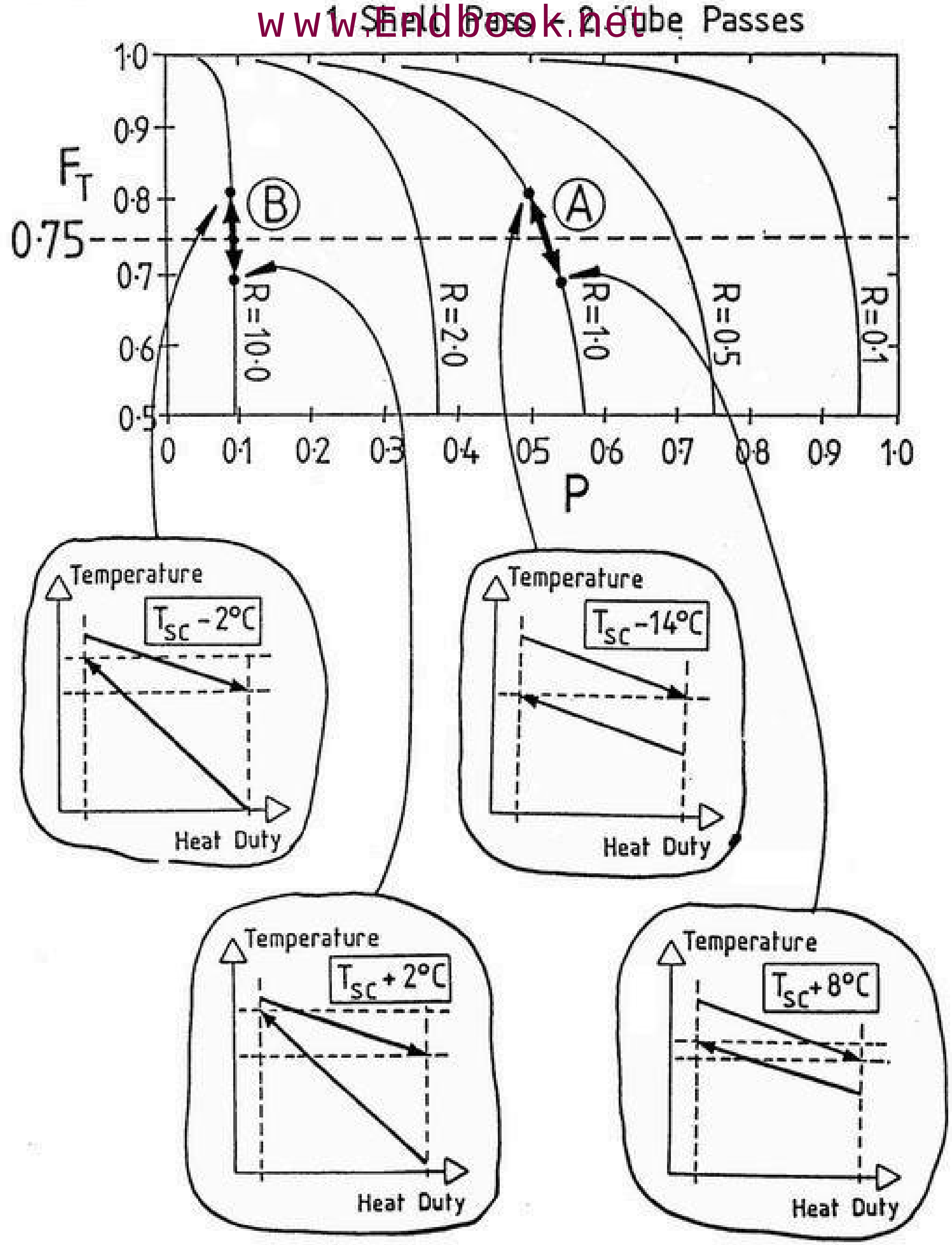
R ≡ Ratio of two heat cap. Flowrates

$$P = \frac{T_{Hi} - T_{Ho}}{T_{Hi} - T_{Ci}} \qquad R = \frac{C_{PH}}{C_{PC}} = \frac{T_{Co} - T_{Ci}}{T_{Hi} - T_{Ho}}$$

Rule of thumb:

Kern (1950): $F_T \geq 0.75$


Temperature
Heat Duty
Temperature
temperature cross
Heat Duty
Temperature
temperature cross
Heat Duty
1 Shell Pass – 2 Tube Passes
1·0
0·9
F_T
0·8
0·75
0·7
0·6
0·5
0
0·1
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0
P
feasible
feasible
infeasible
R=10·0
R=2·0
R=1·0
R=0·5
R=0·1


1 Shell Pass - 2 Tube Passes
F_T
1·0
0·9
0·8
0·75
0·7
0·6
0·5
0
0·1
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0
P
B
A
R=10·0
R=2·0
R=1·0
R=0·5
R=0·1
Temperature
T_SC -2°C
Heat Duty
Temperature
T_SC -14°C
Heat Duty
Temperature
T_SC +2°C
Heat Duty
Temperature
T_SC +8°C
Heat Duty

Taborek(1979,1983)&Liu et al.(1985)

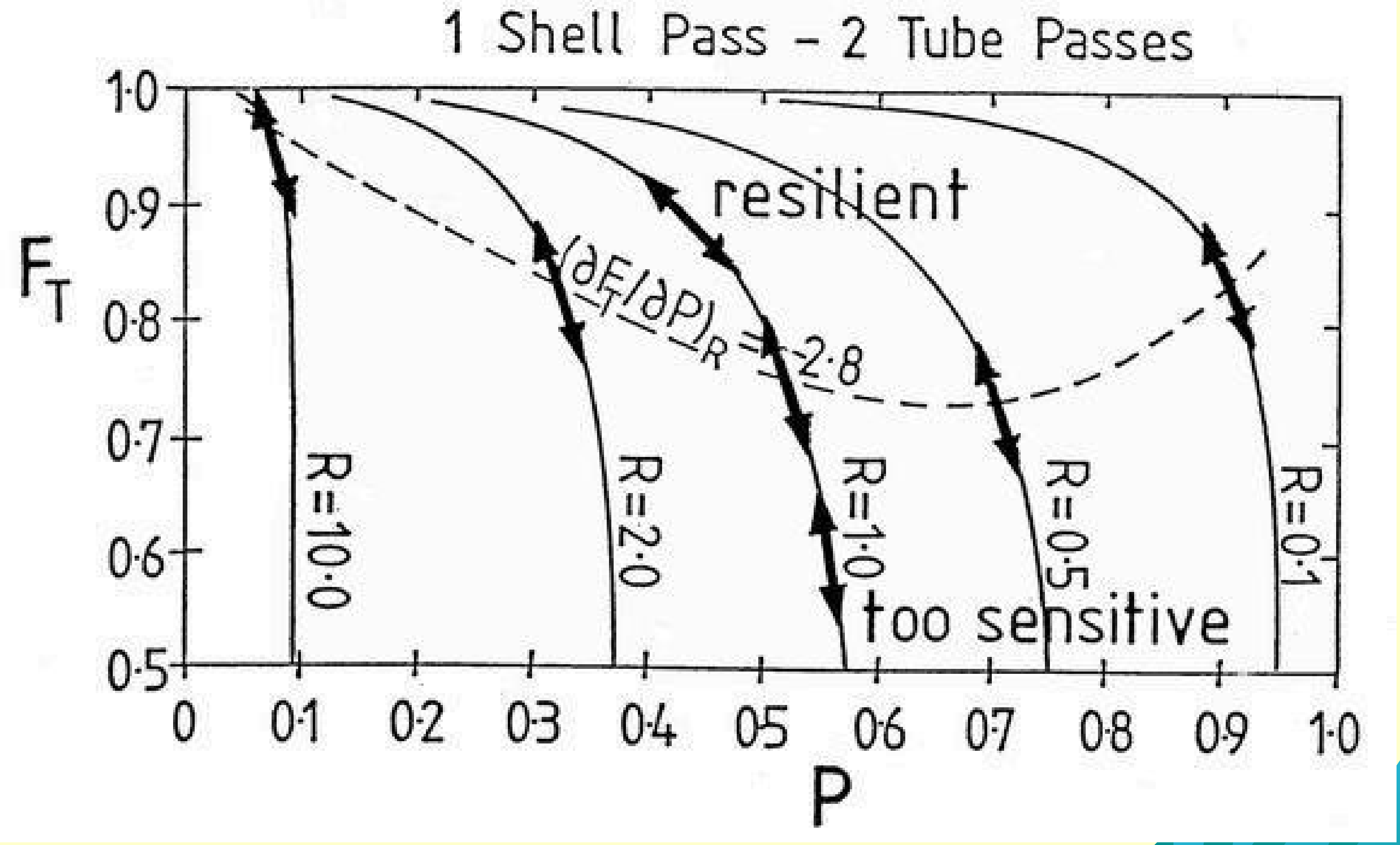
$$(\partial F_T / \partial P)_R = \text{const.}$$

Mitson (1984) gives the expression for $(\partial F_T / \partial P)_R$ for 1-2 shell & tube exchanger:

$$(\partial F_T / \partial P)_R = [\frac{F_T}{P(1-P)}] - [\frac{(1-P)F_T^2}{\sqrt{2}P}][\frac{\beta}{(2-\beta P)} - \frac{\alpha}{(2-\alpha P)}]$$

Where: $\alpha = 2 - \sqrt{2}$

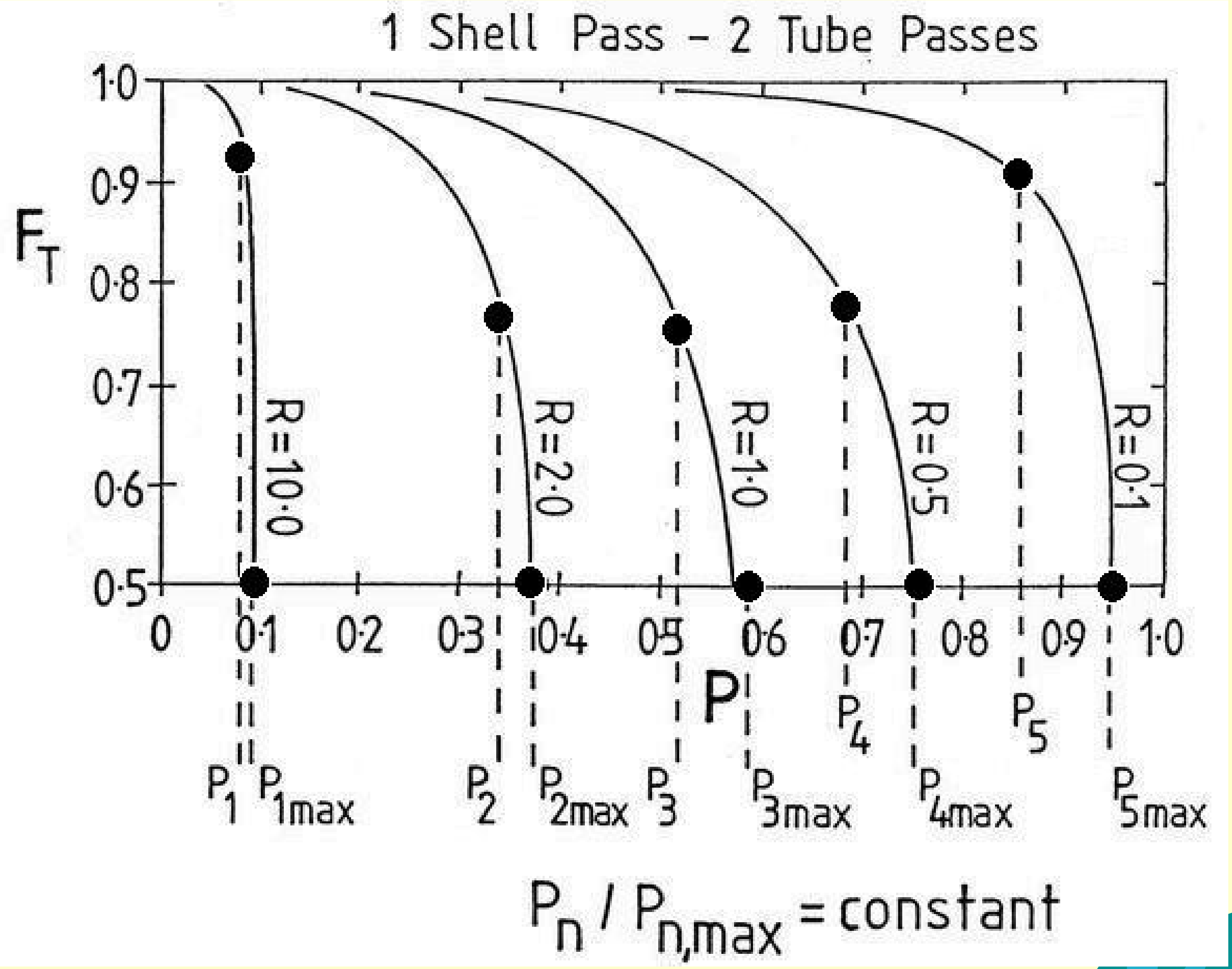
$\beta = 2 + \sqrt{2}$


1 Shell Pass – 2 Tube Passes
F_T
1·0
0·9
0·8
0·7
0·6
0·5
0
0·1
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0
P
resilient
too sensitive
(∂F_T/∂P)_R = -2·8
R=10·0
R=2·0
R=1·0
R=0·5
R=0·1

A constant slop line for F_T=0.75 at R=1 has $(\partial F_T / \partial P)_R = -2.8$

An Alternative Approach

This approach is based upon observation that for any value of “R” there is a maximum asymptotic value for P, say P_{max} when F_T tends to -∞


1 Shell Pass – 2 Tube Passes
F_T
1·0
0·9
0·8
0·7
0·6
0·5
0
0·1
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0
P
R=10·0
R=2·0
R=1·0
R=0·5
R=0·1
P1
P1max
P2
P2max
P3
P3max
P4
P4max
P5
P5max
Pn / Pn,max = constant

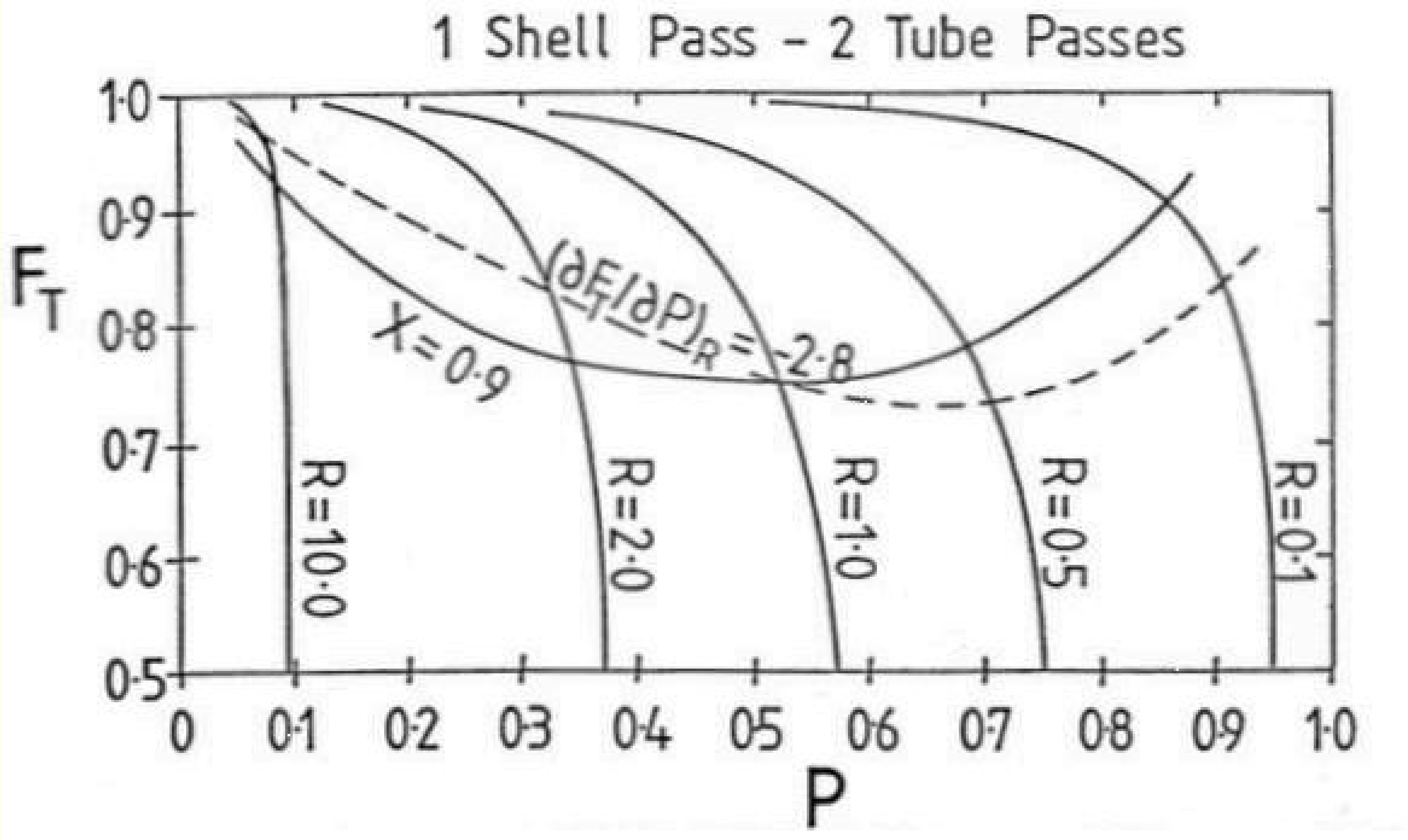
Mitson (1984):

$$P_{\max} = \frac{2}{\left(R + 1 + \sqrt{R^2 + 1}\right)}$$

at $P=P_{max}$ design will not be feasible P should be less than $P_{Max.}$

$P=X_P P_{Max}$

where: $0<X_P<1$

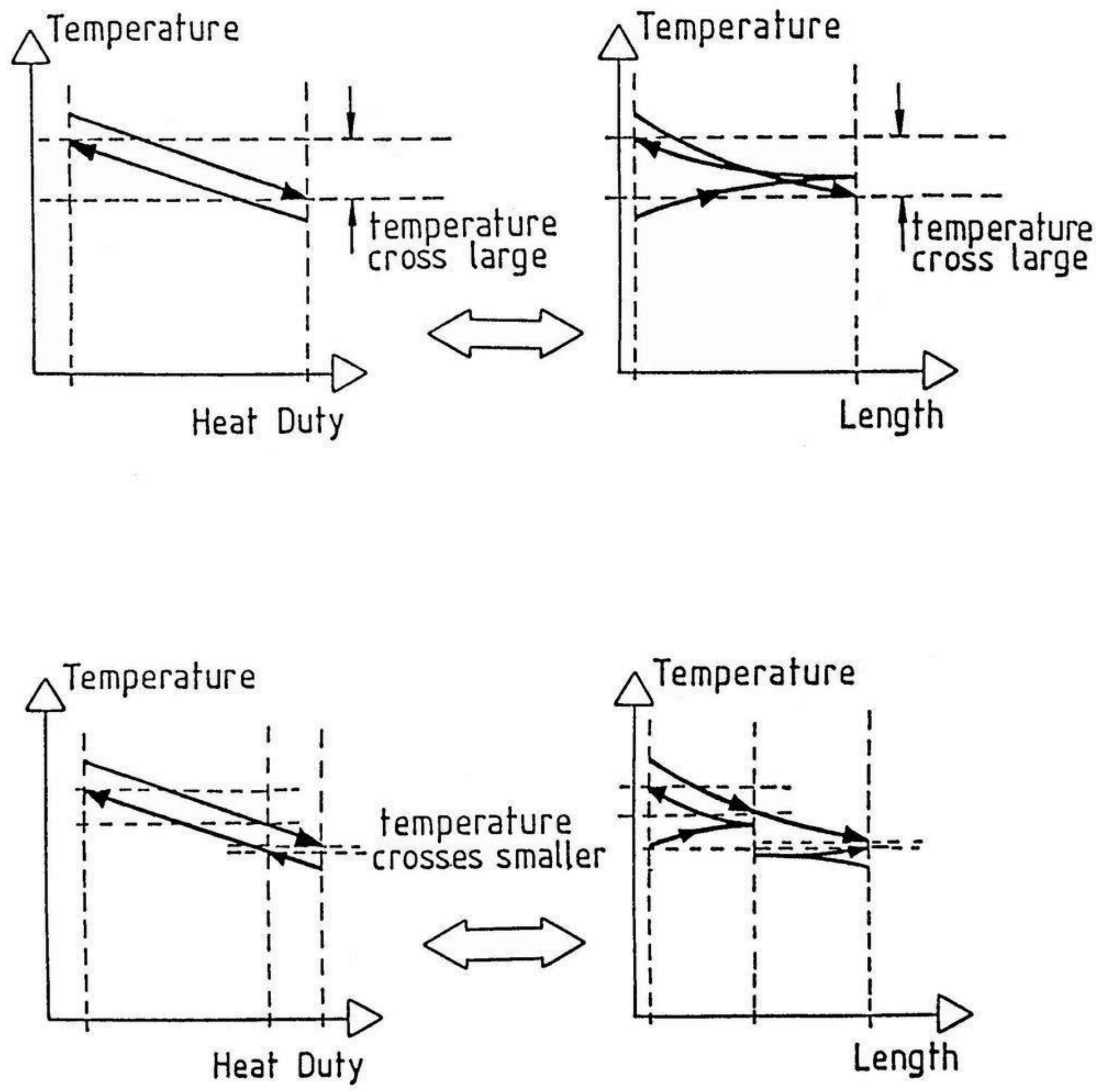

1 Shell Pass – 2 Tube Passes
F_T
1·0
0·9
0·8
0·7
0·6
0·5
0
0·1
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0
P
(∂F_T/∂P)_R = -2·8
X = 0·9
R=10·0
R=2·0
R=1·0
R=0·5
R=0·1

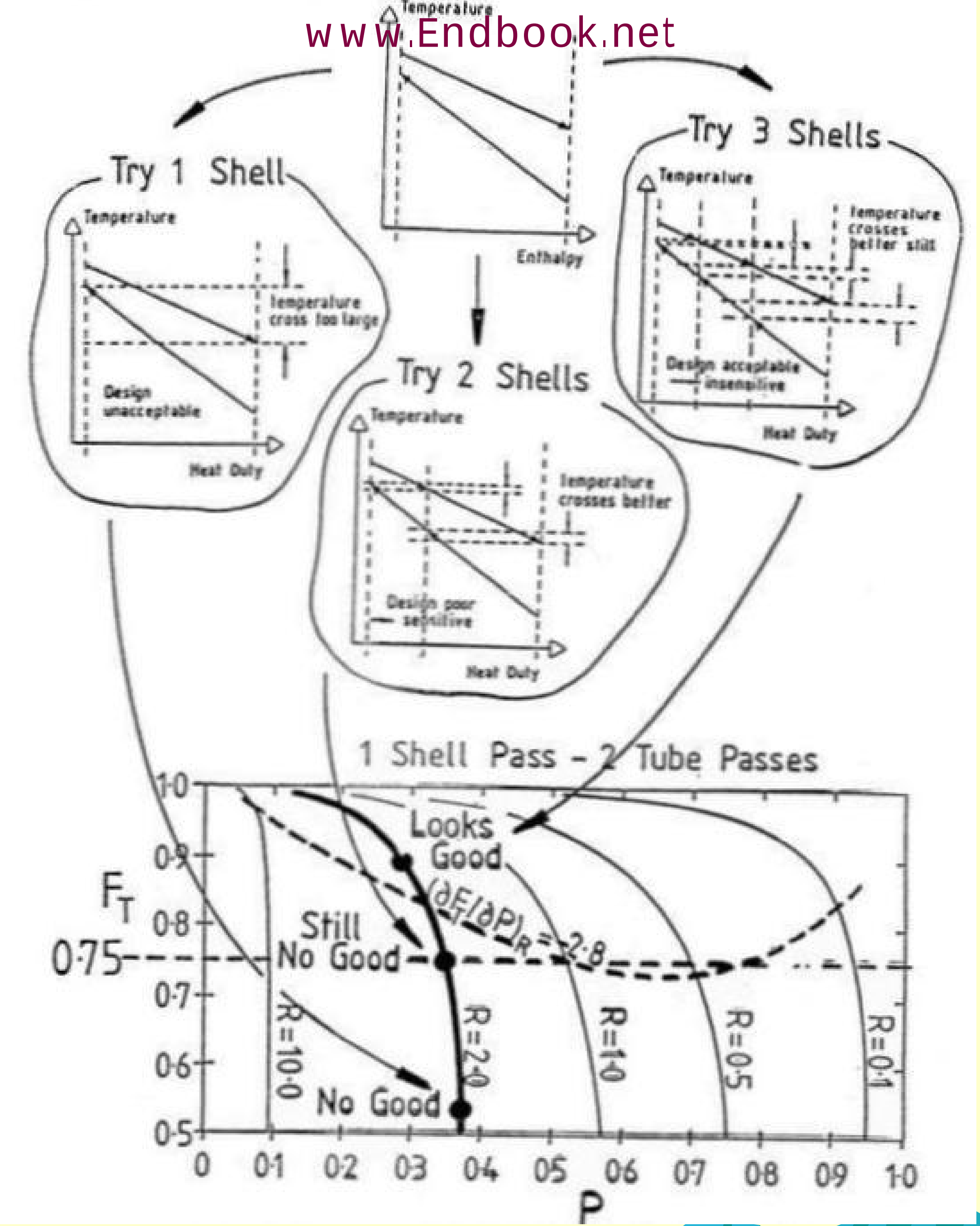
Design with Multiple 1-2 shells

The designer often encounters situations where F_t is too low or the design is too sensitive when using a single 1-2 shell.

In such cases either different type of exchanger or multiple 1-2 shell should be considered.

Traditional Approach $\Rightarrow$ Trial & Error


Temperature
Heat Duty
temperature cross large
Temperature
Length
temperature cross large
Temperature
Heat Duty
temperature crosses smaller
Temperature
Length


Temperature
Enthalpy
Try 1 Shell
Temperature
temperature cross too large
Design unacceptable
Heat Duty
Try 2 Shells
Temperature
temperature crosses better
Design poor — sensitive
Heat Duty
Try 3 Shells
Temperature
temperature crosses better still
Design acceptable — insensitive
Heat Duty
1 Shell Pass - 2 Tube Passes
F_T
1·0
0·9
0·8
0·75
0·7
0·6
0·5
Looks Good
$(\partial F_T/\partial P)_R = -2{\cdot}8$
Still No Good
No Good
R=10·0
R=2·0
R=1·0
R=0·5
R=0·1
0
0·1
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0
P

Example:

410°C ⟶ 110°C

360°C ⟵ 0°C

$$P = \frac{410-110}{410-0} = 0.73 \qquad R = \frac{360-0}{410-110} = 1.2$$

Try one shell ⇒ infeasible (see graph 1-2)

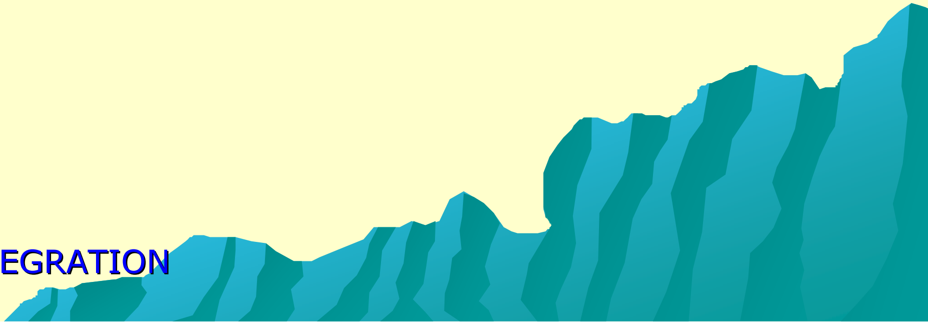
Try two shells ⇒infeasible(see graph 2-4)

Try three shells ⇒F_T=0.65(see graph 3-6)

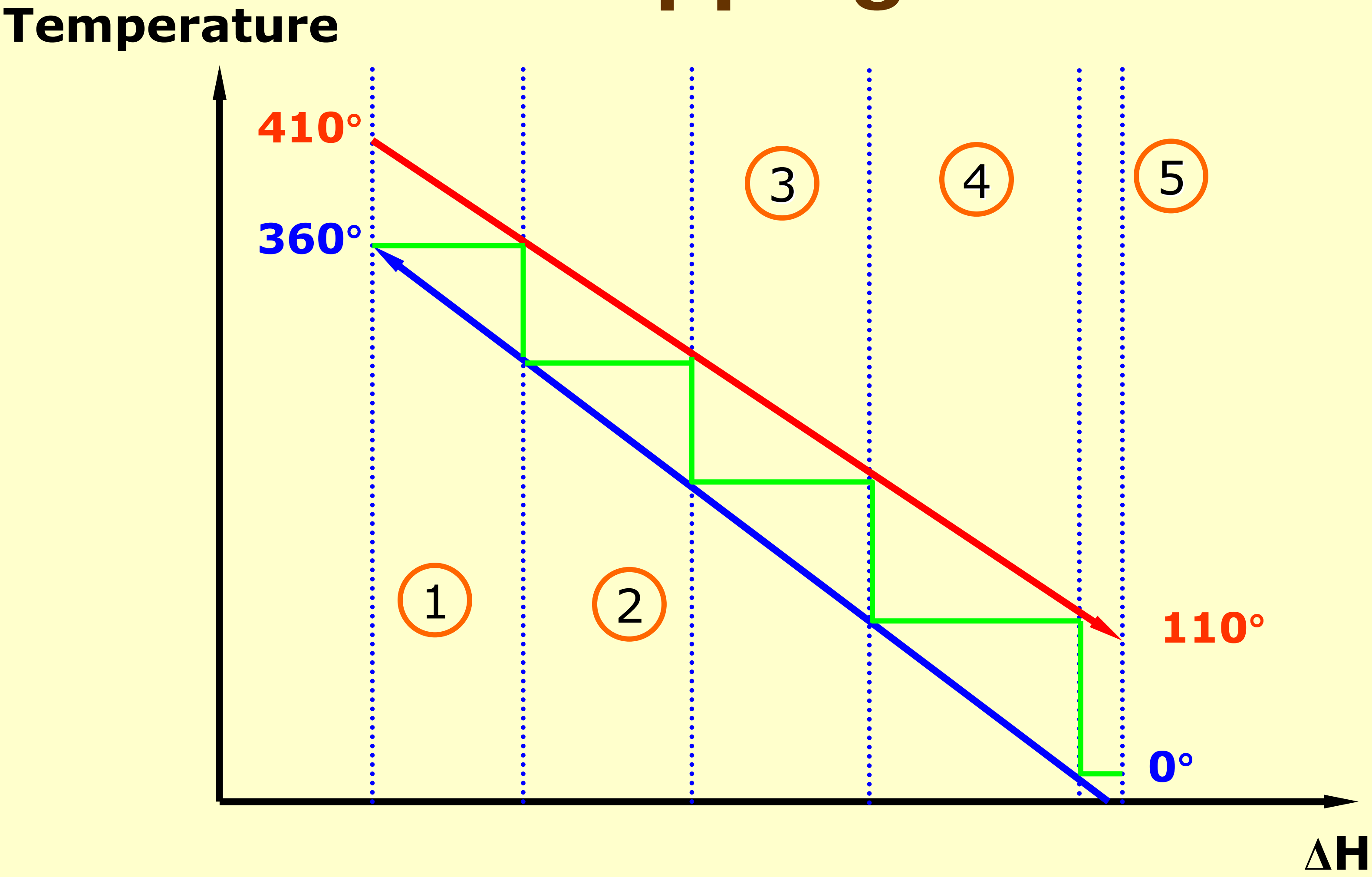
Try four shells ⇒F_T=0.8(see graph 4-8)

Stepping-off Method (Bell & Liu et al.)

A conservative way of applying this method which allows no temperature cross, normally gives more shells than required.



Stepping - off



5 Shells suggested

Stepping – off with Pre-Specified F_T

The unknown temperatures for first step, T_{ho} and T_{Ci} ; can be calculated using equations:

$F_T = f(R,P)$

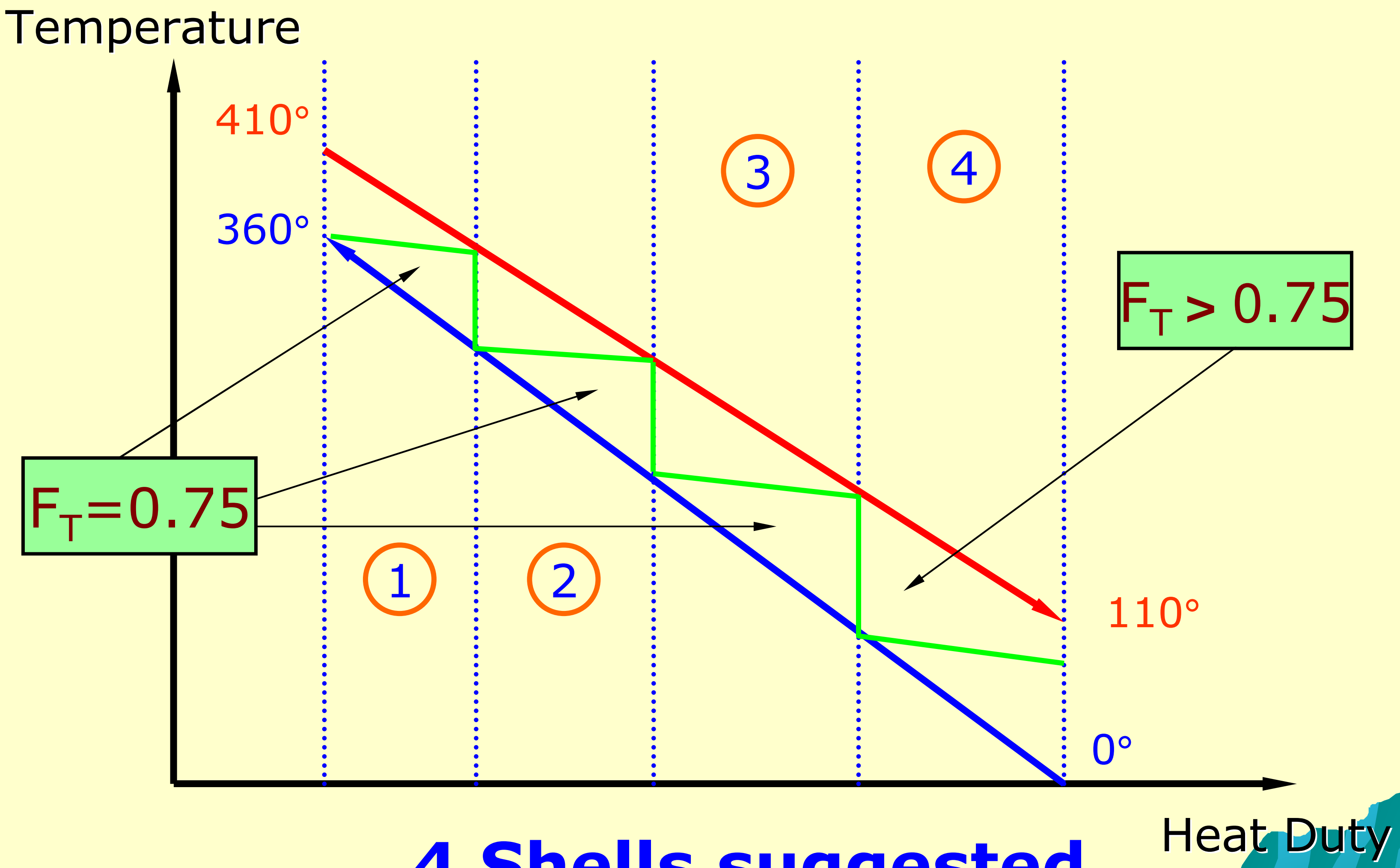
$R = (T_{Co} - T_{Ci})/(T_{hi} - T_{ho})$

$P = (T_{hi} - T_{ho})/(T_{hi} - T_{Ci})$

Note that: R, F_T , T_{hi} and T_{co} for first step are known.

The next step will be found in the same way.

Stepping-off for $F_T \geq 0.75$



4 Shells suggested

Stepping-off with Specified X_P

If X_P is specified then P can be found using $P=X_P P_{max}$

Since $P_{max} = 2 \big/ (R+1+\sqrt{R^2+1})$

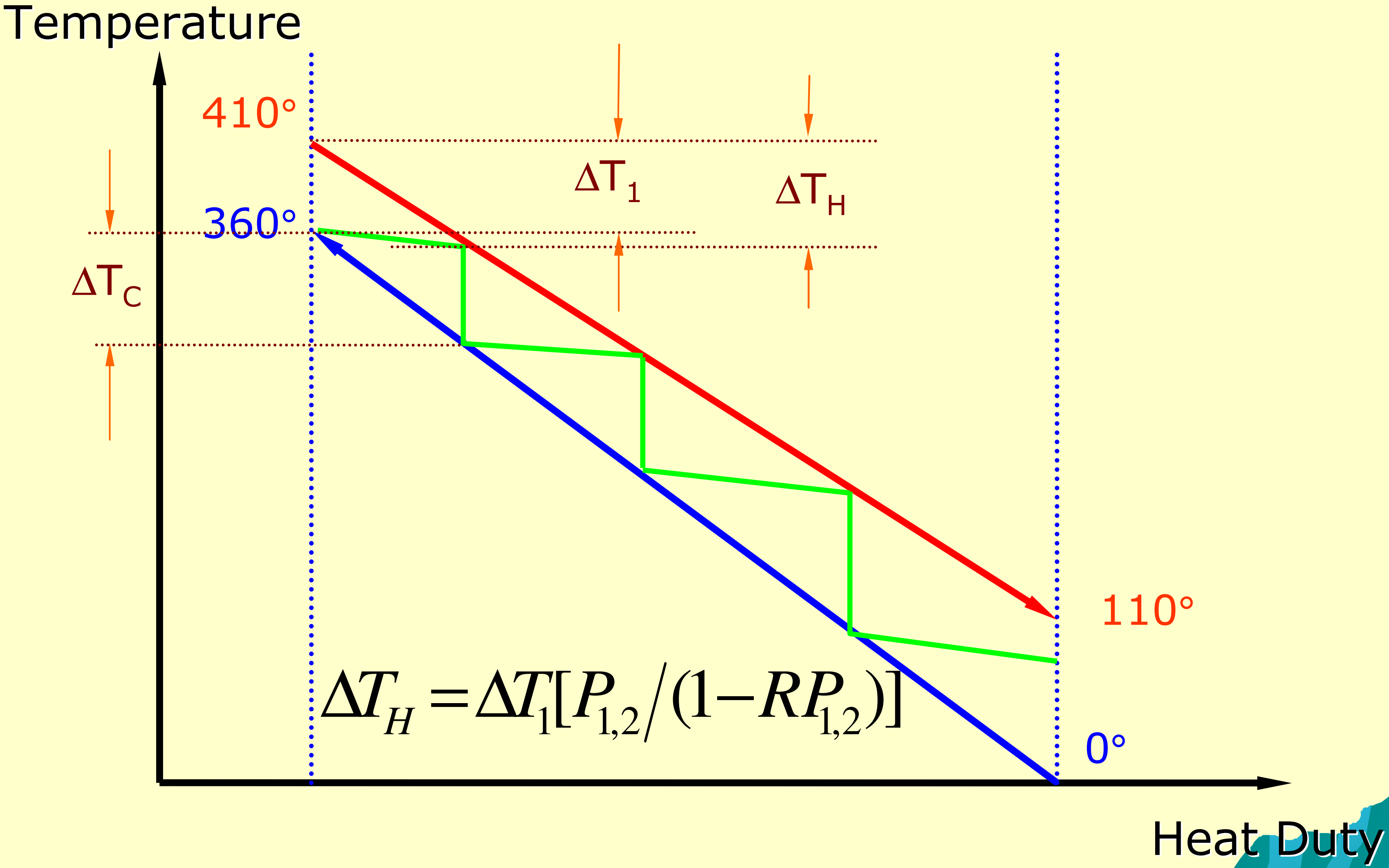
and R is known.

$$P_{1,2} = \Delta T_H \big/ (\Delta T_1 + \Delta T_C)$$

$$R = \Delta T_C \big/ \Delta T_H \Rightarrow P_{1,2} = \Delta T_H \big/ (\Delta T_1 + R\Delta T_H)$$

$$\Delta T_H = \Delta T_1 [P_{1,2} \big/ (1 - RP_{1,2})]$$

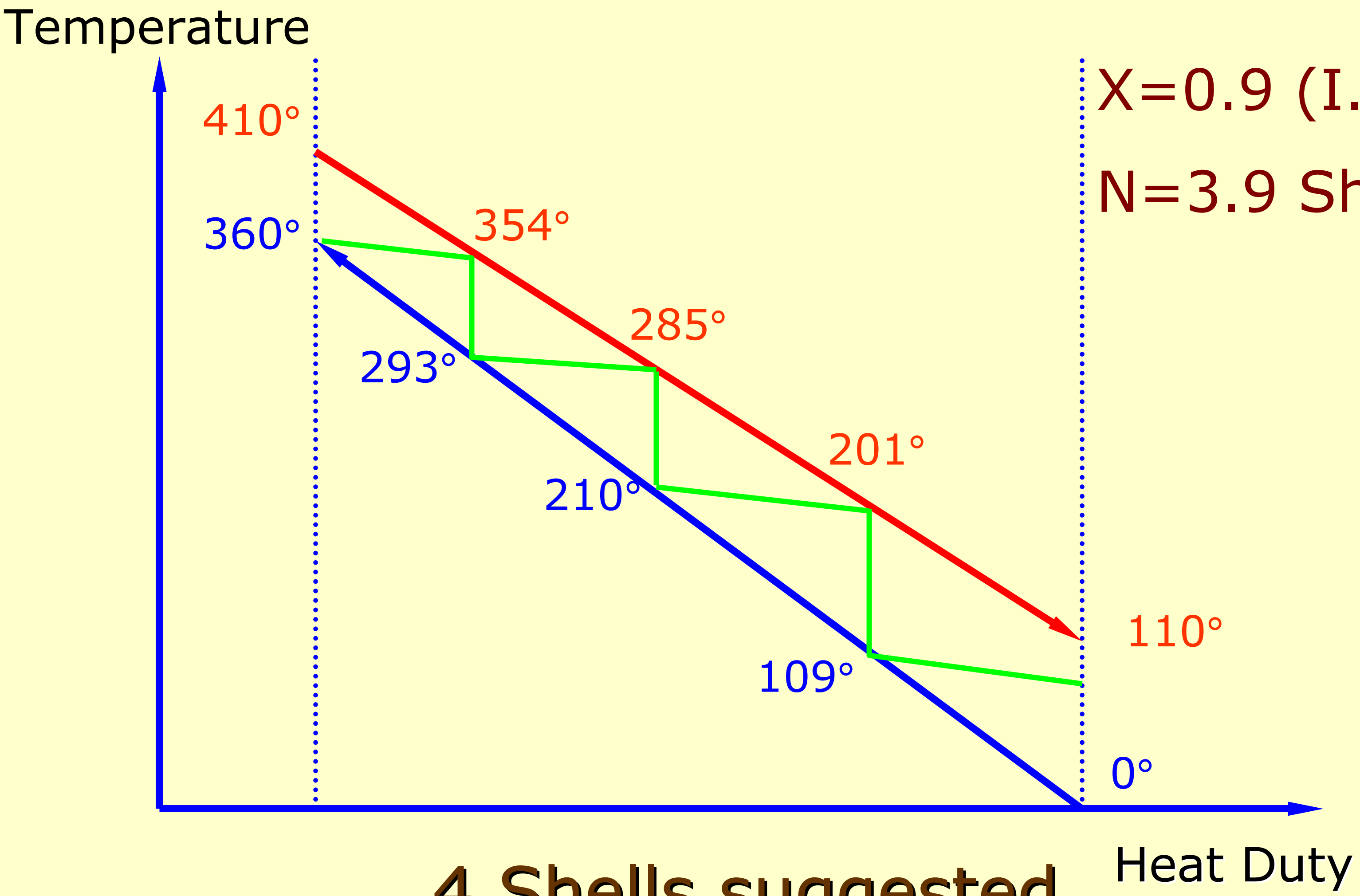
Stepping-off for $P_{1,2}$



$$\Delta T_H = \Delta T_1 [P_{1,2} / (1 - R P_{1,2})]$$

Since $P_{1,2}$ is determined fully from R and X_P , the step slop given by ΔT_H ultimately depends only on the designer's choice of X_P.

Stepping-off for X=0.9



X=0.9 (I.e. F_T=0.75)

N=3.9 Shells

4 Shells suggested

An Analytical Procedure

- ✓ Bowman(1936):

$$P_{N,2N} = f(R, P_{1,2}, N)$$

$$P_{N,2N} = f(R, X_P P_{1,2\max}, N)$$

Since $P_{1,2max}$ is only function of R

$P_{N,2N}=f(R,X_P,N)$

Invert the function $\Rightarrow N = f^{-1}(R, X_P, P_{N,2N})$

- ✓ Ahmad (1985) has derived the equations:

$$for\ R \neq 1$$

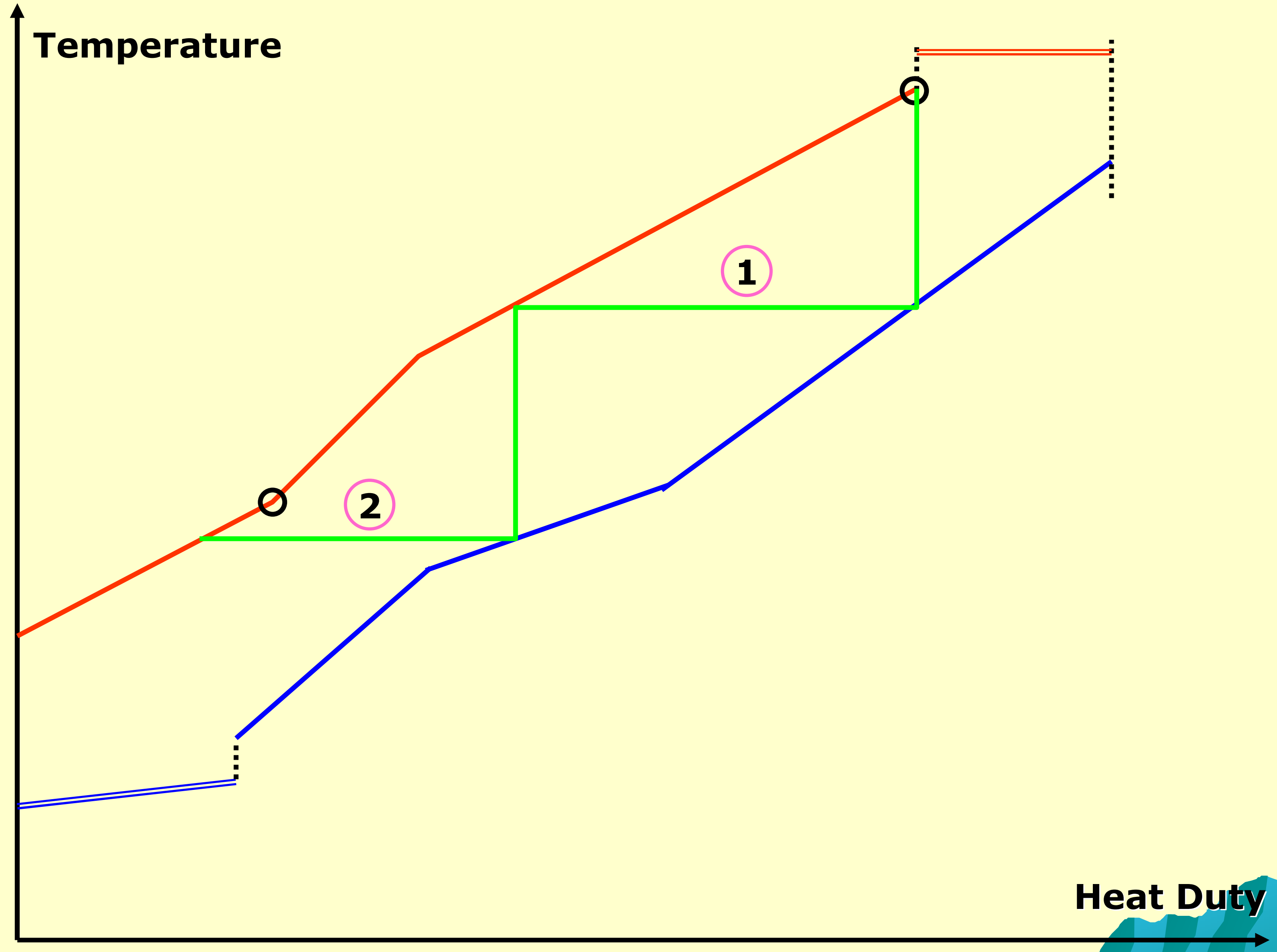
$$N = \ln[(1 - RP_{N,2N})/(1 - P_{N,2N})]/\ln W$$

Where:

$$W = (R + 1 + \sqrt{R^2 + 1} - 2X_P R)/(R + 1 + \sqrt{R^2 + 1} - 2X_P)$$

$$for\ \ R = 1$$

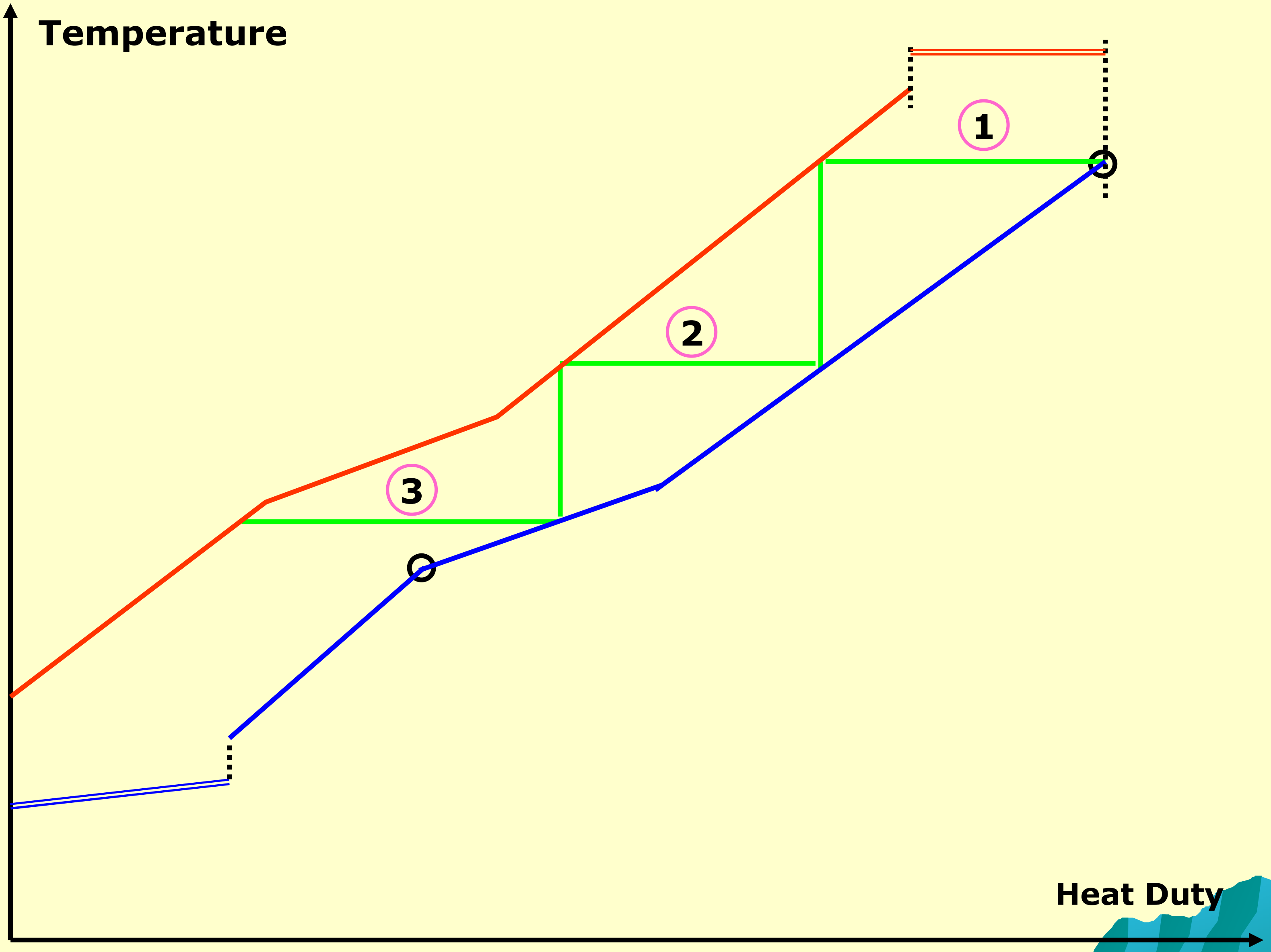
$$N = [P_{N,2N}/(1 - P_{N,2N})][1 + (\sqrt{2}/2) - X_P]/X_P$$


Temperature
1
2
Heat Duty

Estimation of Number of Shells Required by Hot Streams

- Starting with a hot stream supply temperature drop a vertical line on the balanced composite curve until it intercepts the cold composite. From this point draw a horizontal.

- ✓ Repeat the procedure until the horizontal line intercepts the hot composite at or below the target temperature of that hot stream.
- ✓ The number of horizontal lines will be the number of shells which this particular hot stream requires.
- ✓ Repeat the procedure for all the hot streams.
- ✓ The sum of the number of shells for all the hot streams will be the total number of shells required by the hot streams.


Temperature
1
2
3
Heat Duty

Estimate of Number of Shells Required by Cold Streams

- ✓ Starting with a cold stream target temperature a horizontal line is drawn until it intercepts the hot composite curve. From that point a vertical line is dropped to the cold composite curve.
- ✓ Repeat the procedure until the vertical line intercepts the cold composite at or below the target temperature of that particular stream.

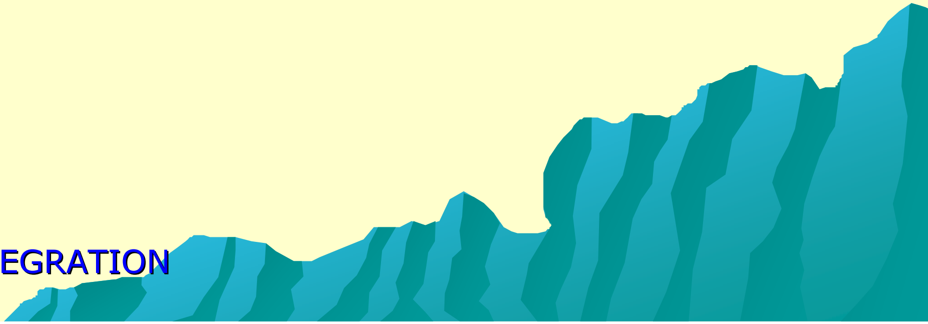
- The number of horizontal lines will be the number of shells which this particular cold stream requires.
- Repeat the procedure for all the cold streams.
- The sum of the number of shells for all the cold streams is the total number of shells required by the cold streams.

Estimation of Number of Shells Required by the Network

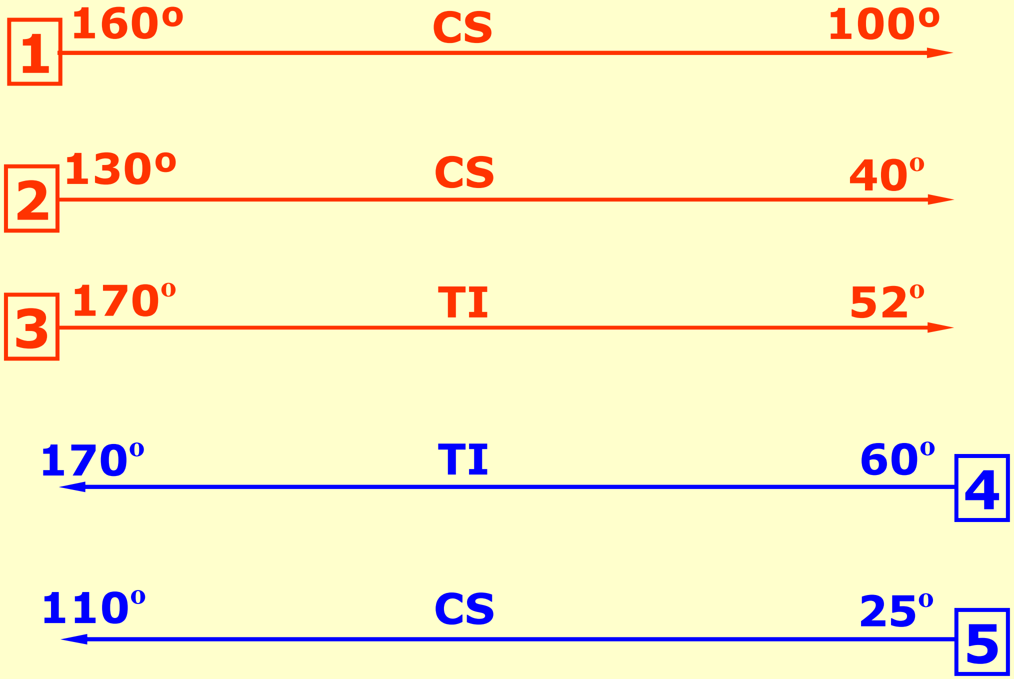
- The quasi-minimum number of shells required in the network would be the maximum of the total number of shells required by the hot streams and the total number of shells required by the cold streams.
- If the total number of shells required by the network which is found in the above method is less than the minimum number of units obtained from Euler's equation,the minimum number of shells will be equal to minimum number of units.

LECTURE 11

Cost Targets for Different Materials of Construction



Cost targets for different materials of construction



				Cp (KW/° C)	h (KW/m²)
1	160°	CS	100°	20	0.25
2	130°	CS	40°	8	0.25
3	170°	TI	52°	24	0.25
4	170°	TI	60°	40	0.25
5	110°	CS	25°	25	0.25

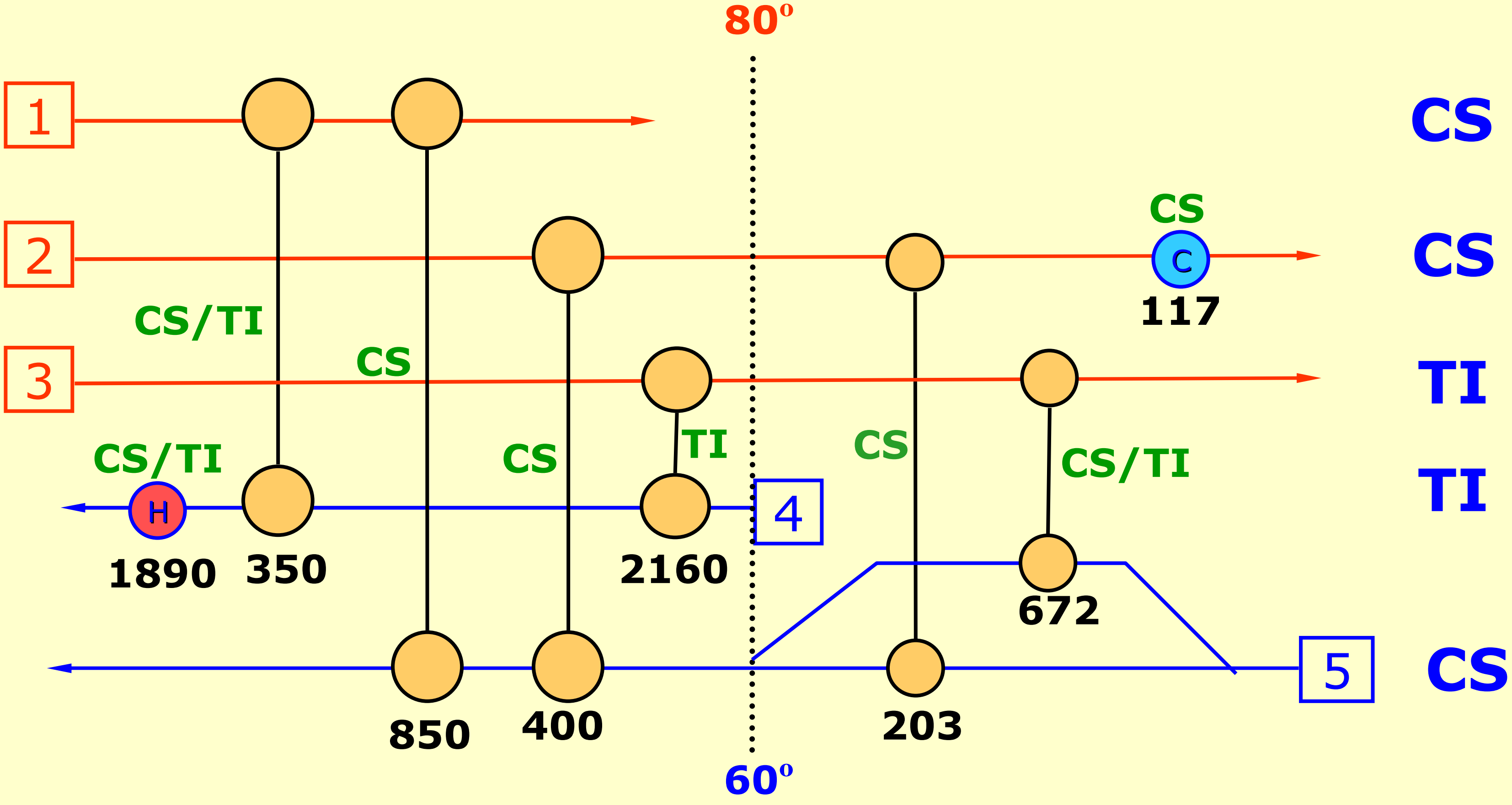
$\Delta T_{min}=10^o$

Utilities:

Steam@190°C; h=0.25kw/m^2°C

Air@18°C; h=0.1kw/m^2°C

One design could be



Network Cost = $1871506

Cost Data
Shell/Tube Exchangers

$$\text{Carbon Steel } (CS), (\$) = 30800 + 750\,A^{0.81}$$

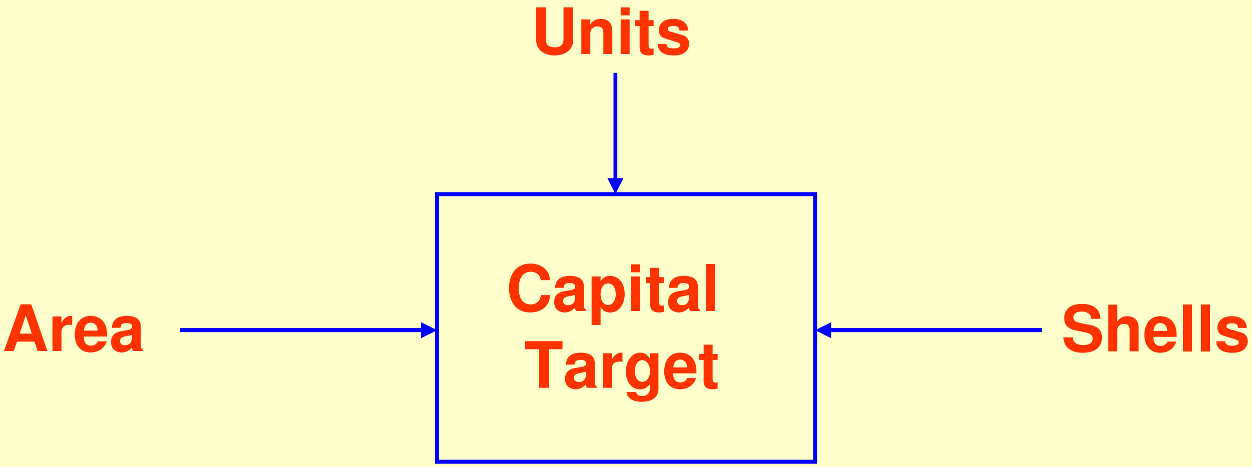
$$\text{Titannium } (TI), (\$) = 30800 + 4407\,A^{0.81}$$

$$\text{Stainless Steel } (\mathrm{SS}), (\$) = 30800 + 1644\,A^{0.81}$$

$$\mathrm{CS/TI\ or\ TI/CS}, (\$) = 30800 + 3349A^{0.81}$$

$$\mathrm{CS/SS\ or\ SS/CS}, (\$) = 30800 + 1339A^{0.81}$$

Existing Capital Targeting Procedure



Units

Area

Capital Target

Shells

With this model of capital cost, we could assume,

a) All exchangers are made from Carbon Steel

capital cost =$689,737

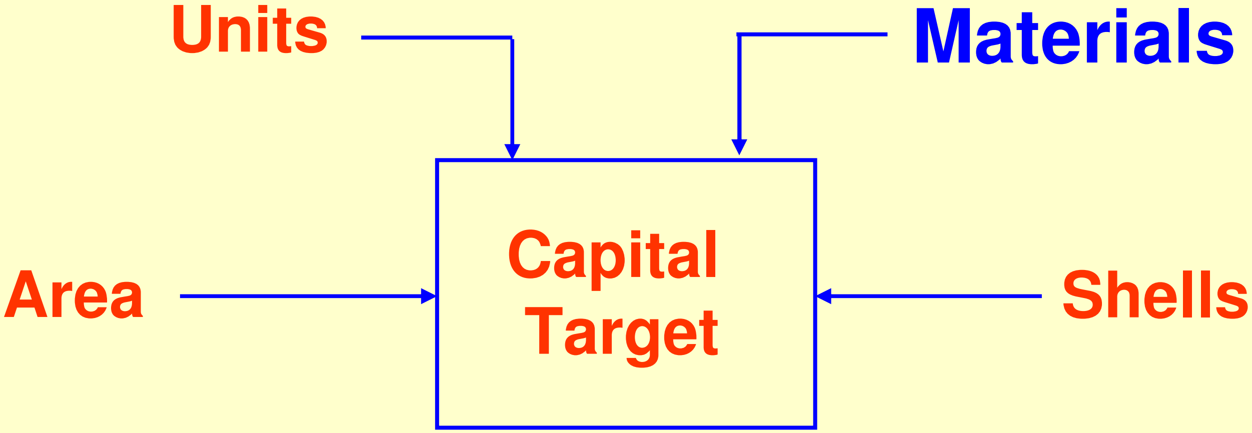
→ **63% less than actual**

b) All exchangers are made from Titanium (TI)

capital cost =$2,851,567

→ **52% higher than actual**

Objective is to find a new capital cost target model in order to accommodate for different materials of construction


Units

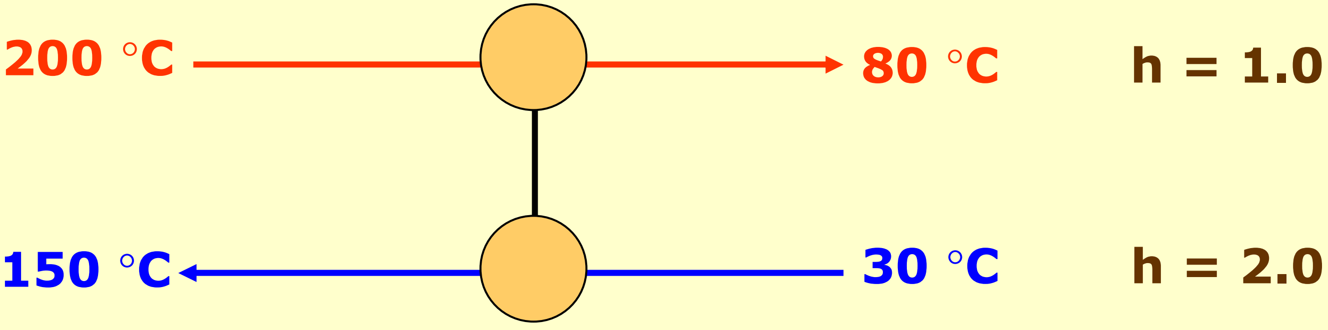
Materials

Area

Capital Target

Shells

Let’s start with just one exchanger,



Q = 6667

Area = 200 m²

With a very simplified cost model:

a) **Carbon Steel (CS)**
Cost($) = 450 * A = $ 90,000

b) **Titanium (TI)**
Cost($) = 1800 * A = $ 360,000

If we wanted to cost a TI exchanger using the CS cost model, we could apply a correction factor Φ within the area term.

Here is one way of doing it :

$$\text{cost } TI = 1800 \times \left(\frac{1}{U} \times \frac{Q}{LMTD} \right) = \$\,360{,}000$$

(by TI cost model)

$$\text{cost } TI = 450 \times \left(\frac{1}{\Phi U} \times \frac{Q}{LMTD} \right) = \$\,360{,}000$$

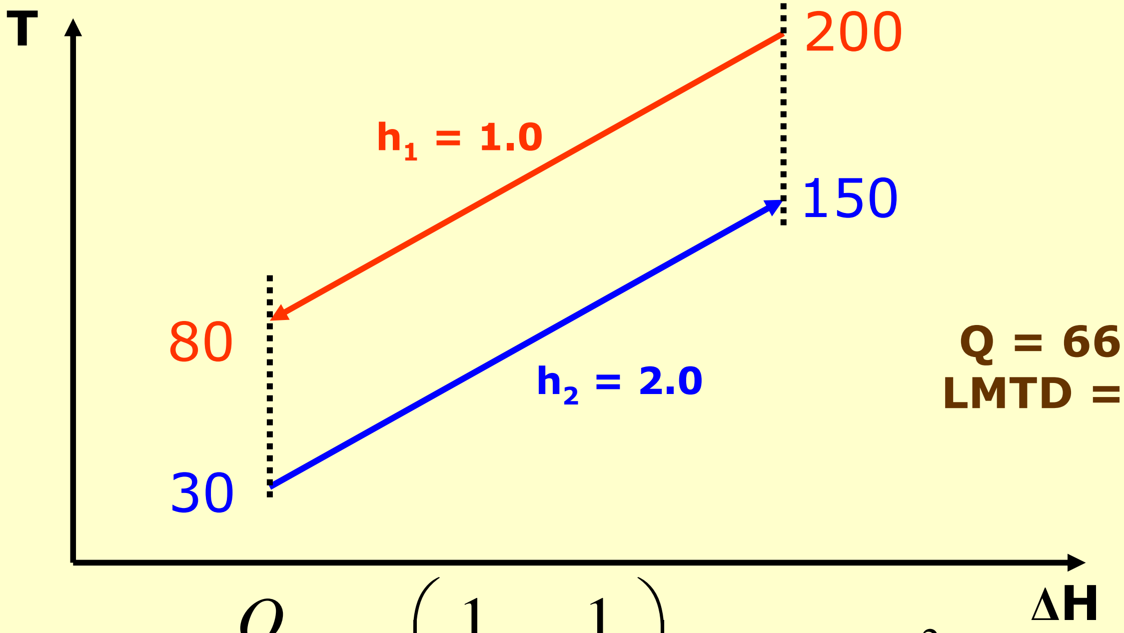
(by CS cost model)

→ **$\Phi = 0.25$**

Now consider somewhat more realistic cost model

$$\text{cost } CS(\$) = 30800 + 750 A^{0.81}$$

$$\text{cost } TI(\$) = 30800 + 4407 A^{0.81}$$



Q = 6667
LMTD = 50

$$A = \frac{Q}{LMTD} \times \left(\frac{1}{h_1} + \frac{1}{h_2} \right) = 200 \ \ m^2$$

Let’s use Φ again

$$Cost\ TI = 30800 + 4407\left[\frac{6667}{50}\left(\frac{1}{1}+\frac{1}{2}\right)\right]^{0.81} = \$\,352{,}890$$

(by TI cost model)

$$Cost\ TI = 30800 + 750\left[\frac{6667}{50}\left(\frac{1}{1\times 0.1123}+\frac{1}{2\times 0.1123}\right)\right]^{0.81}$$

(by CS cost model)

$$= \$\,352{,}890$$

With Φ=0.1123 , we get the correct result

We can always “fudge” Φ to fit any specific case.

But, how can we predict Φ ?

Cost of base case exchanger = $a_1+b_1(A)^{C1}$

Cost of special exchanger = $a_2+b_2(A)^{C2}$

Cost of special exchanger = $a_1+b_1[A_{fudge}]^{C1}$

$A_{fudge}= f\ (\Phi,A)$

Now let us get the Φ

Step 1

$a_2 + b_2\,(A)^{C2} = a_1 + b_1(A_{fudge})^{C1}$

For simplicity, we assume $a_1 = a_2$

$$\Longrightarrow \quad A_{fudge} = \left[\left(\frac{b_2}{b_1} \right)^{\frac{1}{C_1}} \times A^{\frac{C_2}{C_1} - 1} \right] \times A$$

Step 2

$$A = \frac{Q}{\Delta T_{LM}}\left(\frac{1}{h_1}+\frac{1}{h_2}\right)$$

This with the A_{fudge} equation develops into …

$$\frac{1}{h_{fudge}} = \left[\left(\frac{b_2}{b_1}\right)^{\frac{1}{C_1}} \times A^{\frac{C_2}{C_1}-1}\right] \times \frac{1}{h}$$

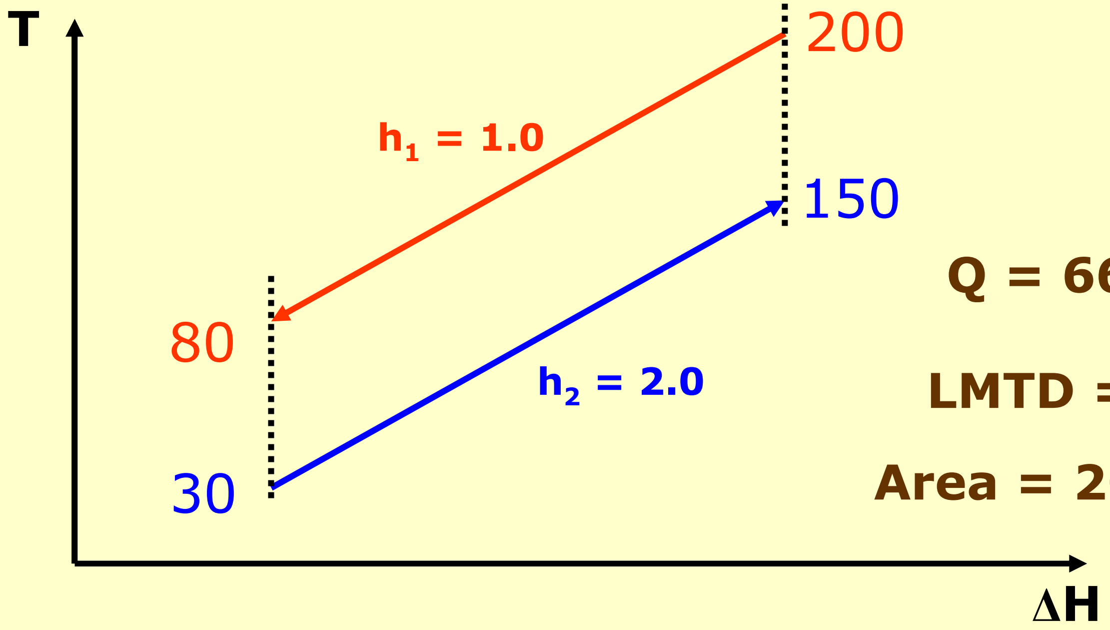
Step 3

Simple idea:

$\Phi = h_{fudge} / h$

$$\Phi = \left[\left(\frac{b_1}{b_2}\right)^{\frac{1}{C_1}} \times A^{1-\frac{C_2}{C_1}}\right]$$

Remember the example?



Q = 6667

LMTD = 50

Area = 200 m²

Network cost = $ 352,890

Now

$$\text{Cost CS} = \underset{\substack{\downarrow\\30800}}{a_1} + \underset{\substack{\downarrow\\750}}{b_1}(A)^{\overset{0.81}{\overset{\uparrow}{c_1}}}$$

$$\text{Cost TI} = \underset{\substack{\downarrow\\30800}}{a_2} + \underset{\substack{\downarrow\\4407}}{b_2}(A)^{\overset{0.81}{\overset{\uparrow}{c_2}}}$$

$$\Phi = \left[\left(\frac{b_1}{b_2}\right)^{\frac{1}{C_1}} \times A^{1-\frac{C_2}{C_1}}\right] = \left[\left(\frac{750}{4407}\right)^{\frac{1}{0.81}}\right] = 0.1123$$

$$Cost\,TI = 30800 + 750\left[\frac{6667}{50}\left(\frac{1}{0.1123\times 1}+\frac{1}{0.1123\times 2}\right)\right]^{0.81} = \$352{,}890$$

Therefore, we can predict the Φ and get the right cost

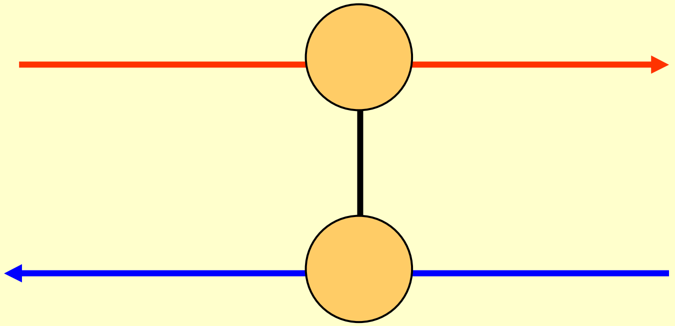
Note 1:

Our cost models had $c_1 = c_2$, but don't worry

Φ still can be used when $c_1 \neq c_2$ with good approximation

Note 2:

Φ is applied to h-value of both streams, therefore it can be easily used for a mixed materials of construction when $\Phi_1 \neq \Phi_2$



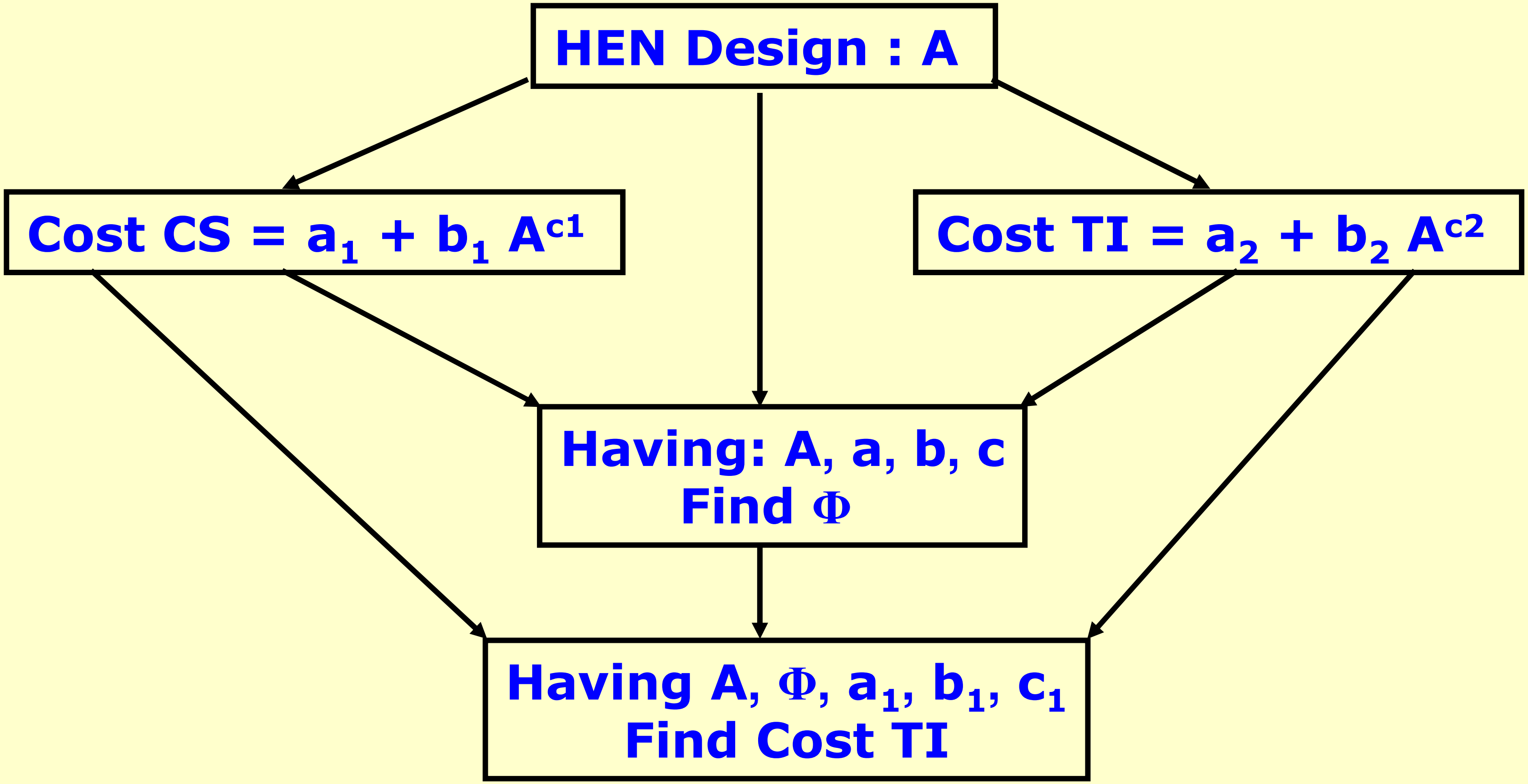
$h_1 \longrightarrow \Phi_1 h_1$

$h_2 \longrightarrow \Phi_2 h_2$

$$Cost\ TI = a_1 + b_1\left[\frac{Q}{\Delta T_{LM}}\left(\frac{1}{\Phi_1 h_1} + \frac{1}{\Phi_2 h_2}\right)\right]^{c_1}$$

(by CS cost law)

Summary



HEN Design : A

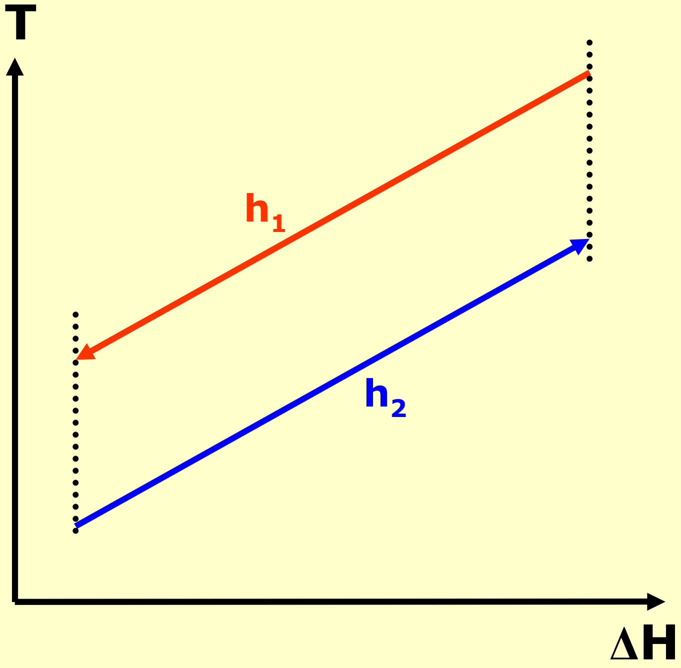
Cost CS = $a_1 + b_1 A^{c1}$

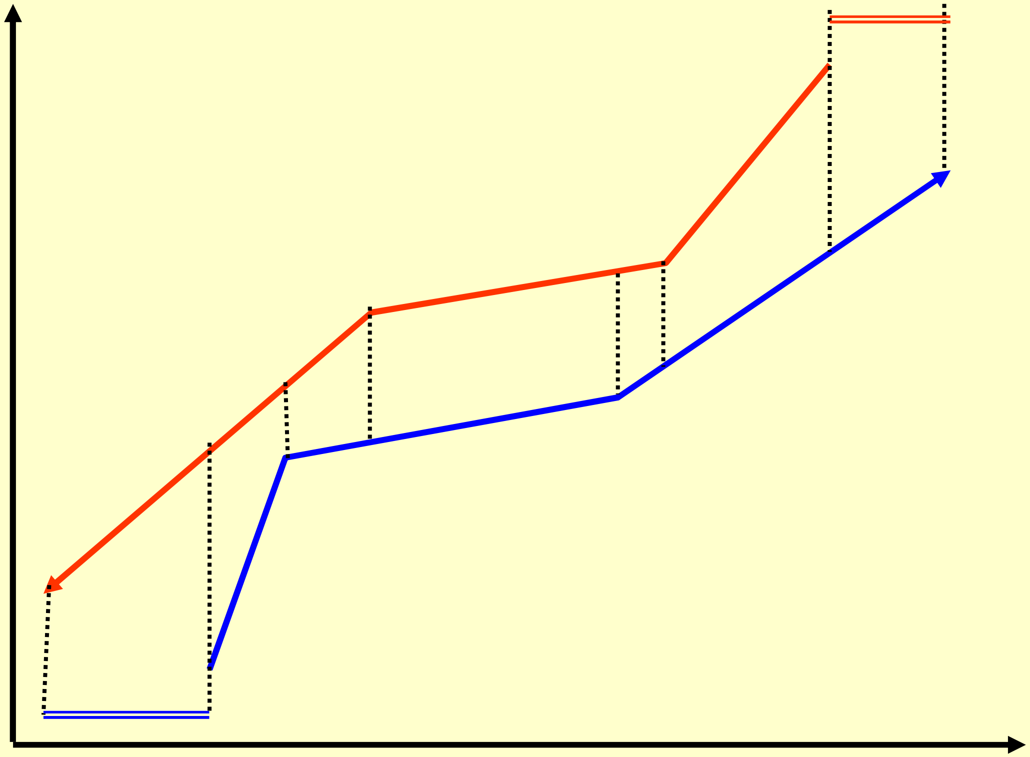
Cost TI = $a_2 + b_2 A^{c2}$

Having: A, a, b, c
Find Φ

Having A, Φ, a_1, b_1, c_1
Find Cost TI

All very well for single exchanger, what about whole network?





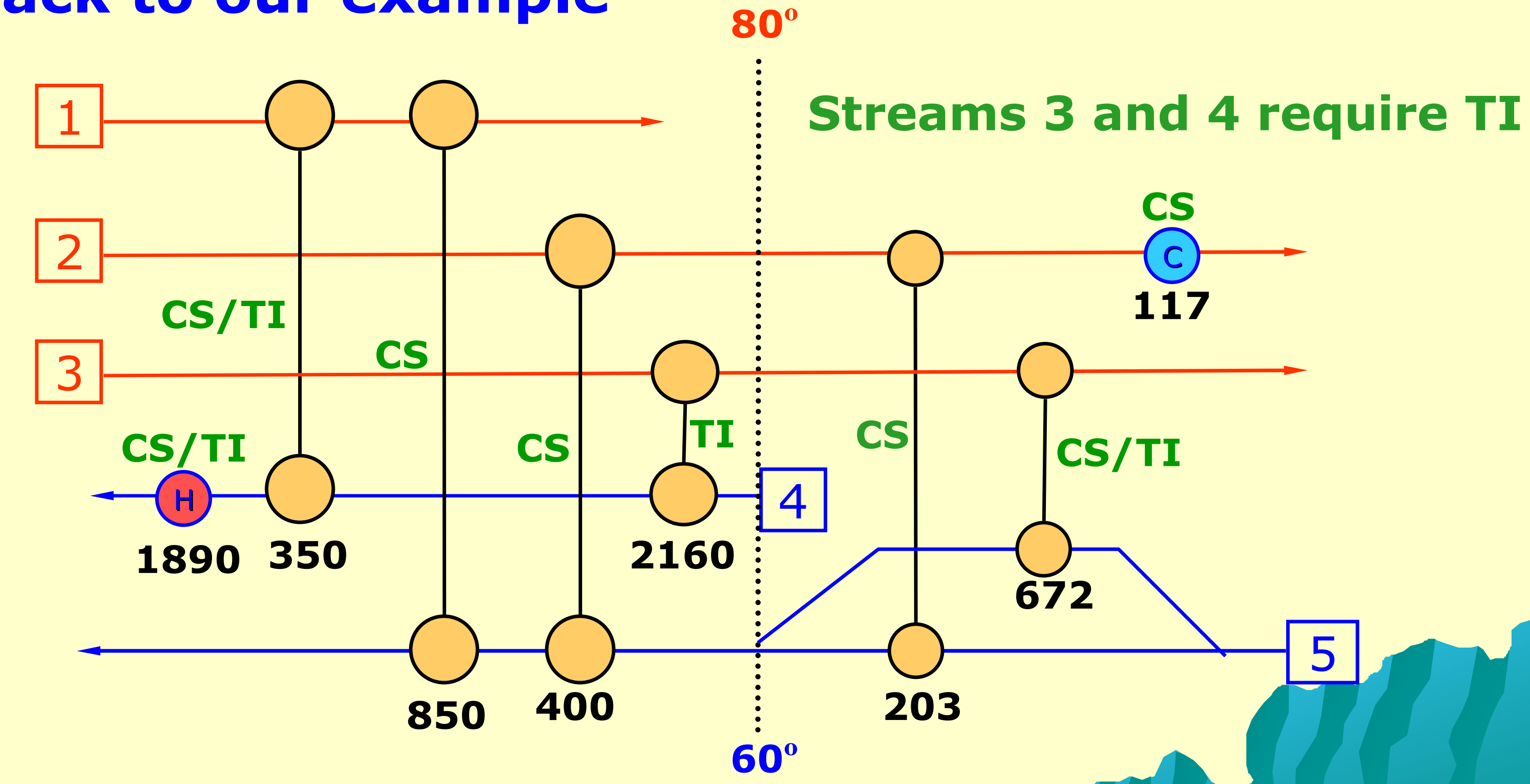
$$A = \frac{1}{(\Delta T_{LM})}\left[\frac{q_1}{h_1} + \frac{q_2}{h_2}\right]$$

$$A_{\min} = \sum_i \frac{1}{(\Delta T_{LM})_i}\left[\sum_j \frac{q_j}{h_j}\right]_i$$

Using strong similarity we can write

$$(A_{\min})_{fudge} = \sum_i \frac{1}{(\Delta T_{LM})_i} \left[\sum_j \frac{q_j}{\Phi_j h_j} \right]_i$$

Back to our example



Streams 3 and 4 require TI

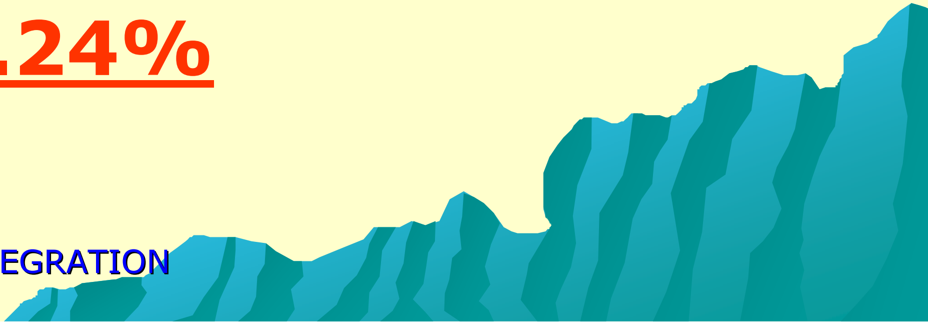
Apply Φ to h-values of streams 3 and 4

$$\Phi_3 = \Phi_4 = \left[\left(\frac{750}{4407} \right)^{\frac{1}{0.81}} \right] = 0.1123$$

Target Capital cost = $ 1,894,766

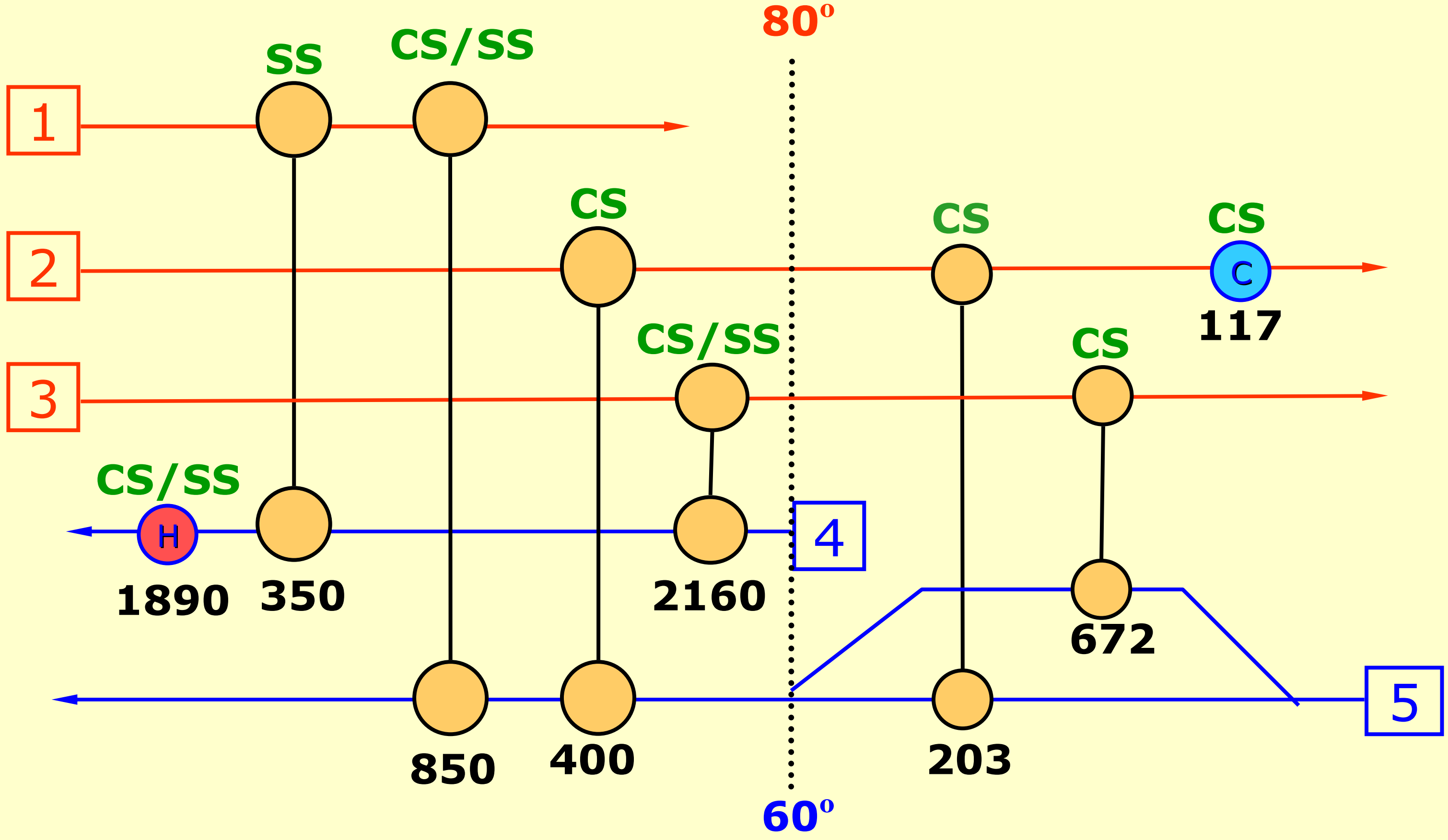
Actual Capital cost = $ 1,871,506

<u>Error = +1.24%</u>



Another Example:

This time assume streams 1 and 4 require SS



Network Cost = $ 928,724

$$\Phi_1 = \Phi_4 = \left[\left(\frac{750}{1644}\right)^{\frac{1}{0.81}}\right] = 0.3795$$

Target Capital Cost = $ 891,293

Actual Capital Cost = $ 928,724

Error = -4%

Procedure

Stream Data including Materials

↓

Select base case

↓

Cost 1 = $a_1+b_1A^{c1}$, Cost 2 = $a_2+b_2A^{c2}$

↓

Determine Φ for special streams

↓

$$(A_{\min})_{\text{fudge}} = \sum_i \frac{1}{(\Delta T_{LM})_i}\left[\sum_j \frac{q_j}{\Phi_j h_j}\right]_i$$

↓

Capital Cost Target of Network in Mixed Materials
= f (a_1, b_1, c_1, A_{min}, N_{min} or N_{shell})

Homework 2

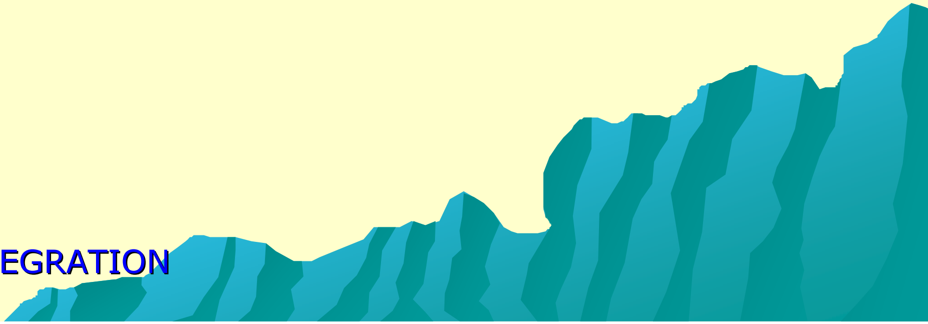
Following assignment is due to be returned in two weeks.

LECTURE 12

Multiple Utilities

There are different utilities that can be used in process such as:

- **Furnace**
- **Steam at different levels, (VLP, LP, MP, HP, VHP)**
- **Hot oil circuit**
- **Cooling water**
- **Air**
- **Refrigeration cycles**



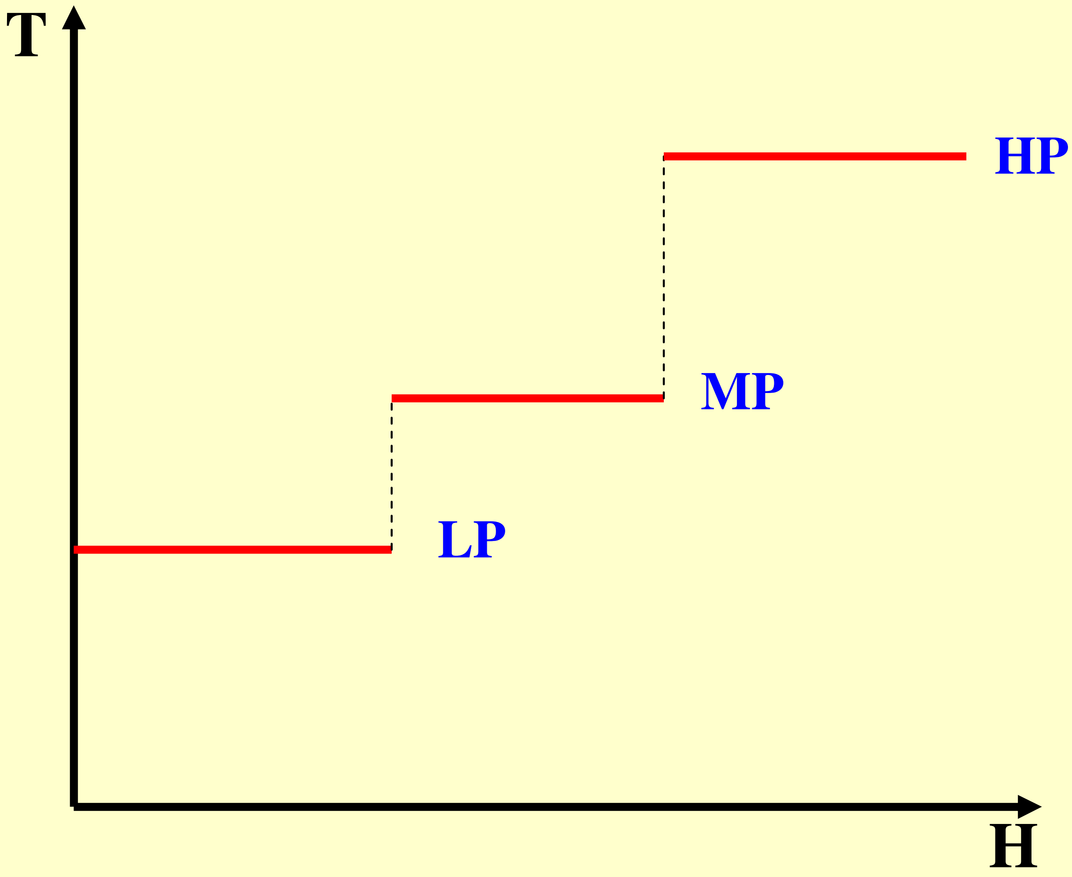
Hot Utilities:

We want to USE at the LOWEST level and GENERATE at the HIGHEST level

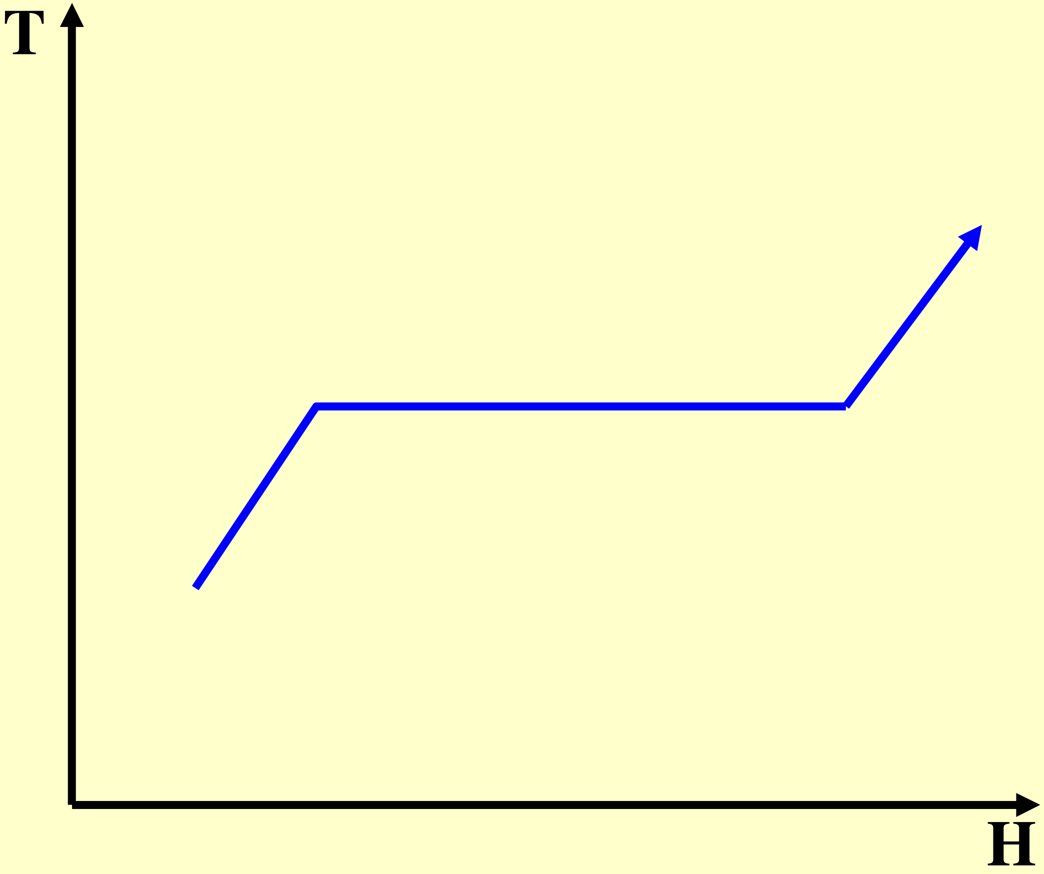
Cold Utilities:

We want to USE at the HIGHEST level and GENERATE at the LOWEST level

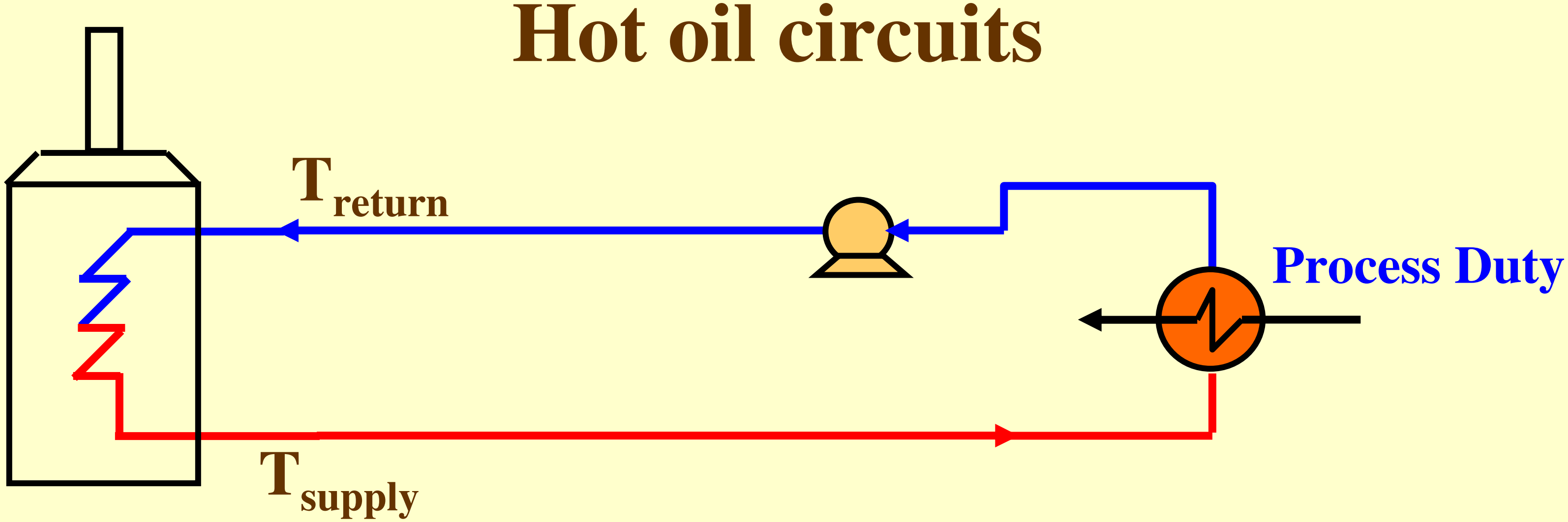
We can show multiple steam levels on a T-H diagram:

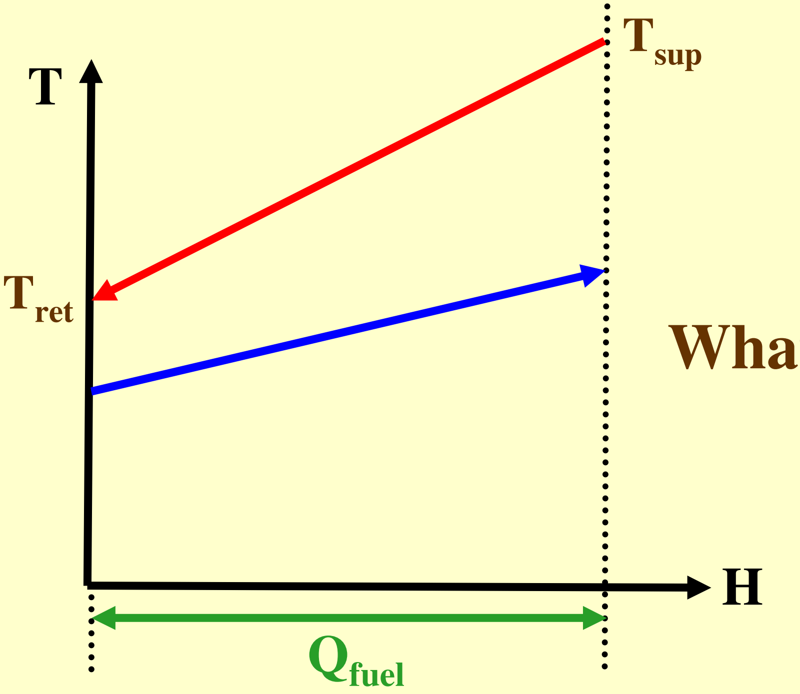


Steam generation



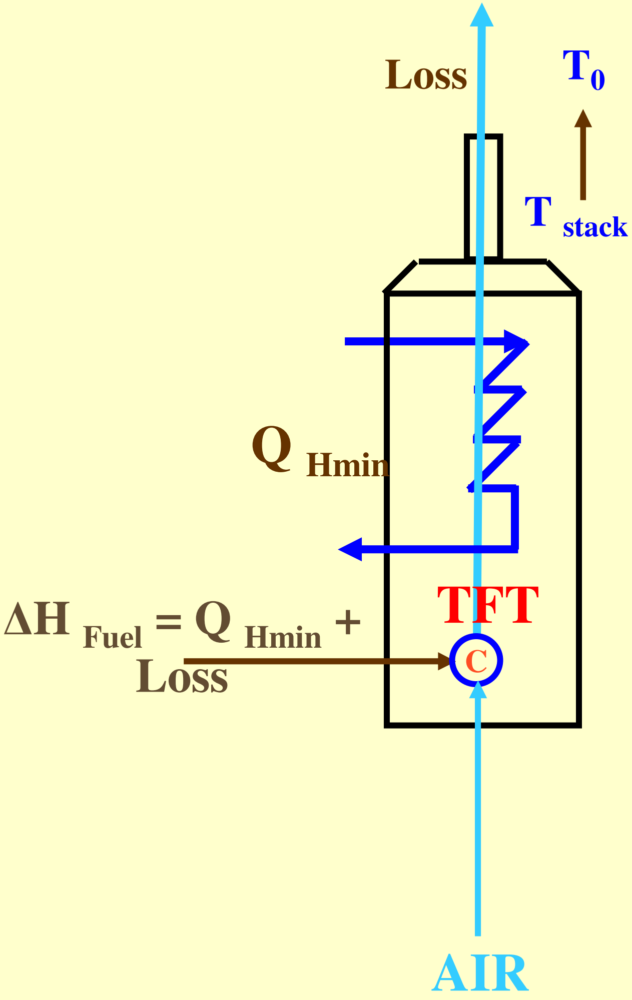
Hot oil circuits

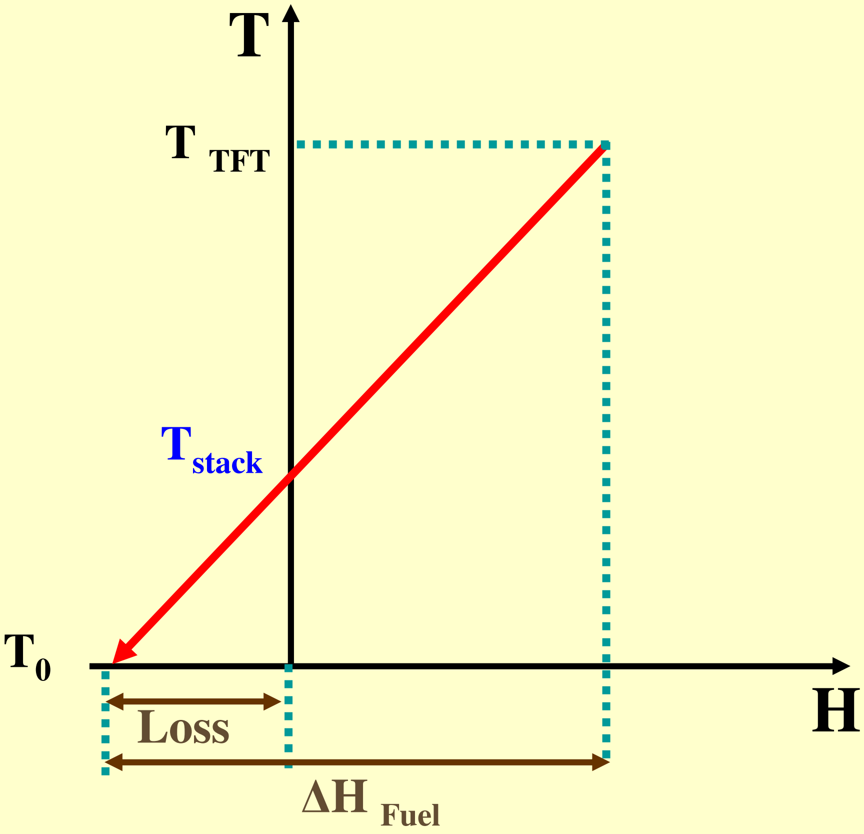




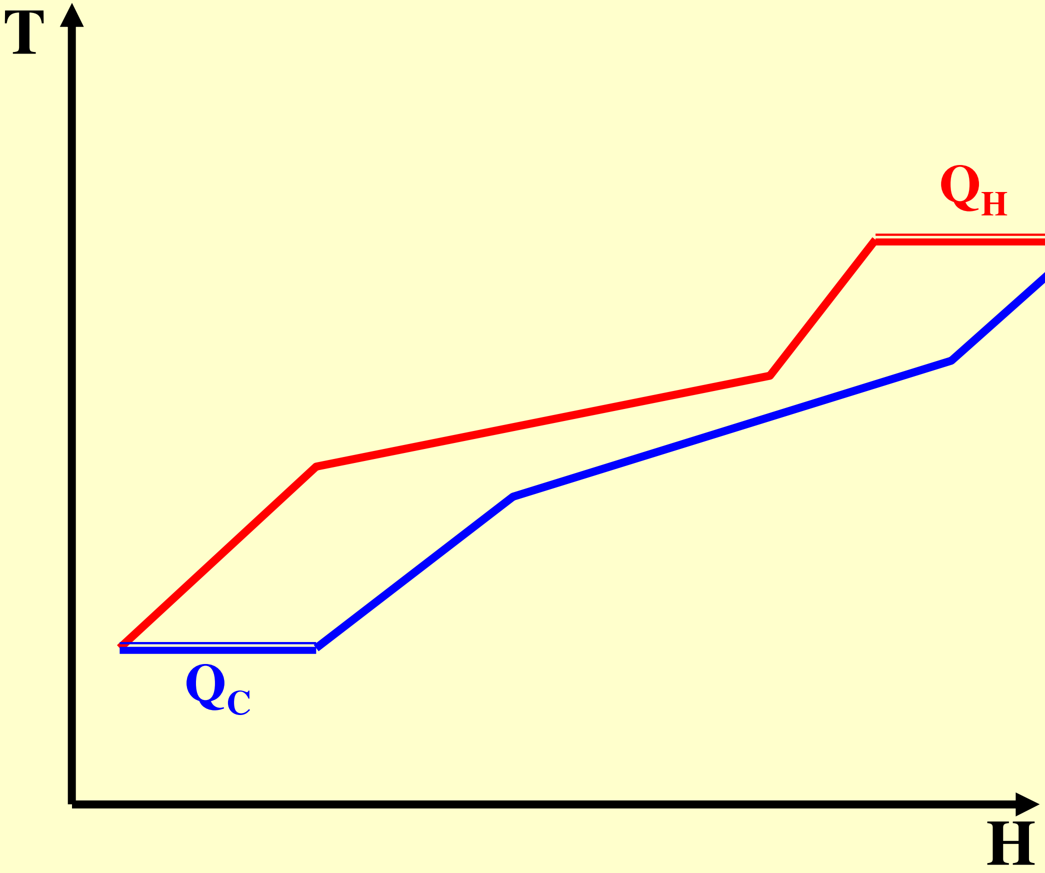
What is the minimum hot oil flowrate?

Simple Furnace Model



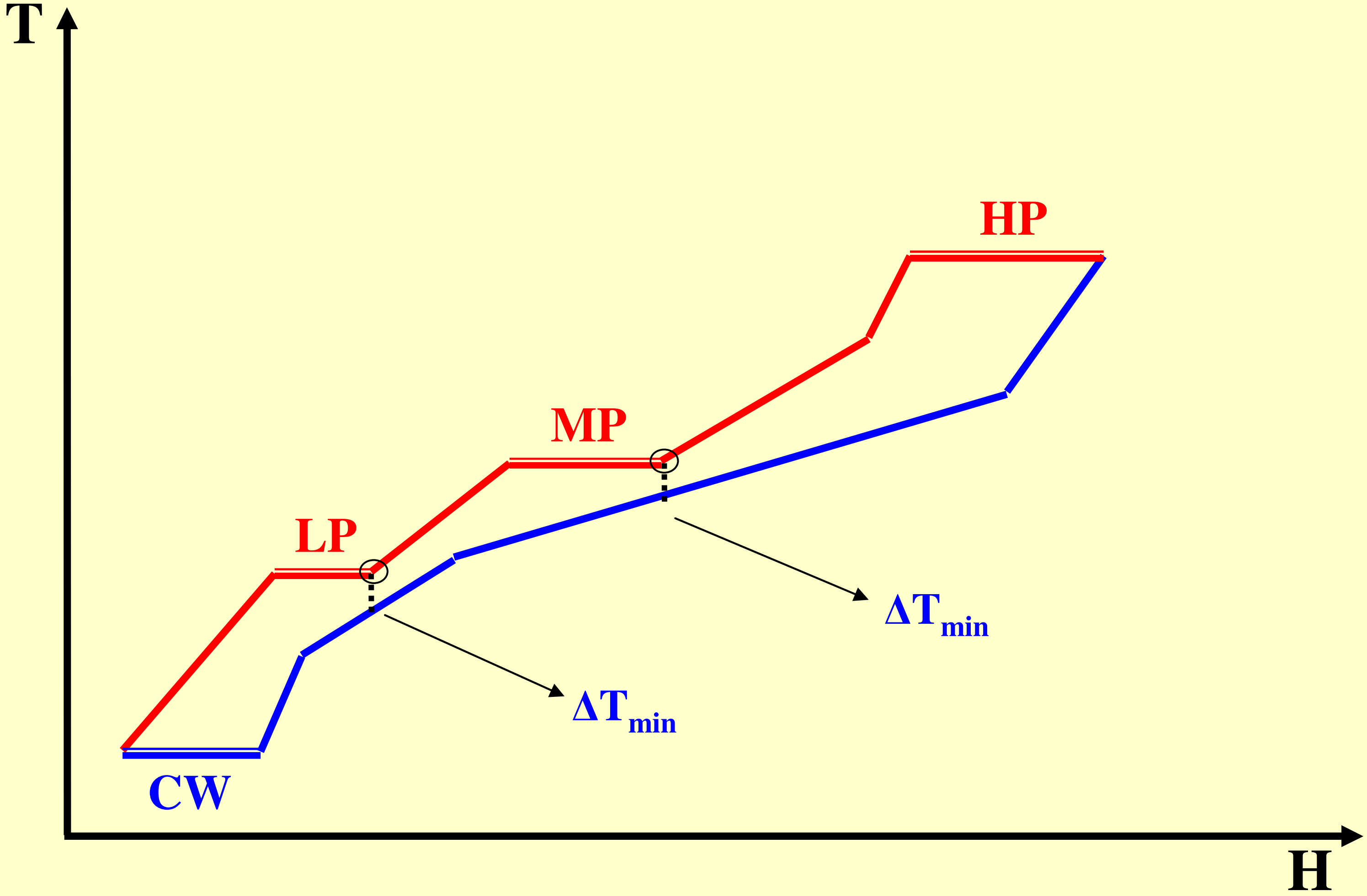


How do we target for the best mix of utilities?



Up to now, we use hottest hot utility and coldest cold utility

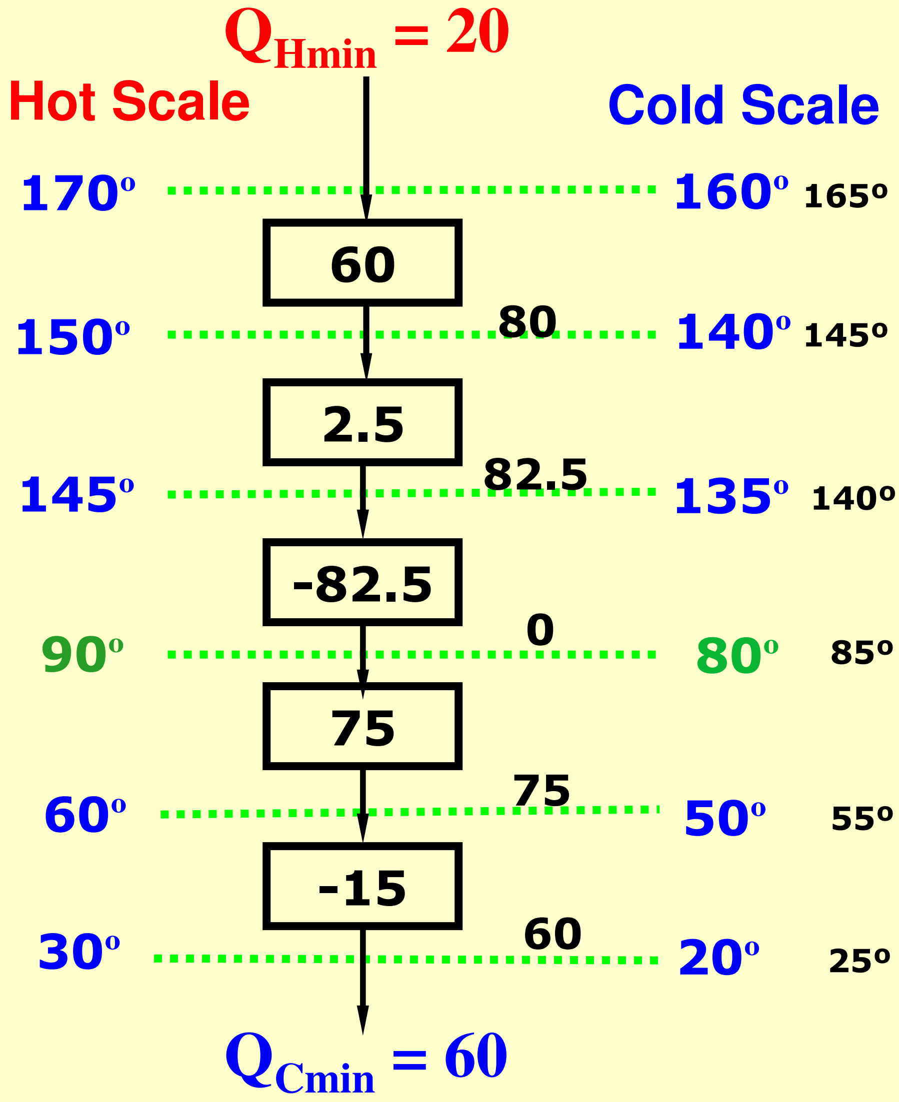
Composite curves with multiple utilities



The additional utility causes utility pinch

- **Composite Curves are not ideal tool for utility selection**
- **Let’s introduce Grand Composite Curve (GCC)**

Remember the Cascade Diagram?



$Q_{Hmin} = 20$

Hot Scale **Cold Scale**

170° 160°

60

150° 80 140°

2.5

145° 82.5 135°

-82.5

90° 0 80°

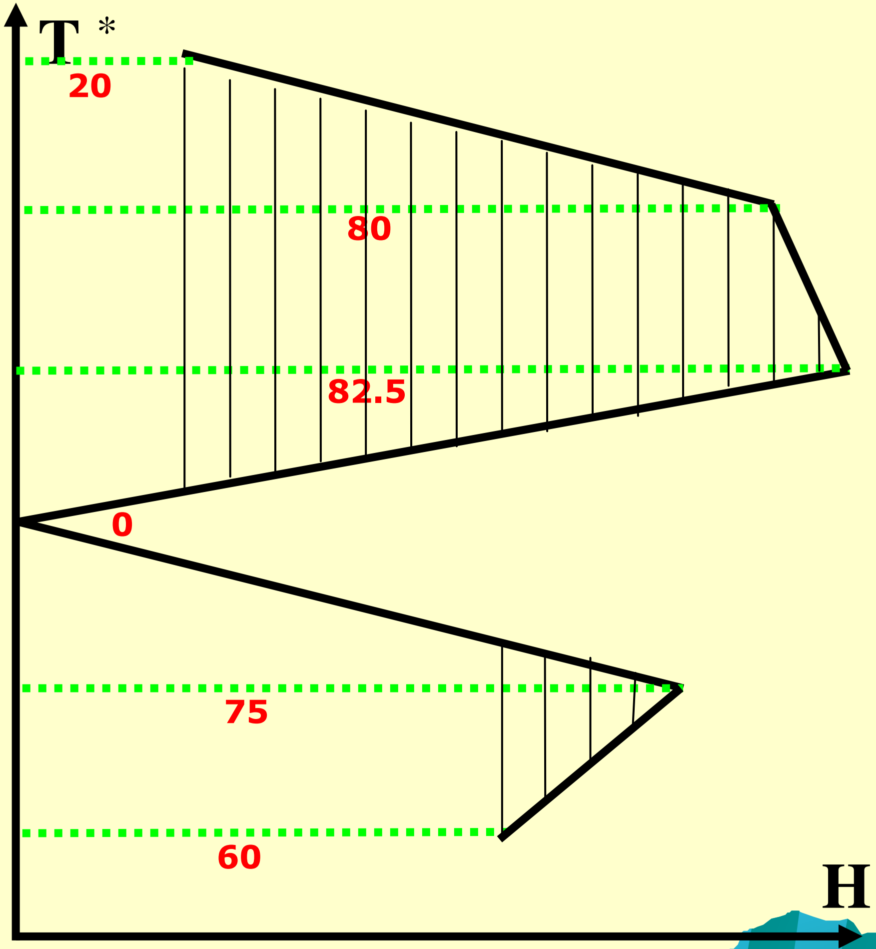
75

60° 75 50°

-15

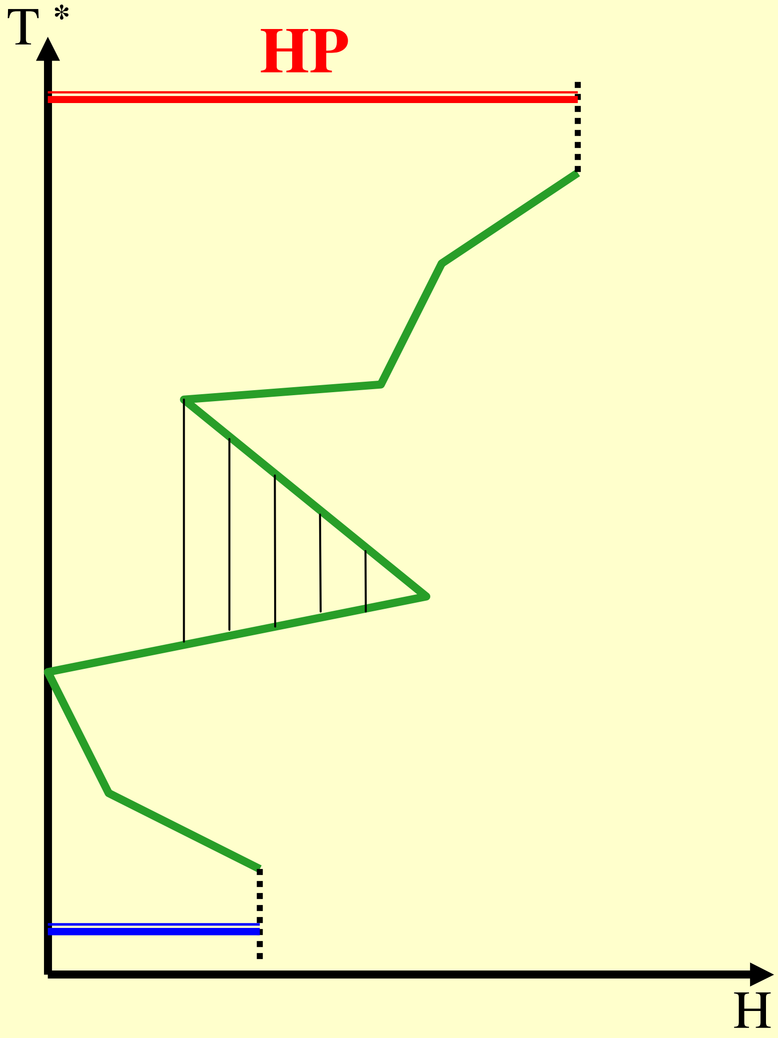
30° 60 20°

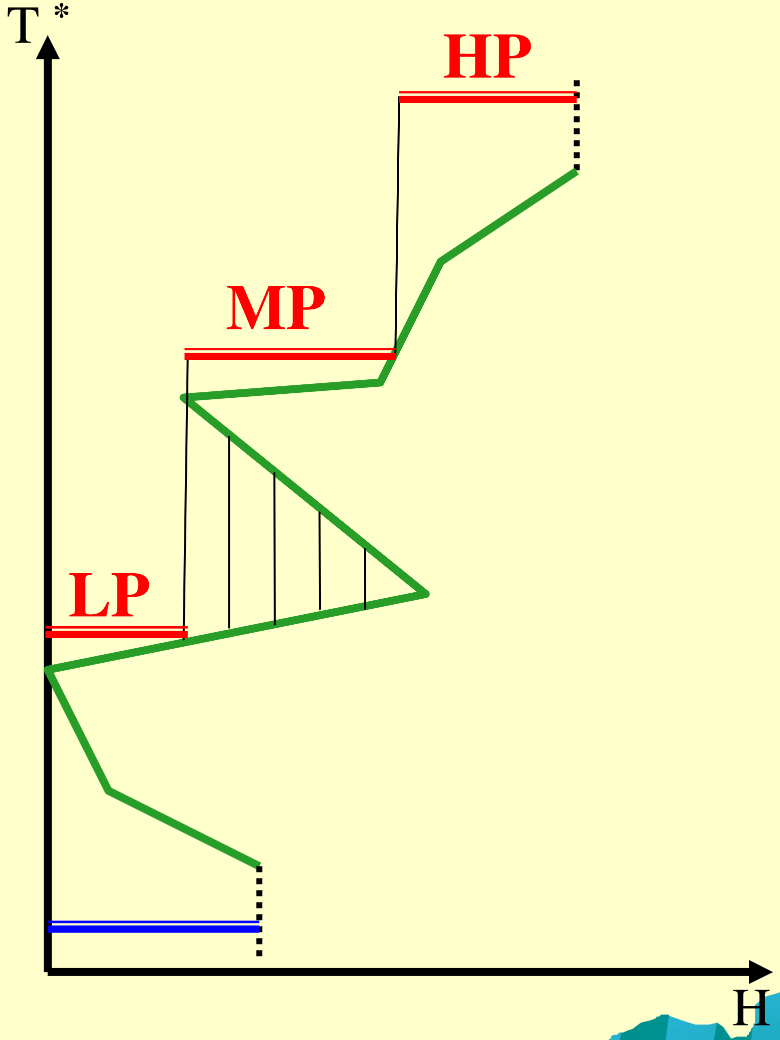
$Q_{Cmin} = 60$



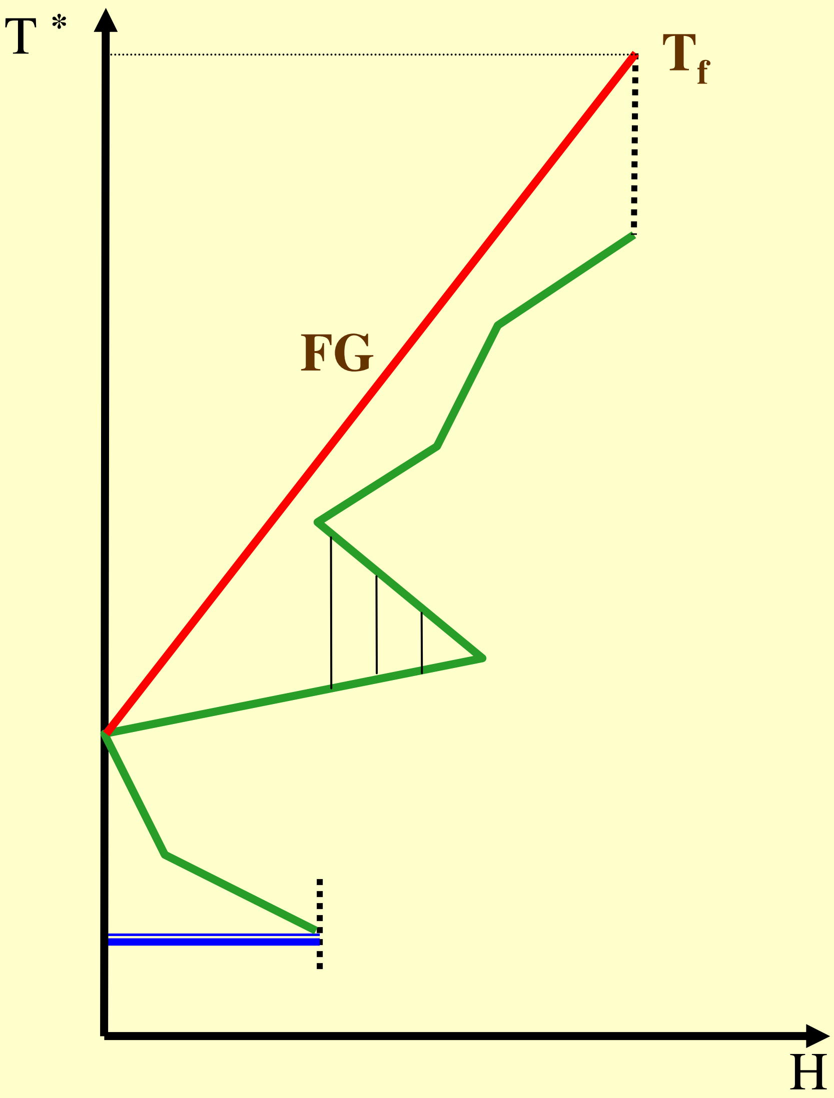
The Grand Composite Curve gives the hot and cold utility requirements of the process both in ENTHALPY and TEMPERATURE

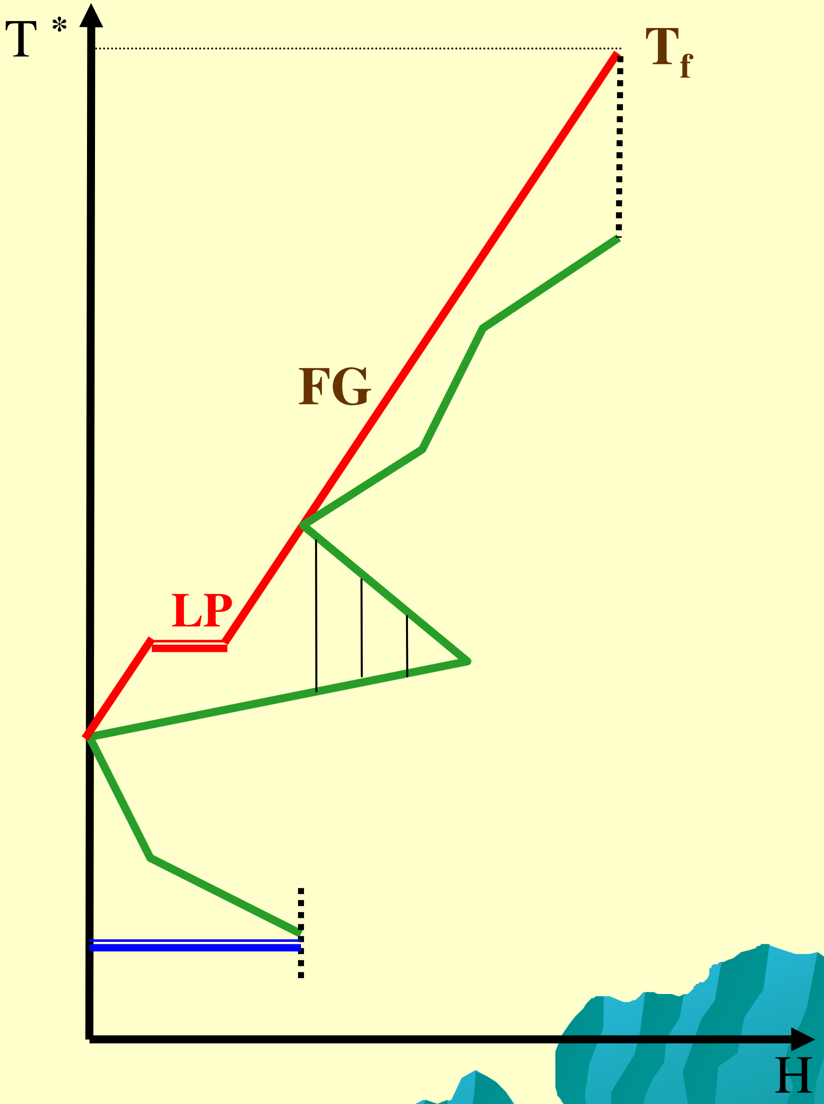
Now we can easily place multiple utilities –Constant Temp.





Placing variable temperature utilities

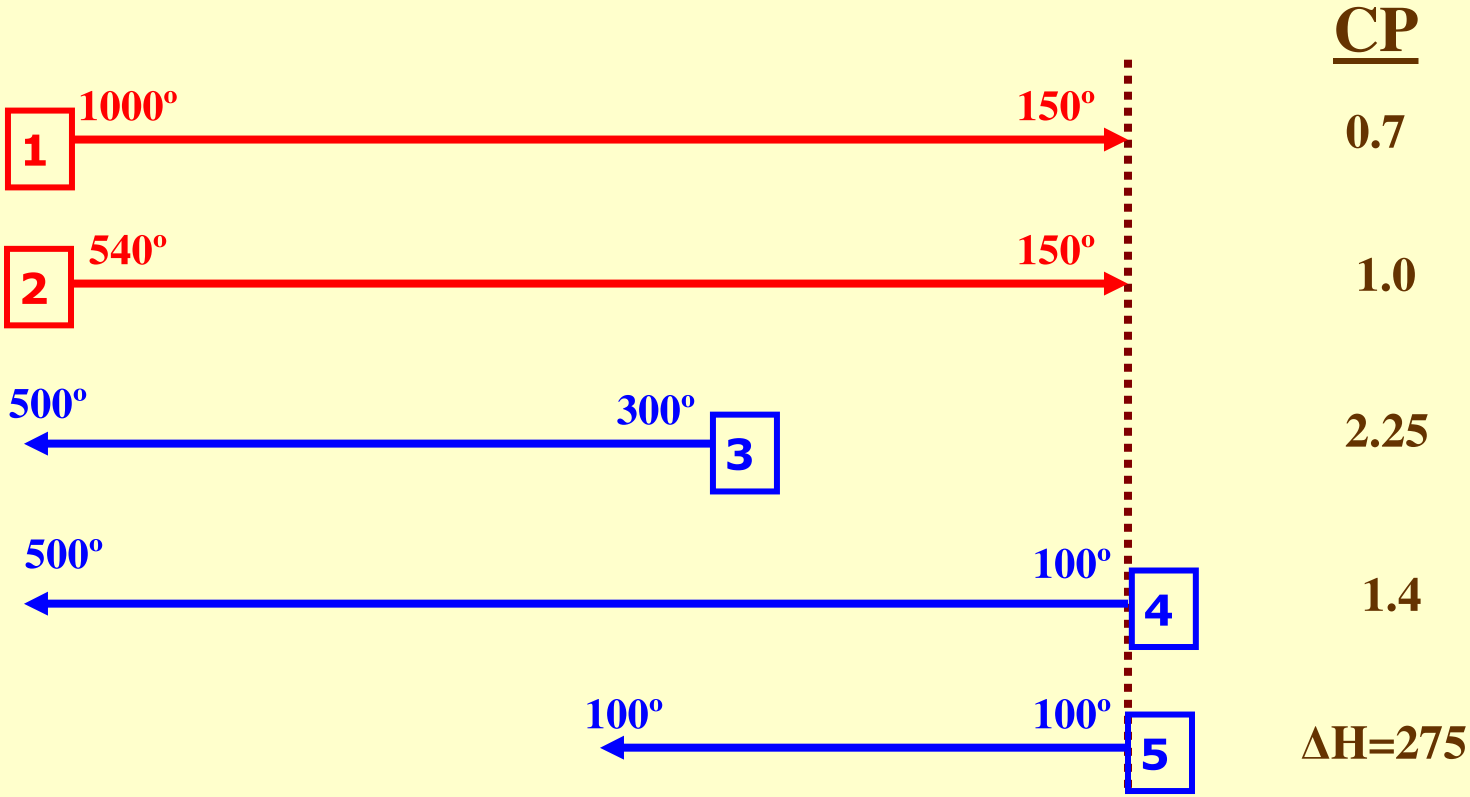




LECTURE 13

Process Utility Interface

Hot End Stream Data



CP

1 1000° 150° 0.7

2 540° 150° 1.0

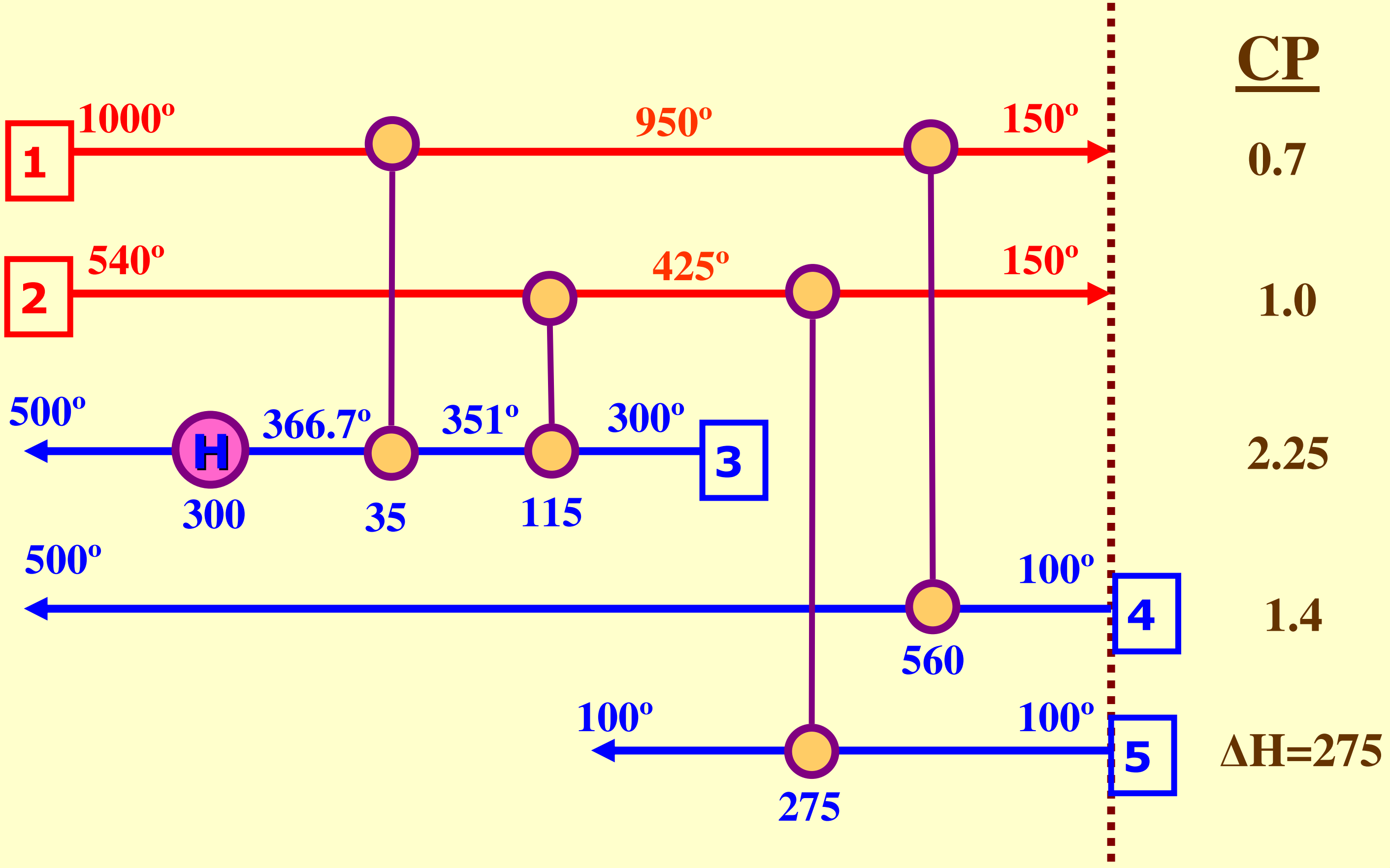
3 300° 500° 2.25

4 100° 500° 1.4

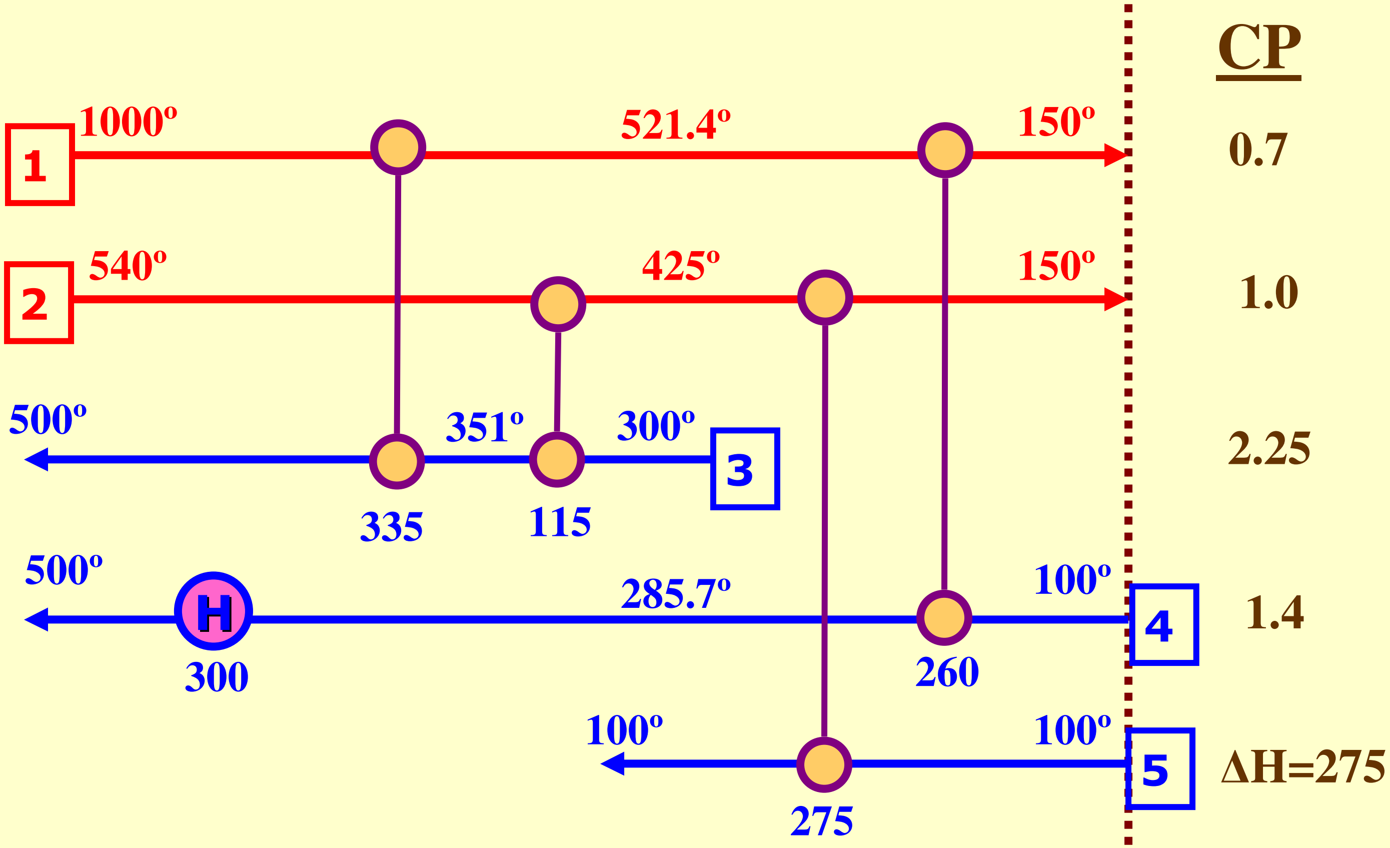
5 100° 100° $\Delta H = 275$

$Q_{Hmin} = 300$

Design No. 1

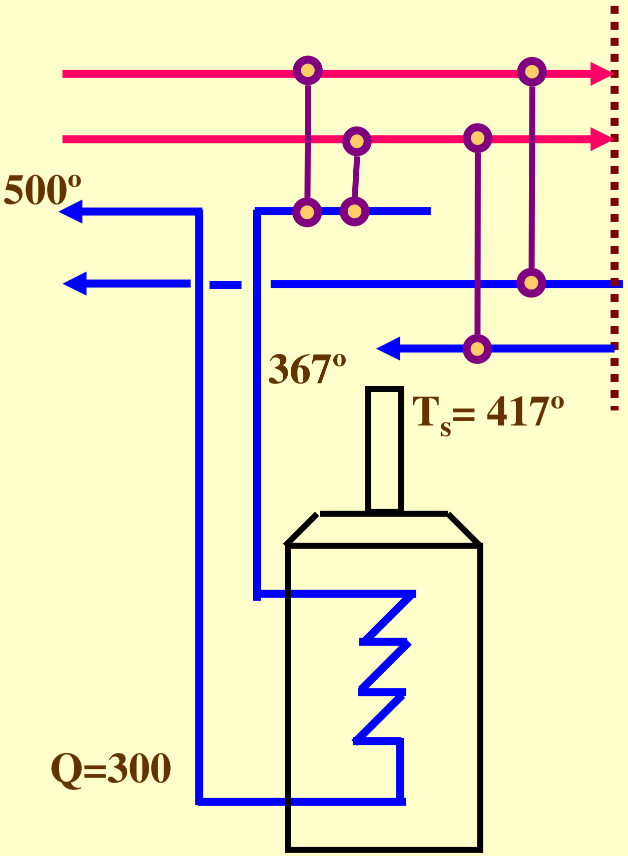

CP
1
1000°
950°
150°
0.7
2
540°
425°
150°
1.0
500°
H
366.7°
351°
300°
3
300
35
115
2.25
500°
100°
4
560
1.4
100°
100°
5
275
ΔH=275

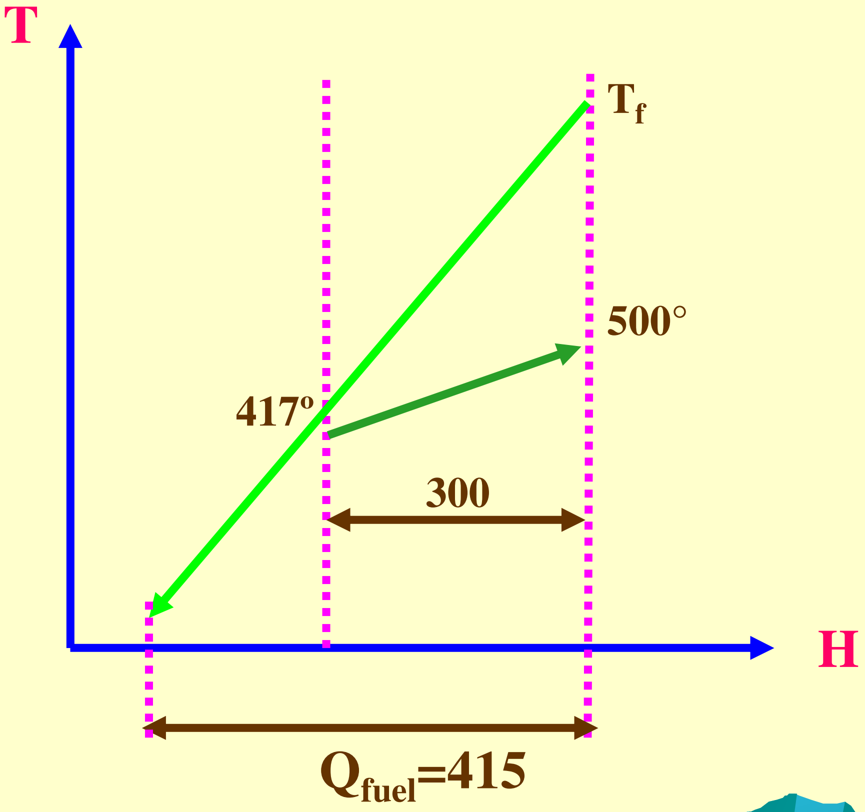
Design No. 2


CP
1
1000º
521.4º
150º
0.7
2
540º
425º
150º
1.0
500º
351º
300º
3
2.25
335
115
500º
H
285.7º
100º
4
1.4
300
260
100º
100º
5
ΔH=275
275

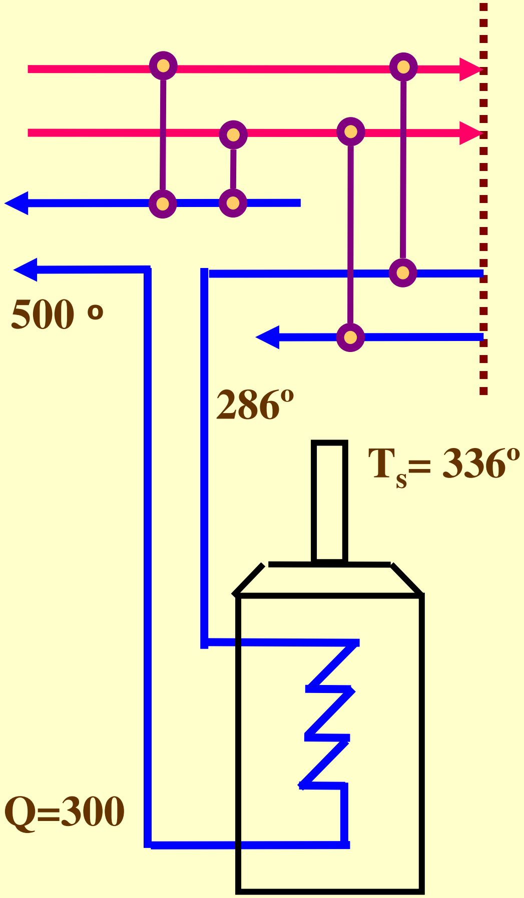
There seems little to choose Until we think about the utilities!

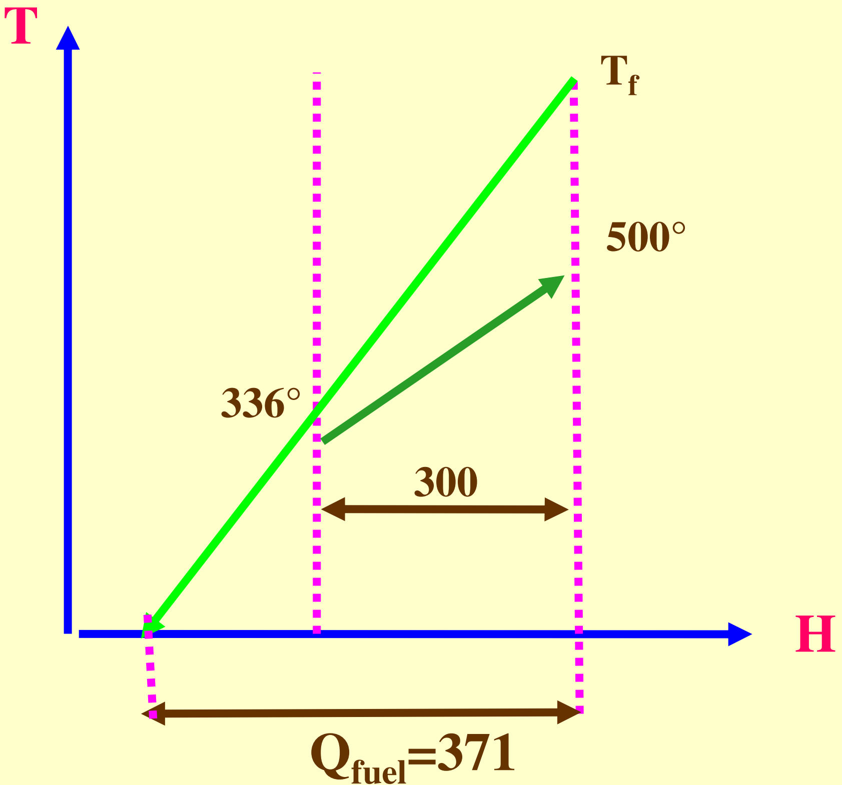
Design No. 1





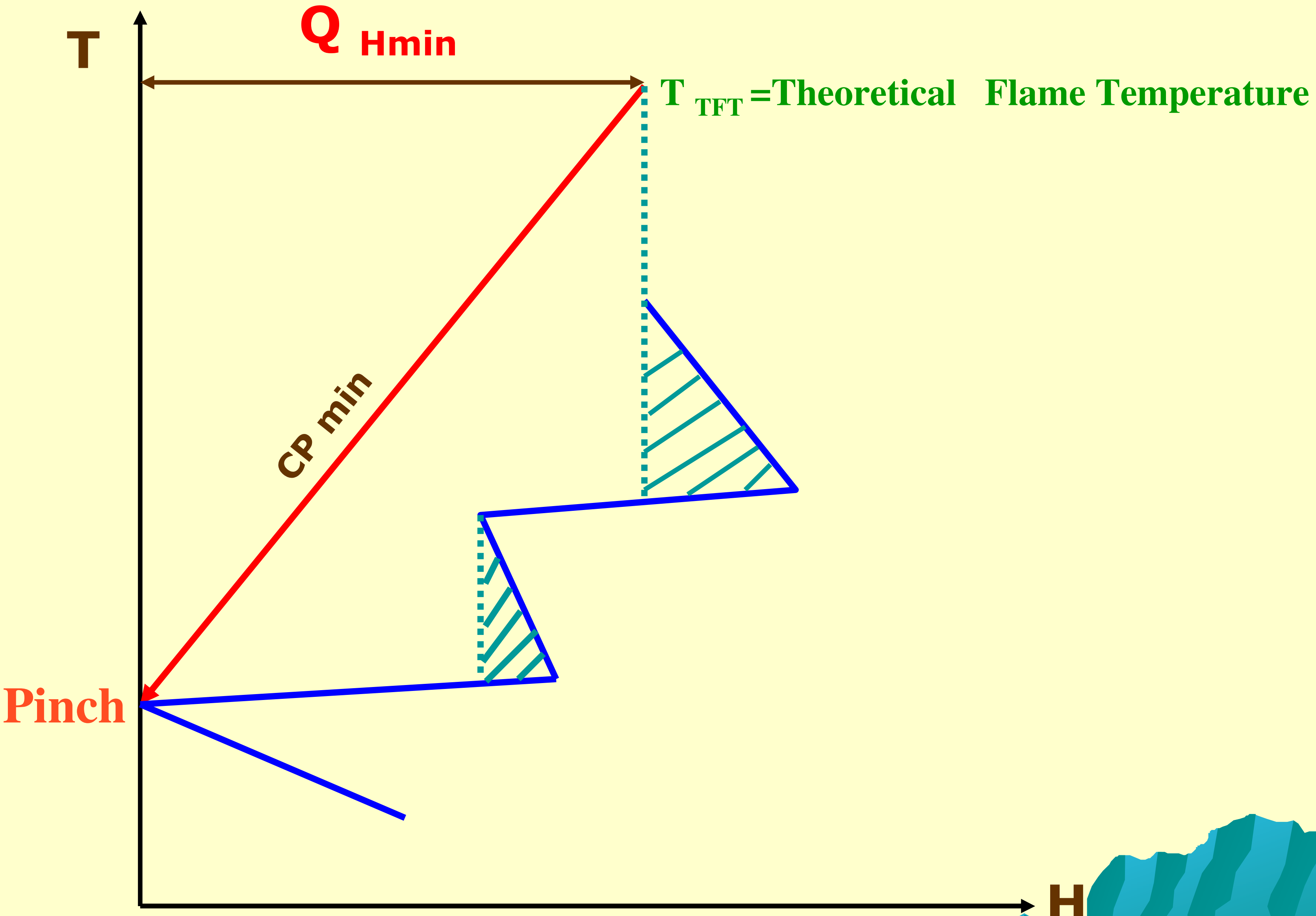
Design No. 2



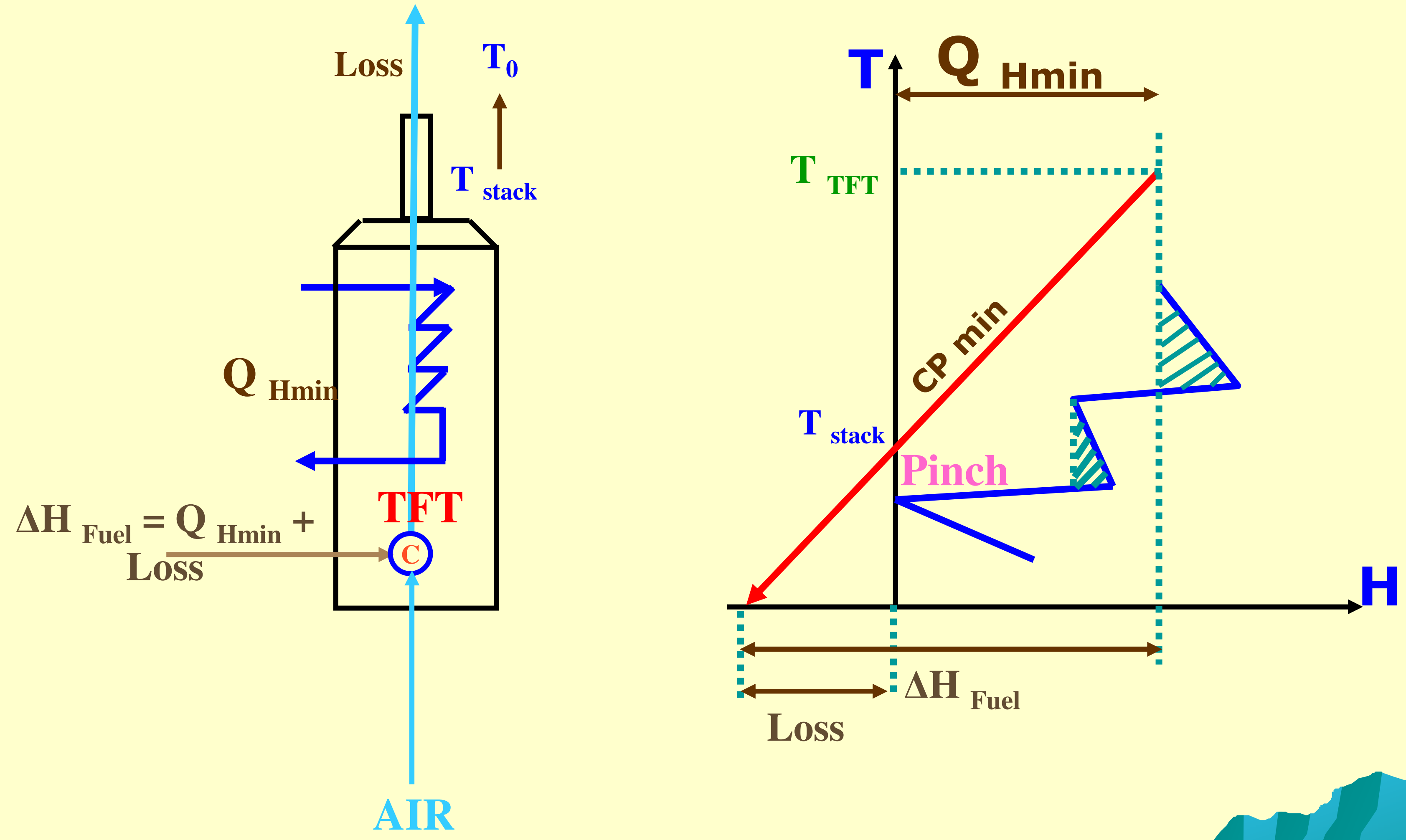


Q_{Hmin} has been achieved in both MER designs, but the furnace efficiency is different

Use the Grand Composite Curve



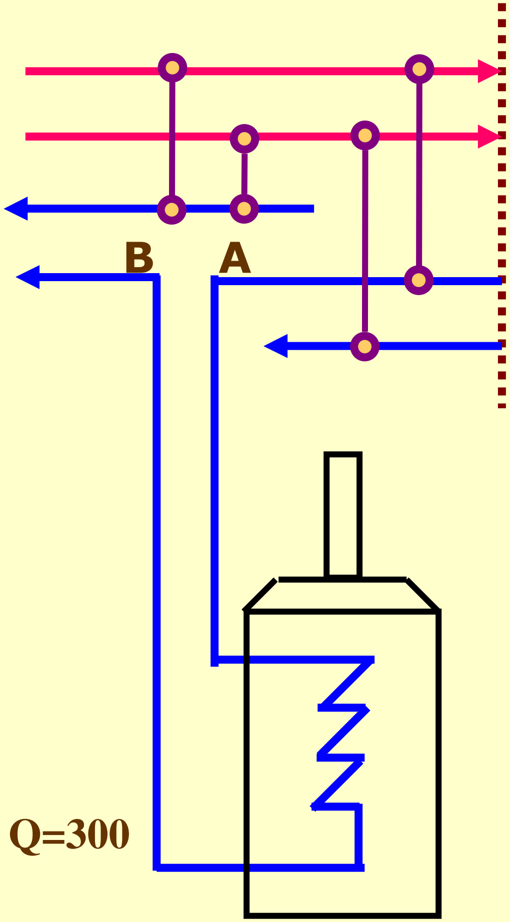
Simple Furnace Model



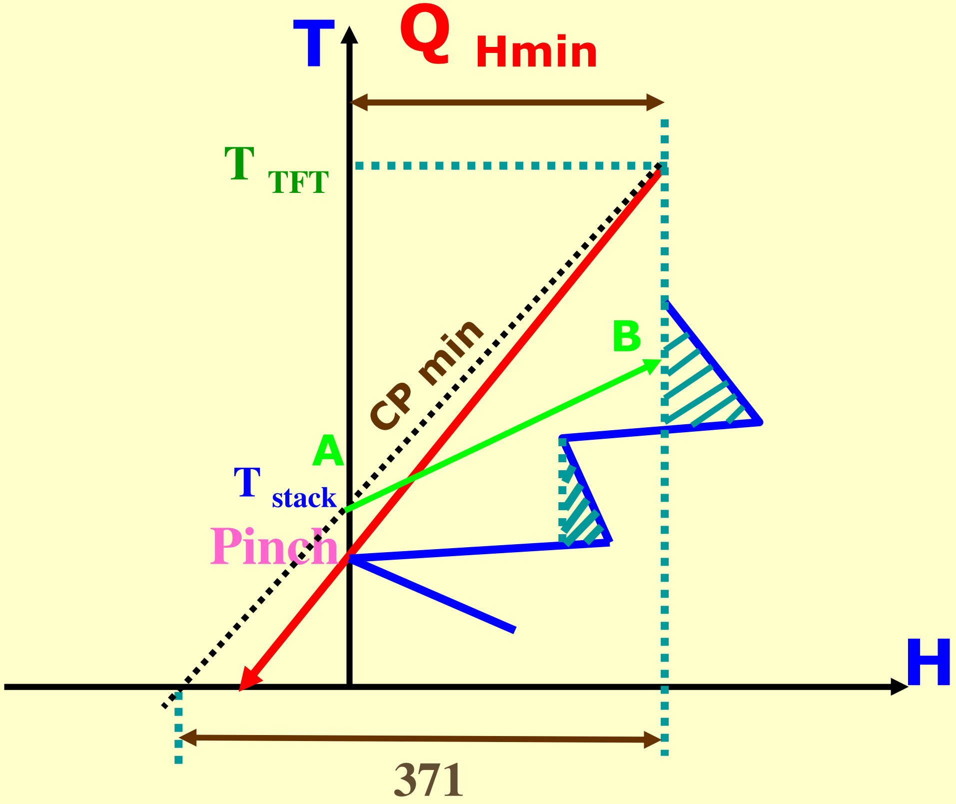
$\Delta H_{Fuel} = Q_{Hmin}$ + Loss

Now we understand what happened

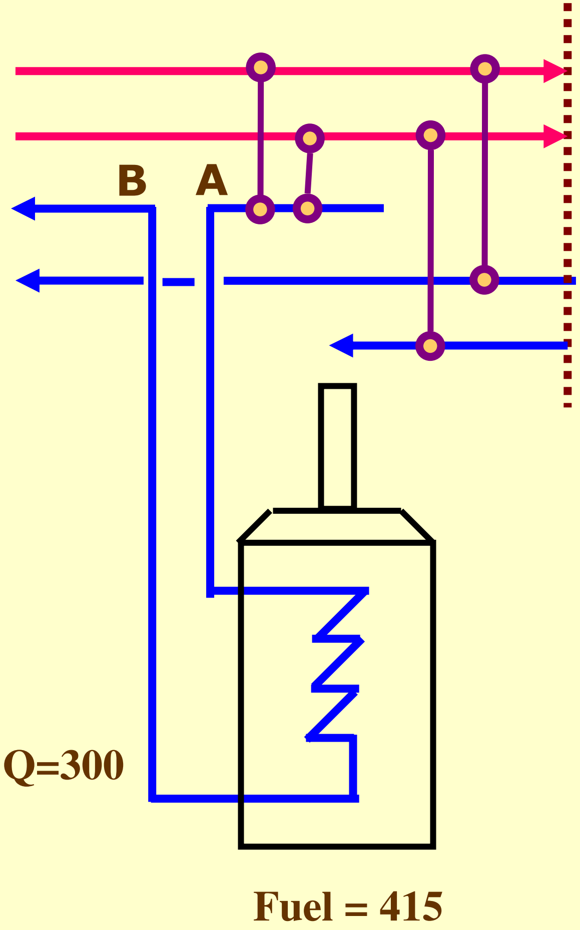
Design No. 2

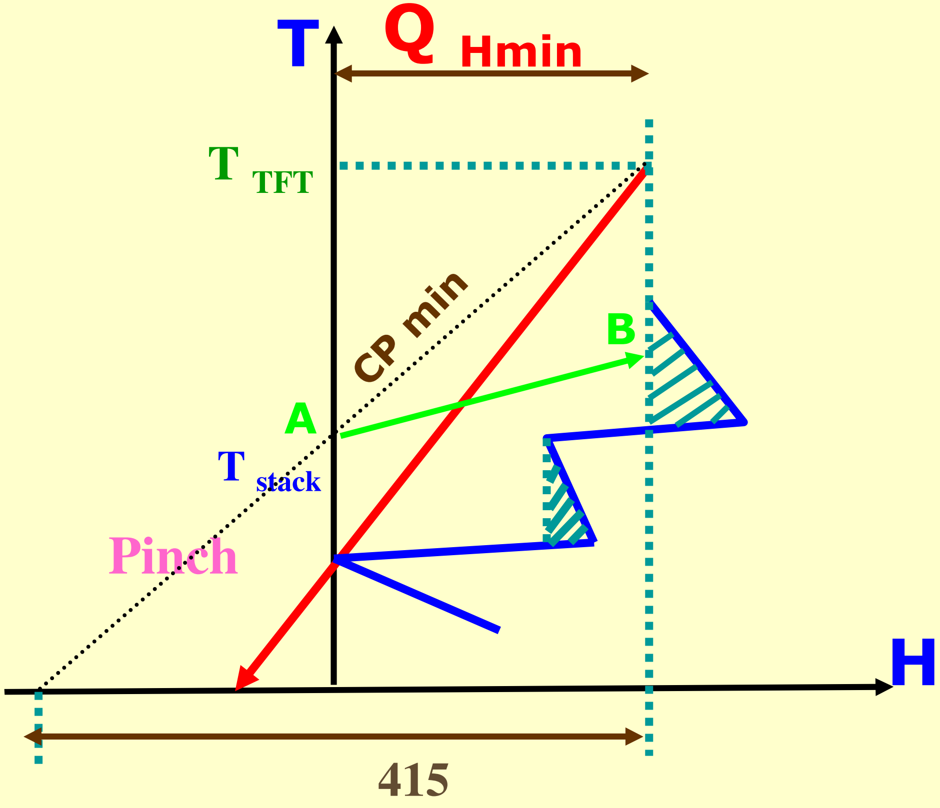


Fuel = 371



Design No. 1

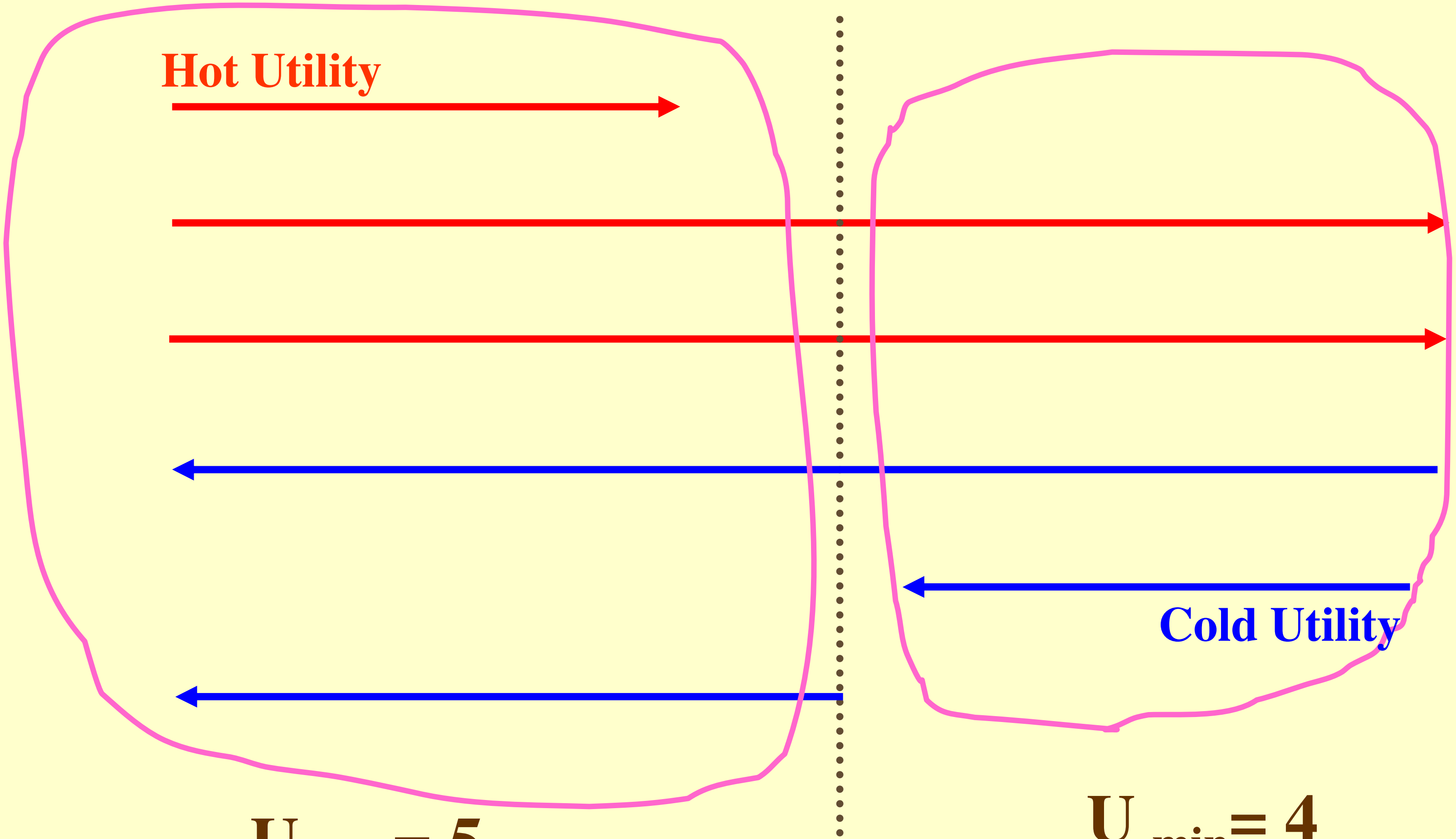




PROCEDURE

1. **Draw Grand Composite Curve**
2. **Determine best utility mix**
3. **Draw “Balanced Grid”**
4. **Design “Balanced Network”**
5. **Convert into HEN + Utilities**

3. Draw "Balanced Grid"

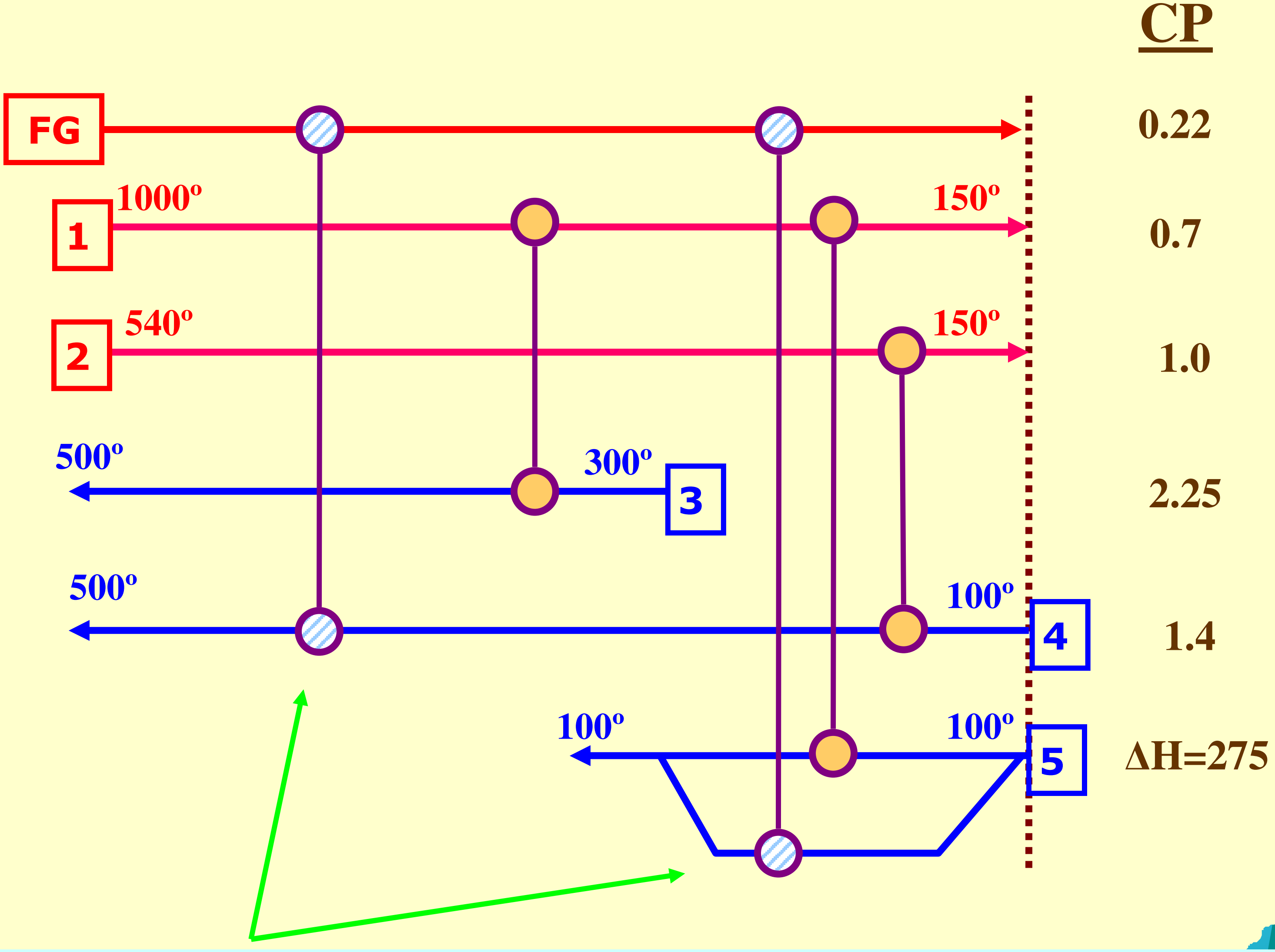


$U_{min} = 5$

$U_{min} = 4$

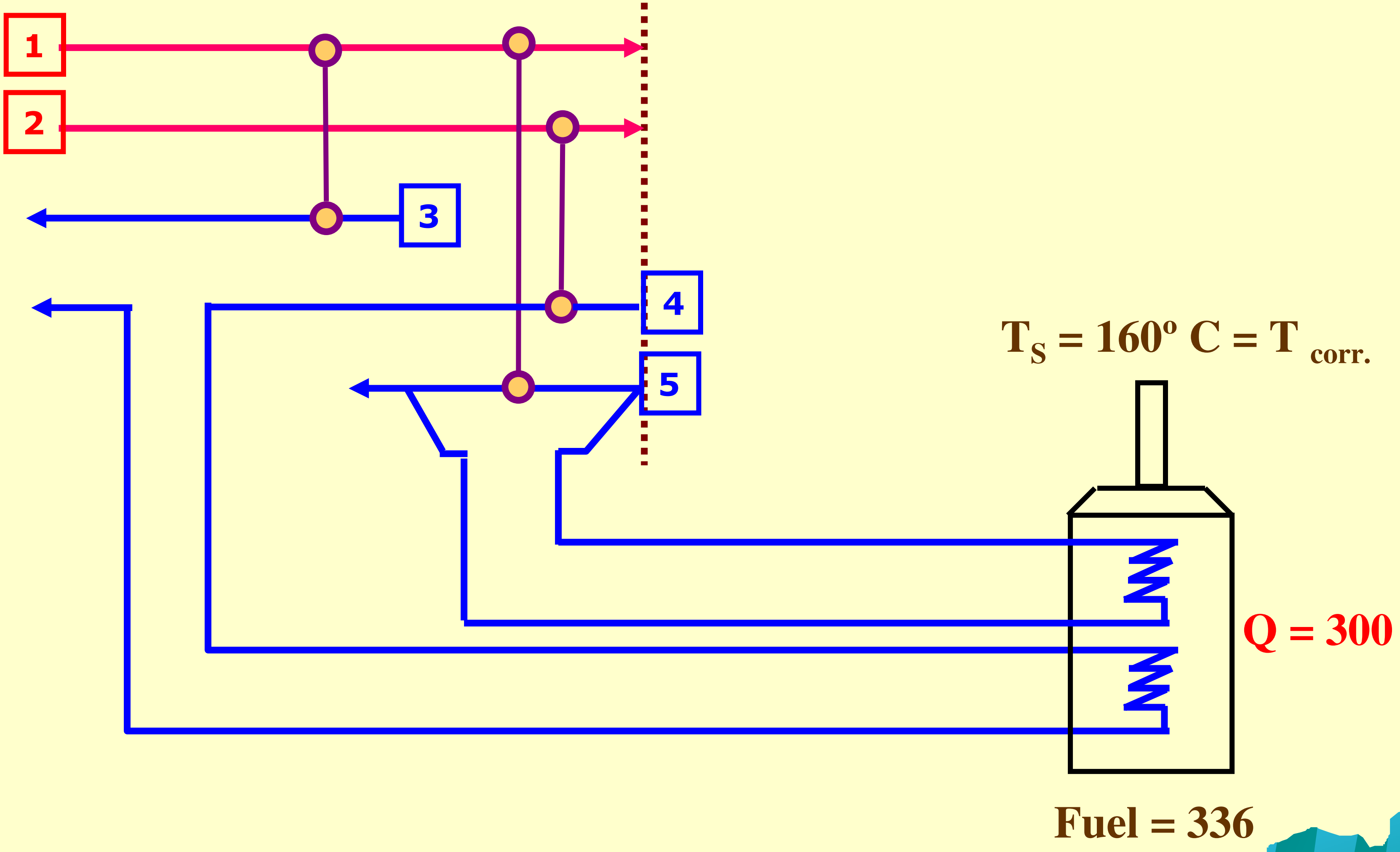
(no further utility)

4. Design “Balanced Network”

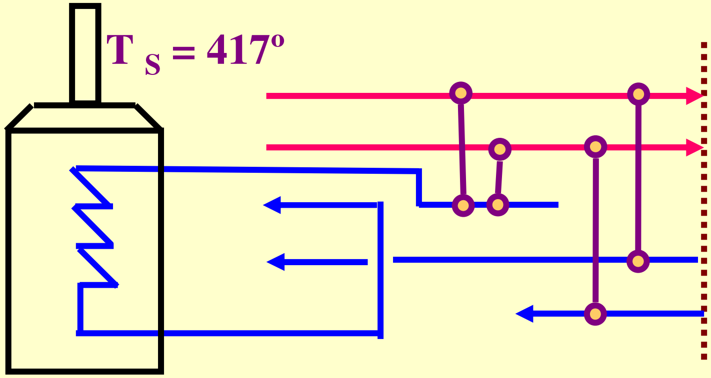


These ‘exchangers” will later trun into furnace coils

5. Convert into HEN + Utilities

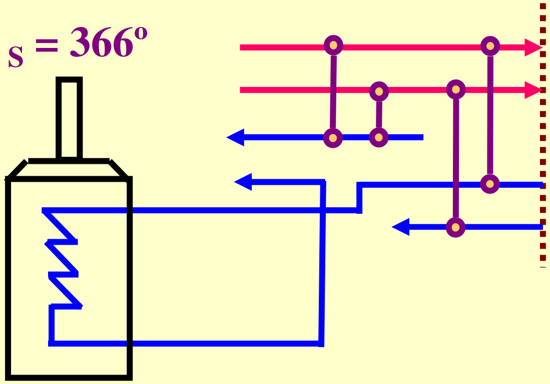


For Comparison



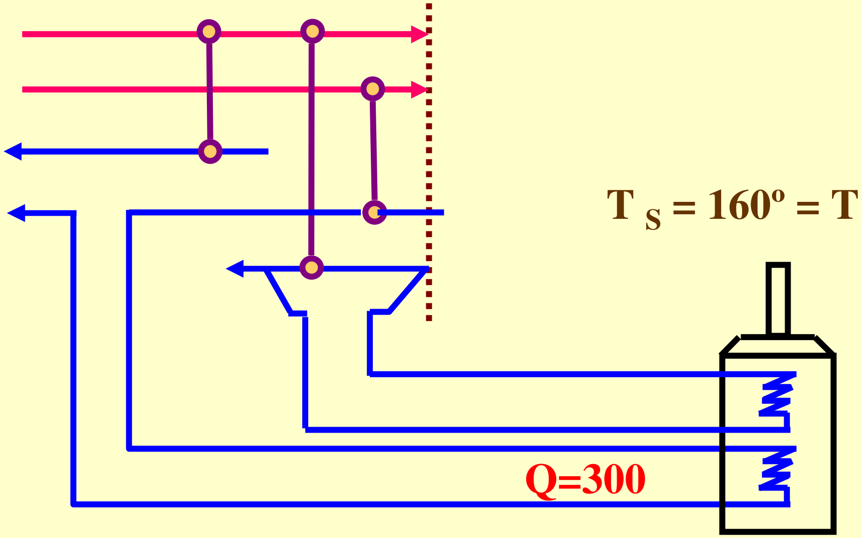
$T_S = 417^o$

Q=300 Fuel = 415



$T_S = 366^o$

Q=300 Fuel = 371



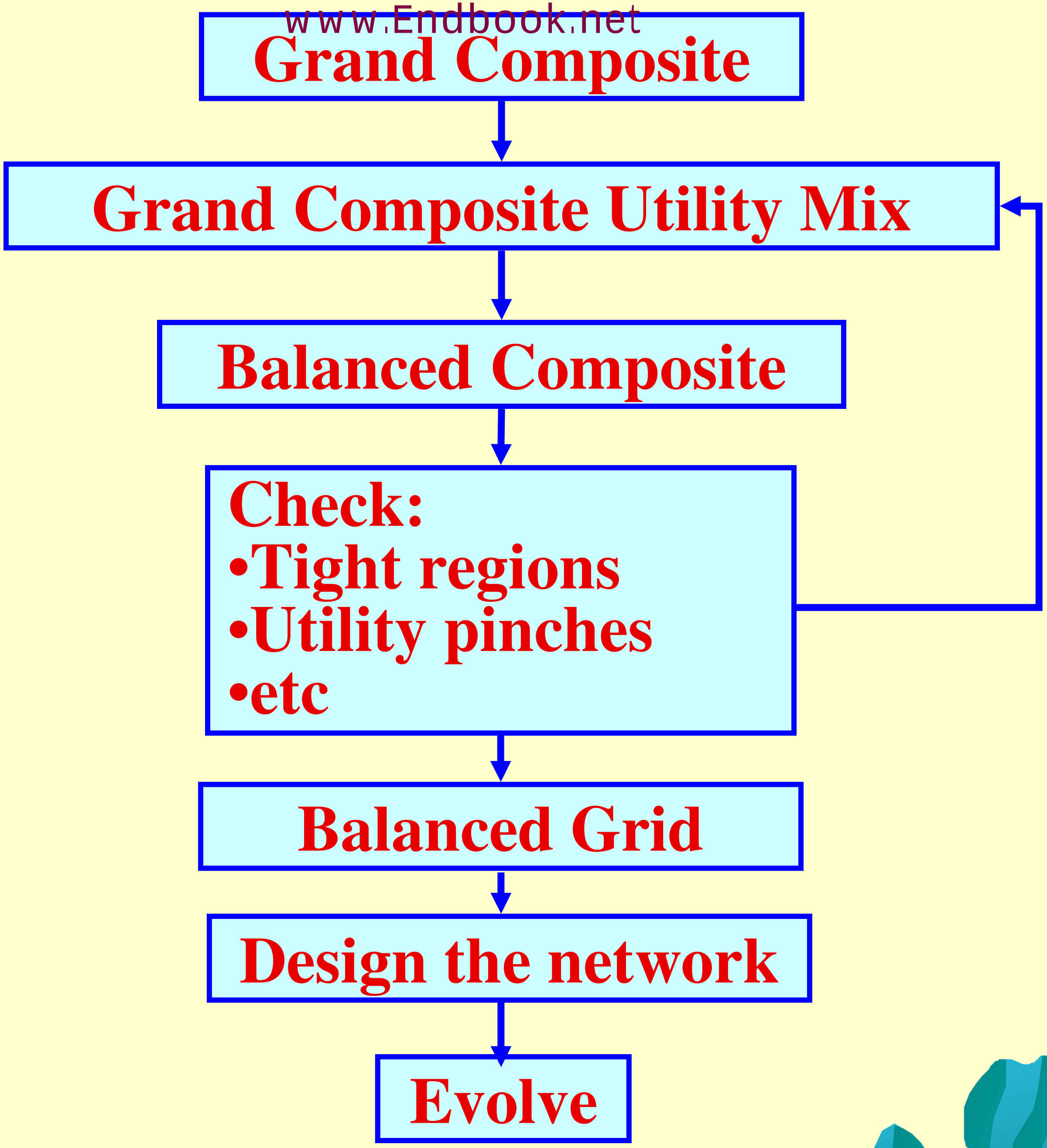
$T_S = 160^o = T_{corr}$

Q=300

Fuel = 336

PROCEDURE
(Once again)

1. Draw Grand Composite Curve
2. Determine best utility mix
   - choose between options (tariffs, load, etc.)
3. Draw "Balanced Composite Curves"
   - utility pinches,"narrow regions", etc.
4. Draw "Balanced Grid"
   -usually no further utility
5. Design "Balanced Network"
   -future utility exchangers are integrated
6. Convert into HEN + Utilities
7. Evolve (we always need to leave a door open)



Grand Composite

Grand Composite Utility Mix

Balanced Composite

Check:
- Tight regions
- Utility pinches
- etc

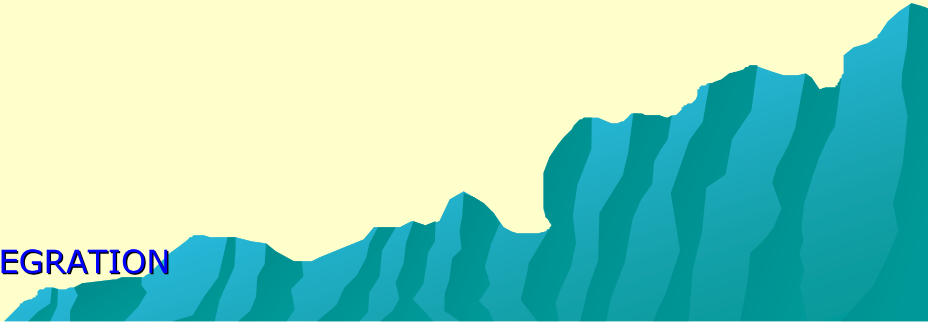
Balanced Grid

Design the network

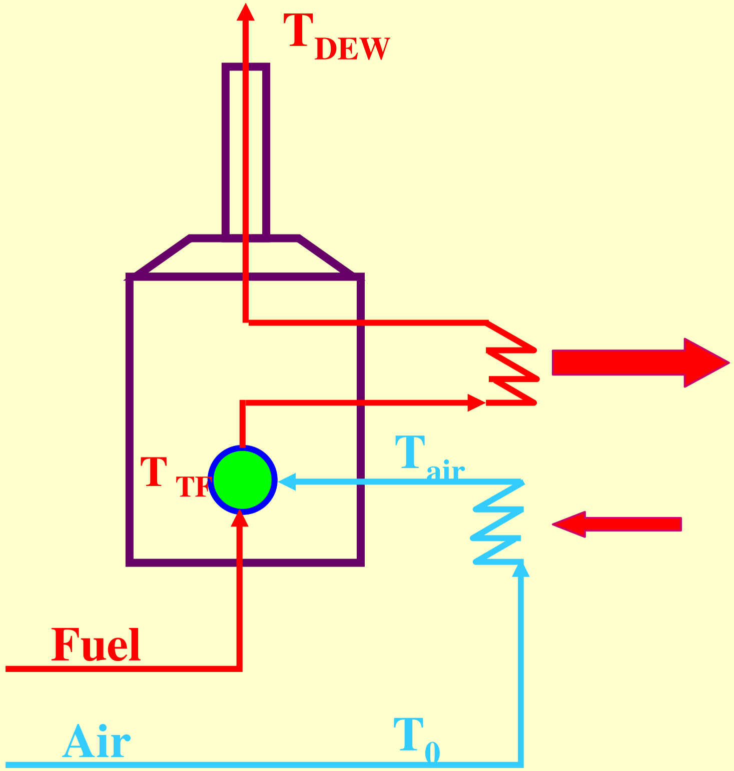
Evolve

LECTURE 14

Furnace



Independent Degrees of Freedom in a Furnace

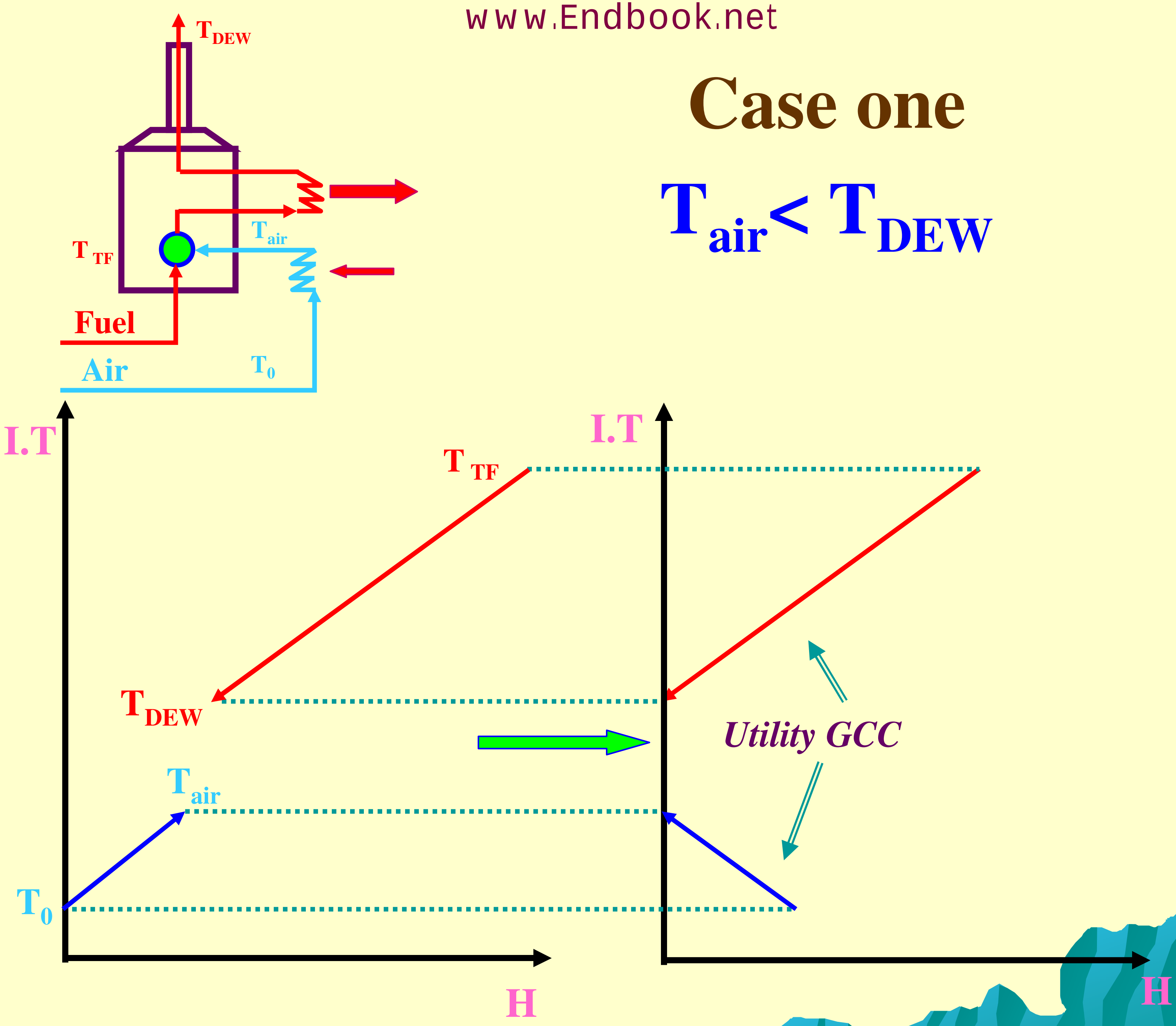


We choose :

- ✓ Fuel flow
- ✓ T_{air}
- ✓ Excess Air

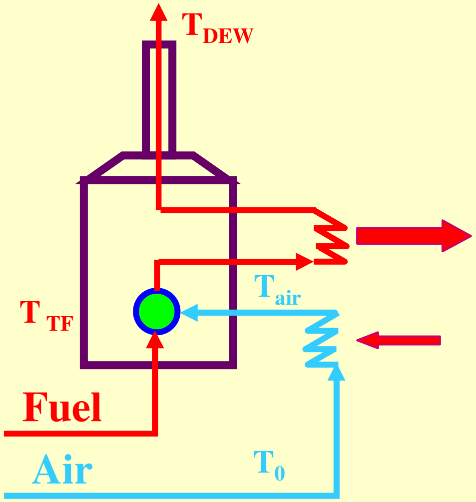
Case one

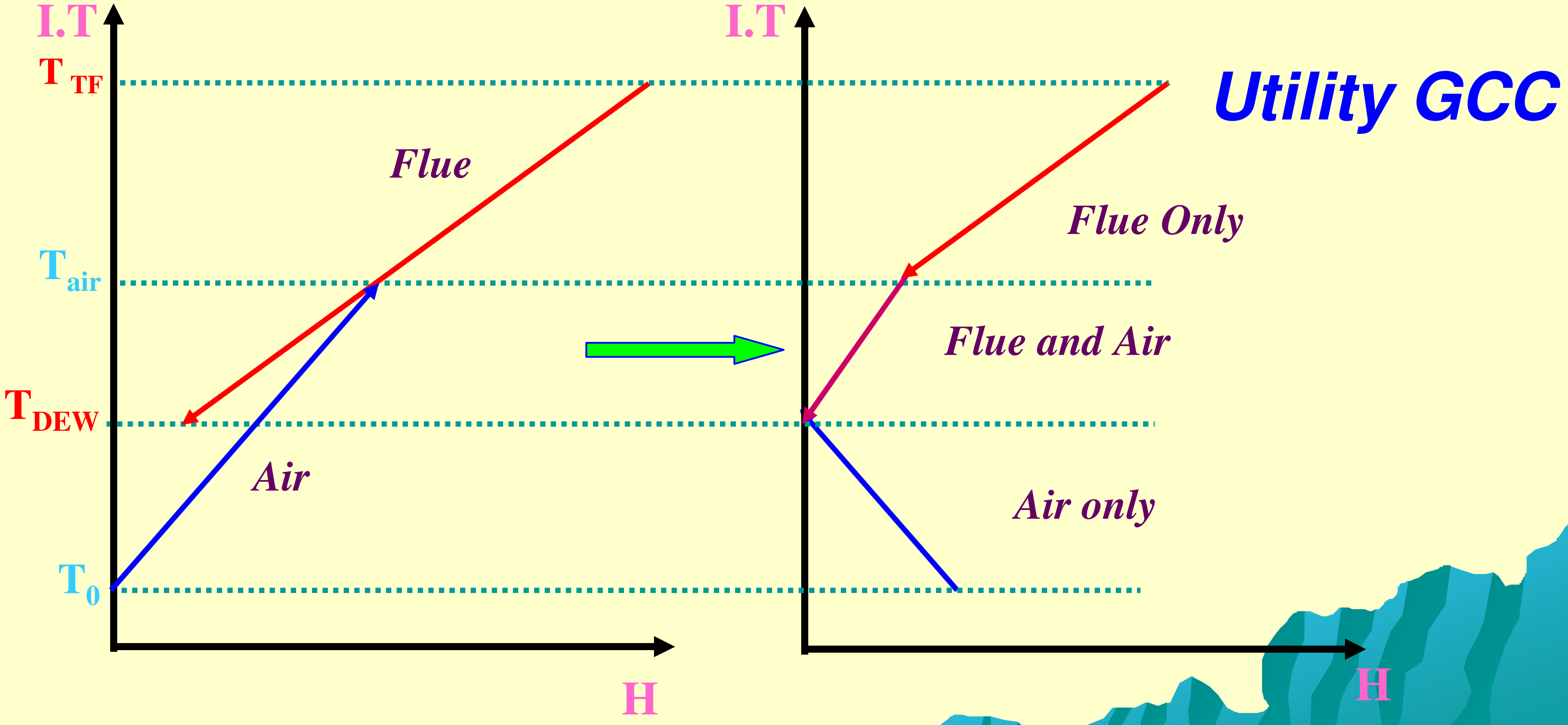
$T_{air} < T_{DEW}$



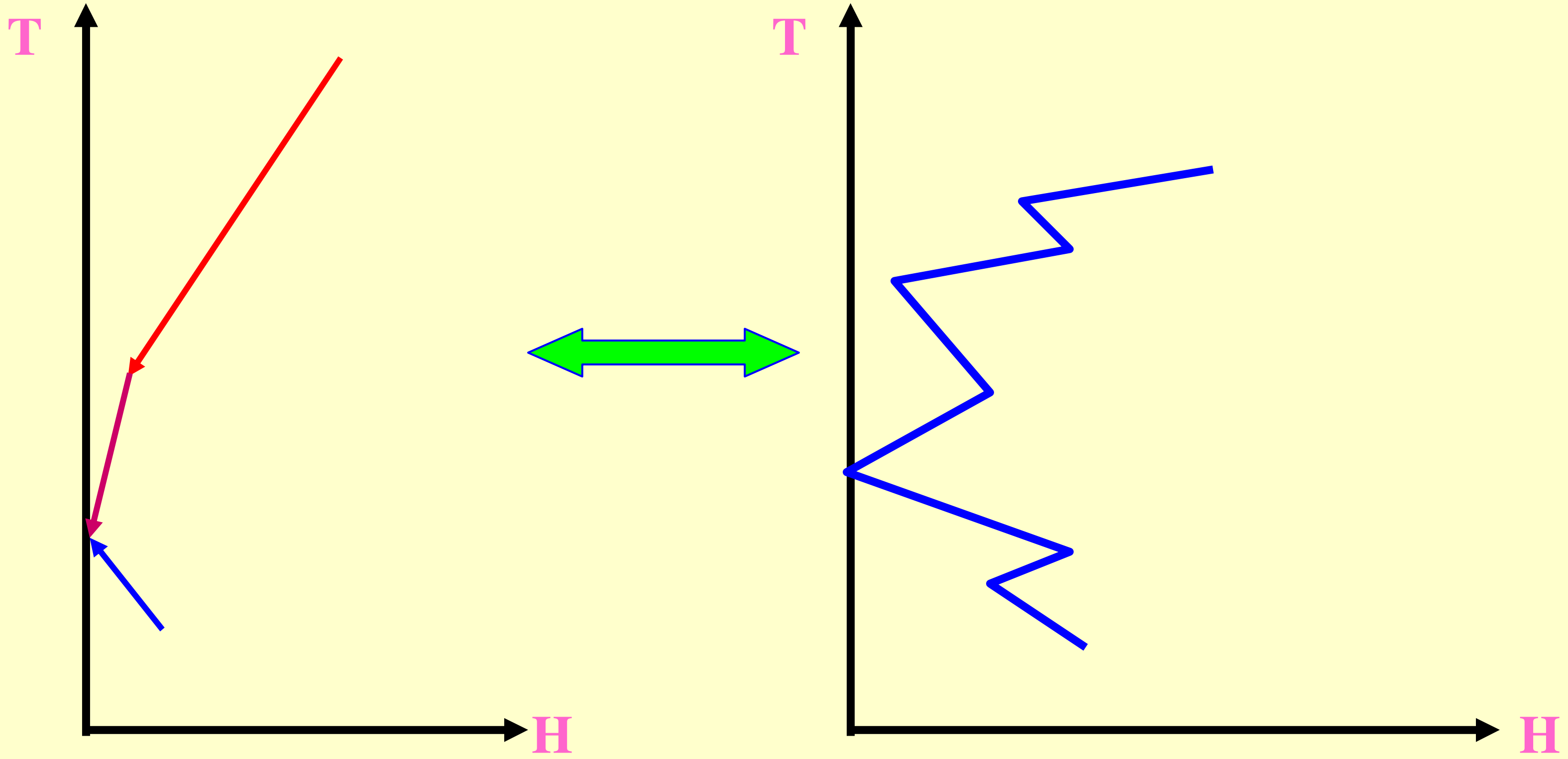
Case Two

$T_{air} > T_{DEW}$





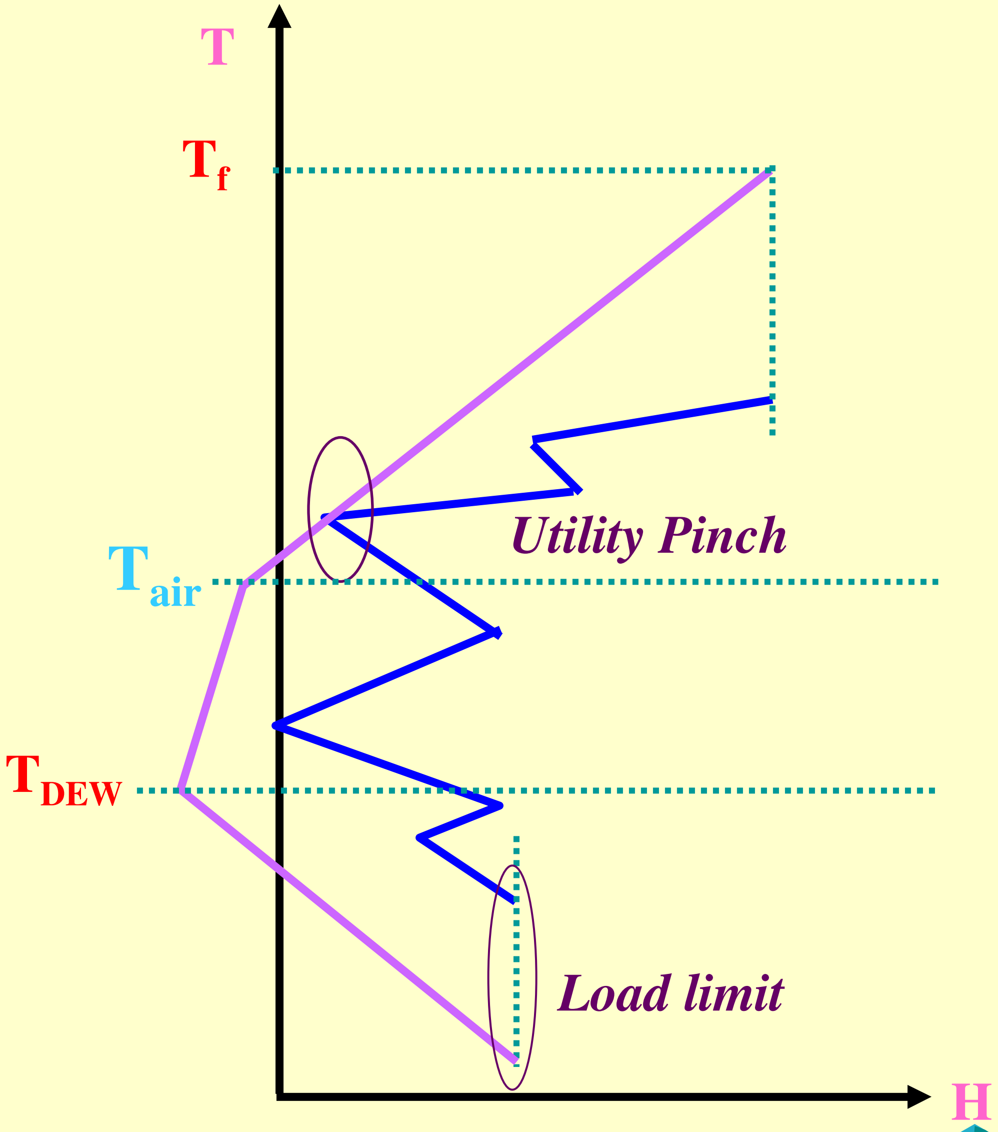
Now let's look again at our problem (T_{air}>T_{DEW})



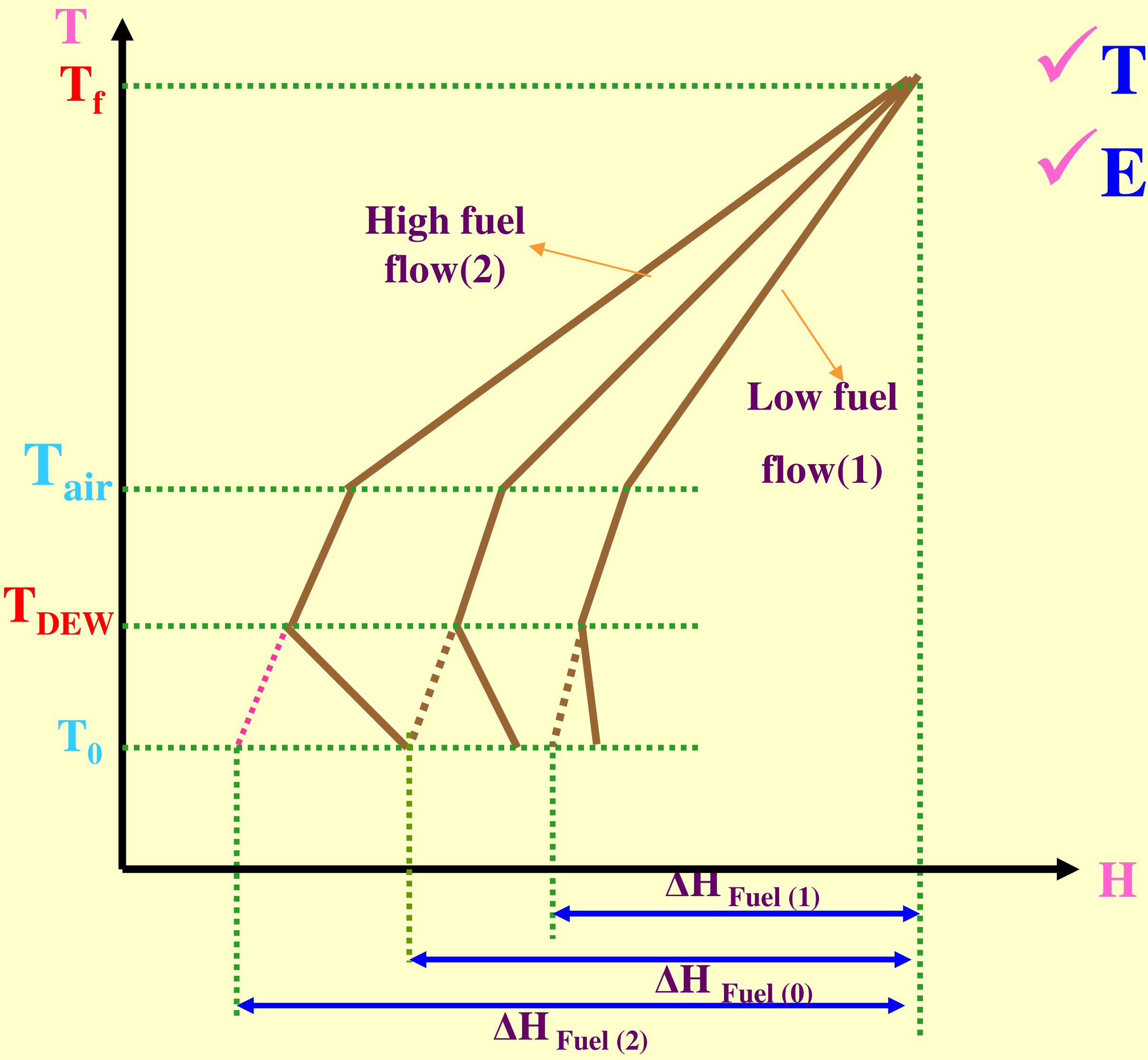
Utility GCC

Process GCC

Utility and Process together



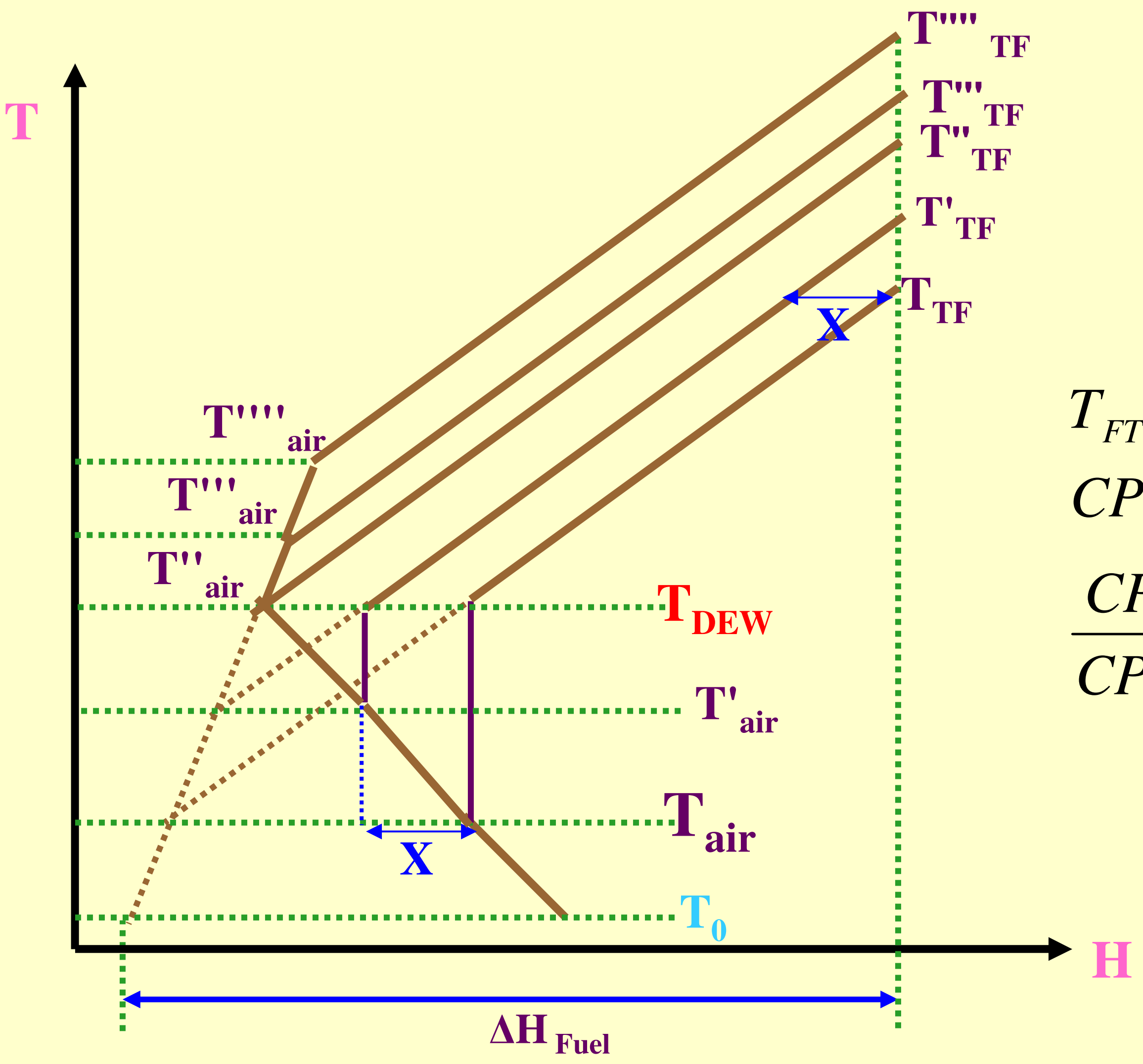
A. Vary Fuel Flow



- ✓ T_{air} = constant
- ✓ Excess air = constant

B. Vary T_{air}

- ✓ **Fuel flow = constant**
- ✓ **Excess air = constant**



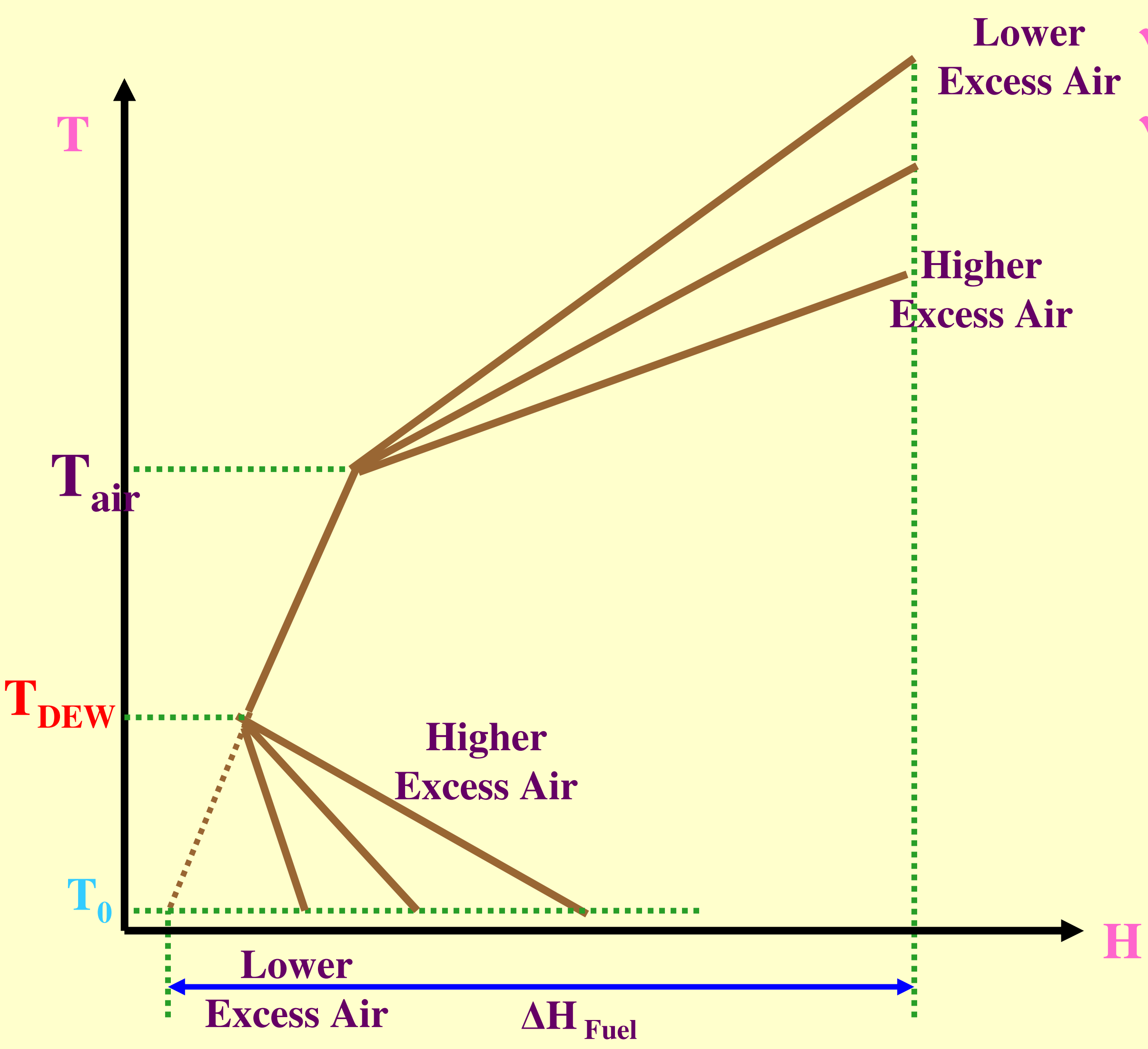
$$T_{FT} = 1074.39 + 0.853\,T_{air}$$

$$CP_{flue} = CP_{air} + CP_{fuel}$$

$$\frac{CP_{air}}{CP_{flue}} = 0.853$$

C. Vary Excess Air

- ✓ Fuel Flow = constant
- ✓ T_{air} = constant



How can we use these DOF to minimize fuel consumption?

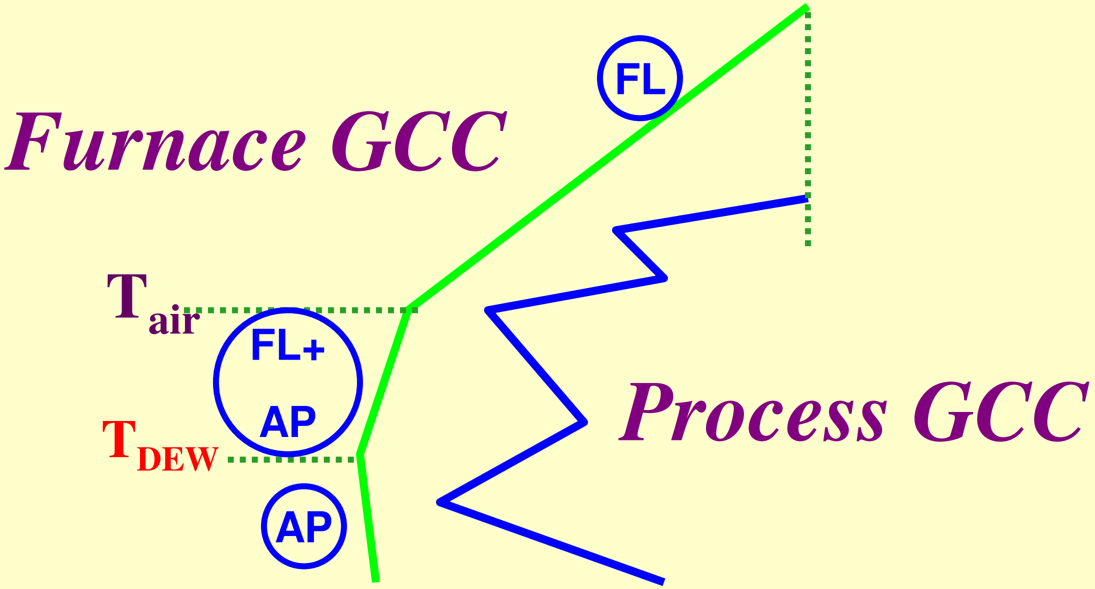
A. Excess Air,

We have already seen that more excess air will never reduce fuel consumption

Initialize

$XS_{air} = 0$ or $(XS_{air})_{min}$

B. Air Preheat

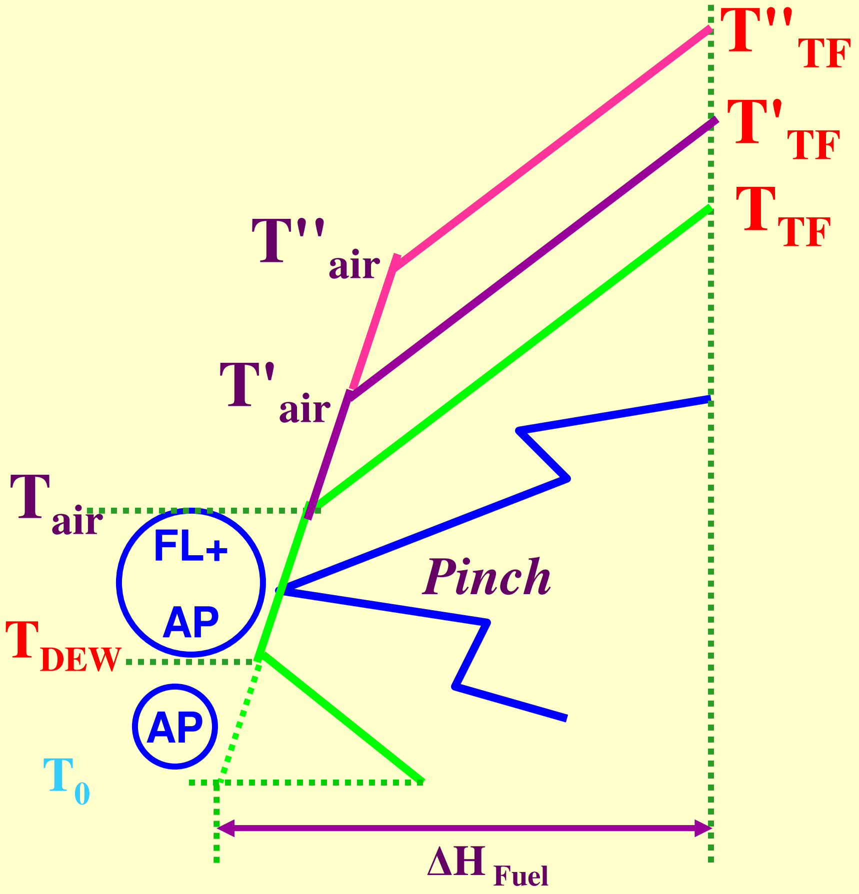


Fix T_{air} and “shrink” furnace GCC onto process GCC (decrease fuel). One of two cases can occur :

- ✓ **Utility Pinch on *AP* or *FL+AP***
- ✓ **Utility Pinch on *FL***

First Case

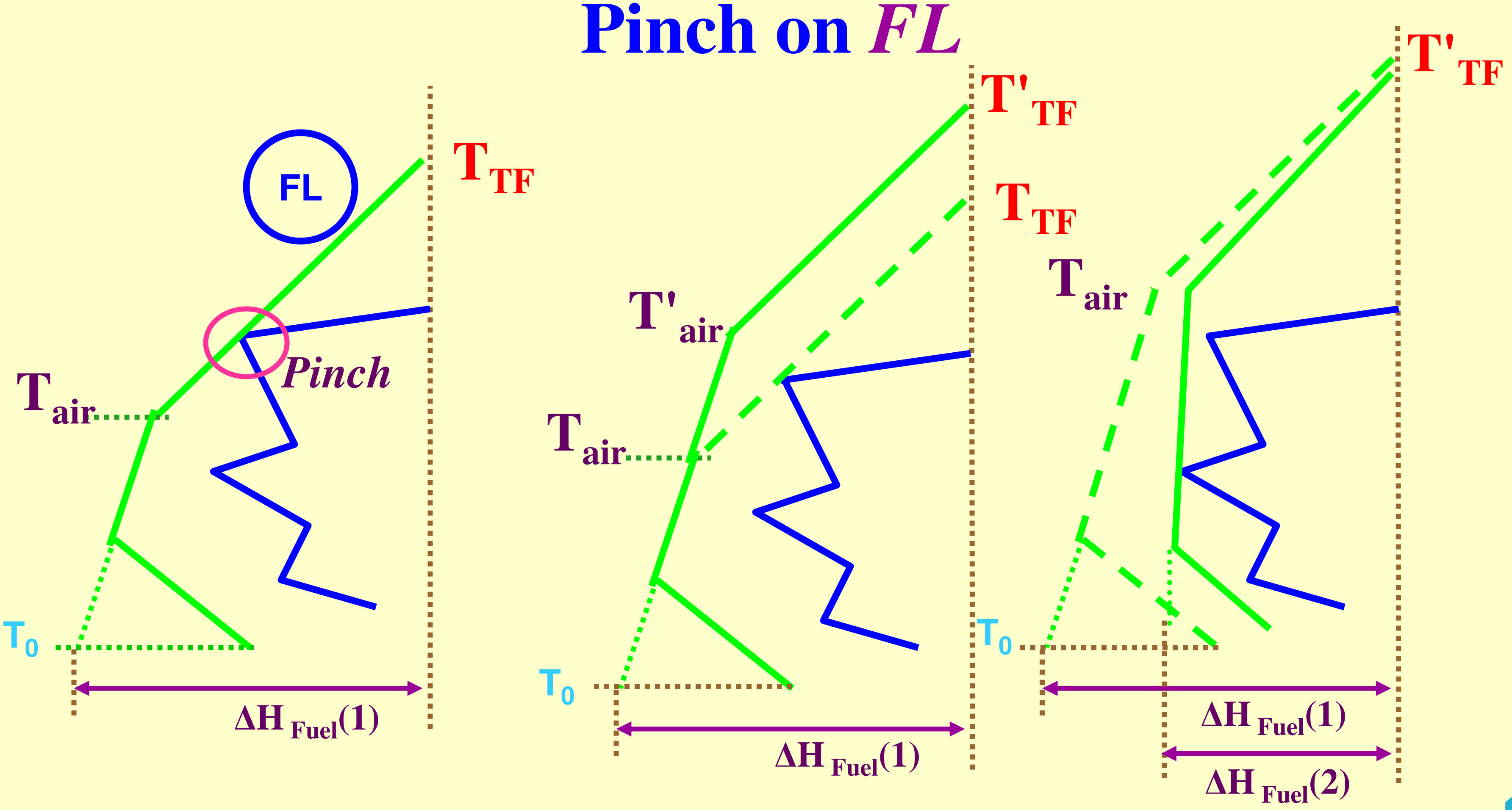
Pinch on *AP* or *FL+AP*



Increasing T_{air} has no effect on fuel flow

Second Case

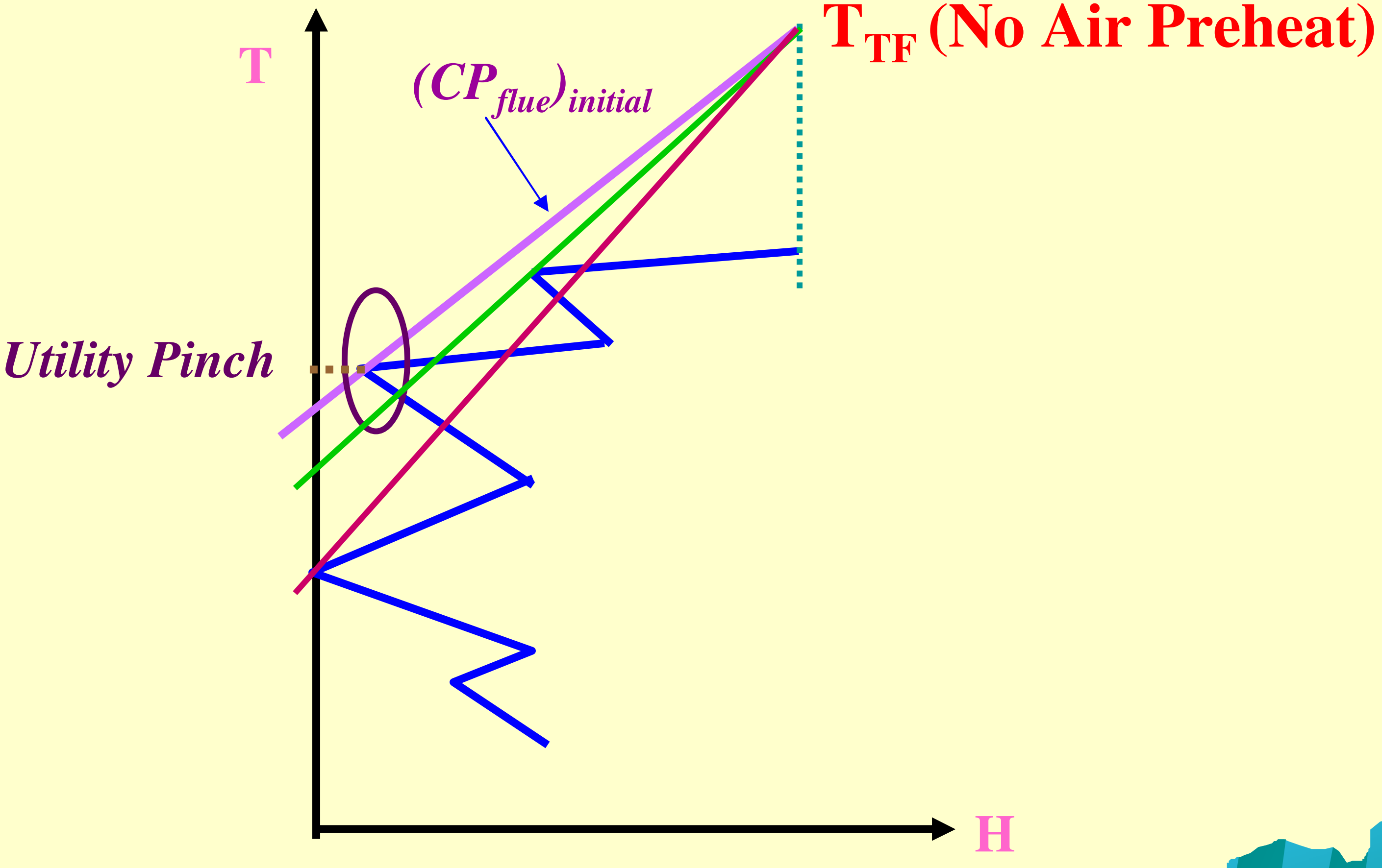
Pinch on *FL*



Increasing T$_{air}$ allows fuel to be decreased

Step 1

Assume no Air preheat to identify $(CP_{flue})_{initial}$

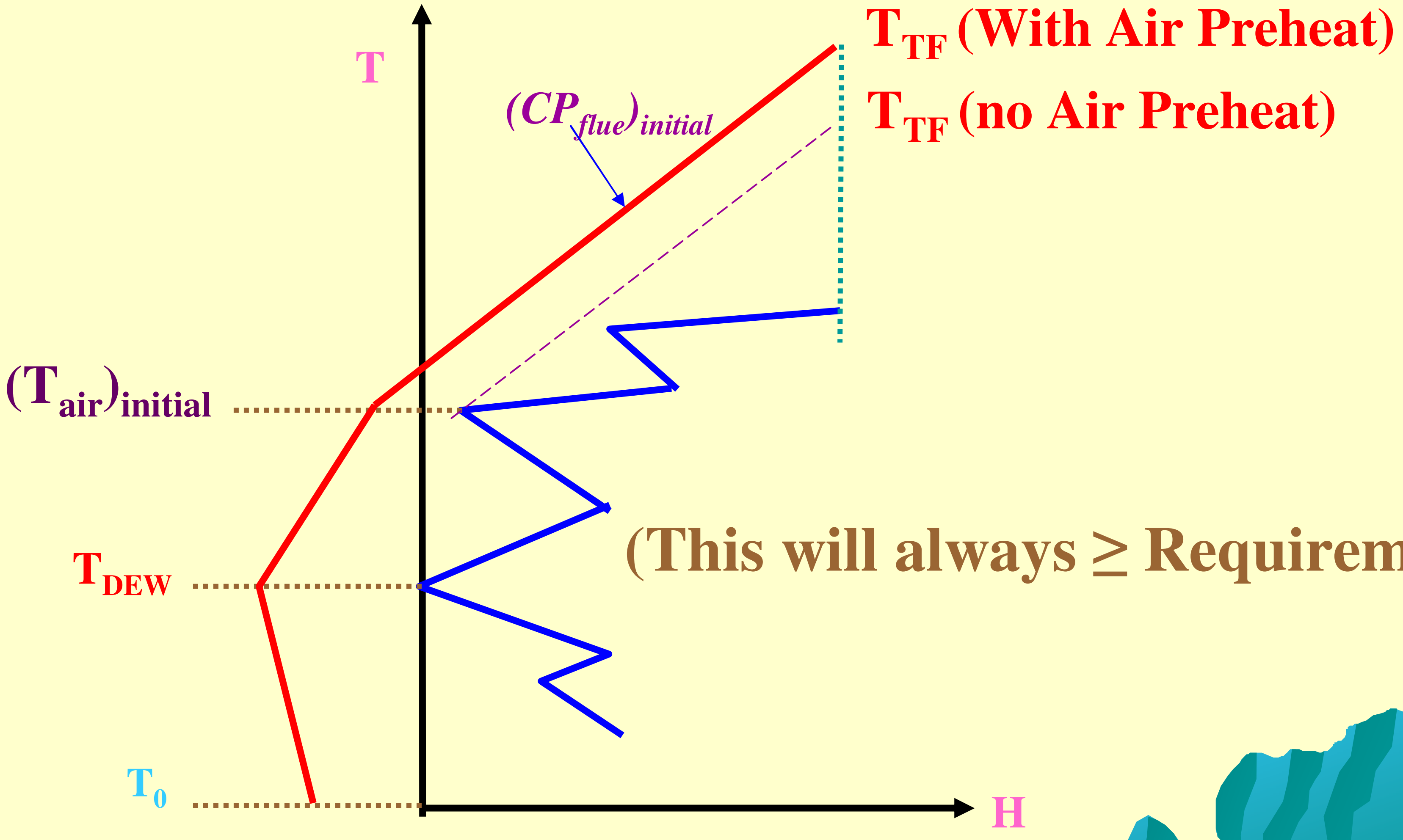


$(CP_{flue})_{initial}$ = f (Most protruding "*Candidate Pinch*")

Step 2

Set $(T_{air})_{initial} = T_{utility\ pinch}$

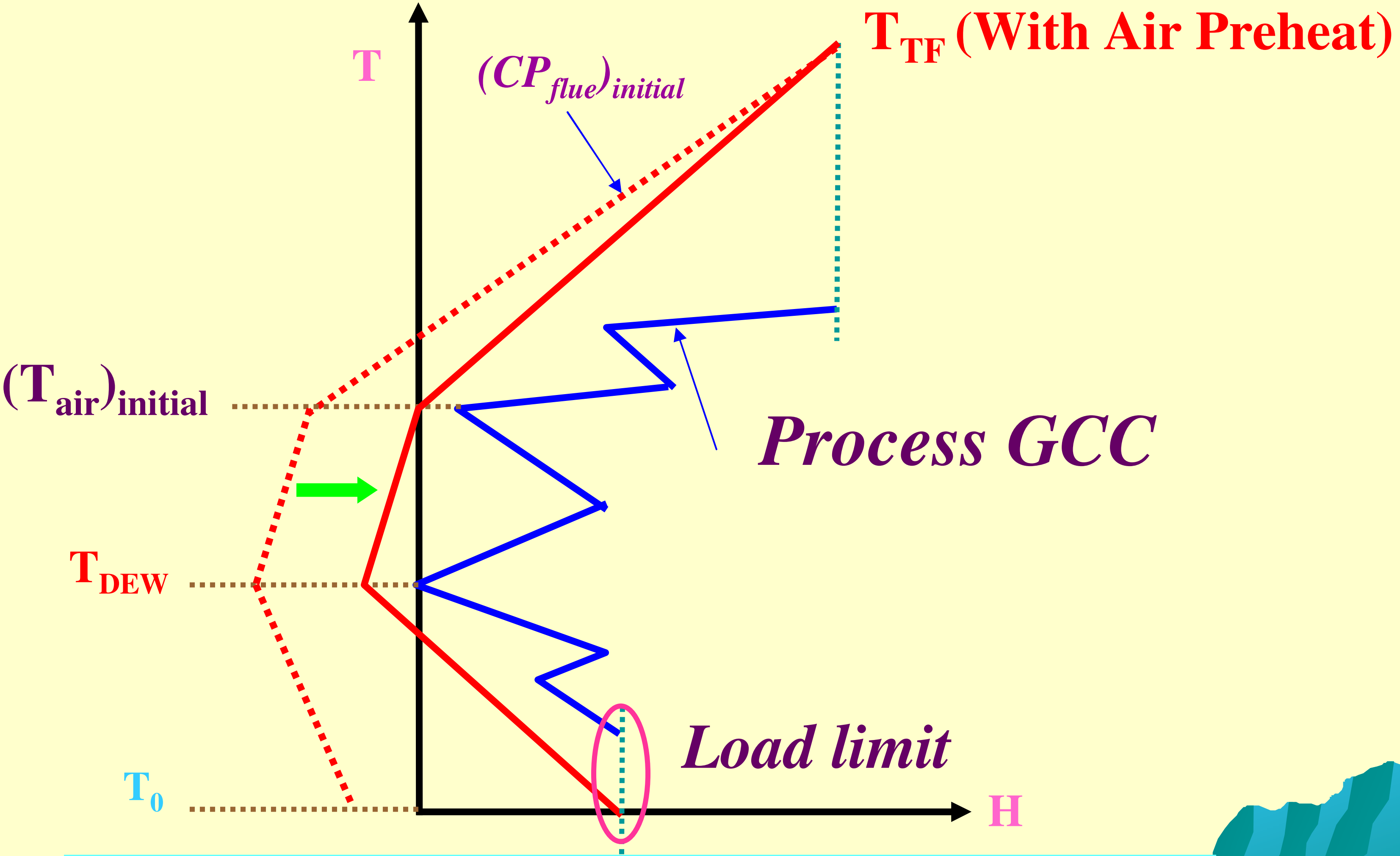
(This will always be hot enough)



(This will always ≥ Requirement)

Step 3

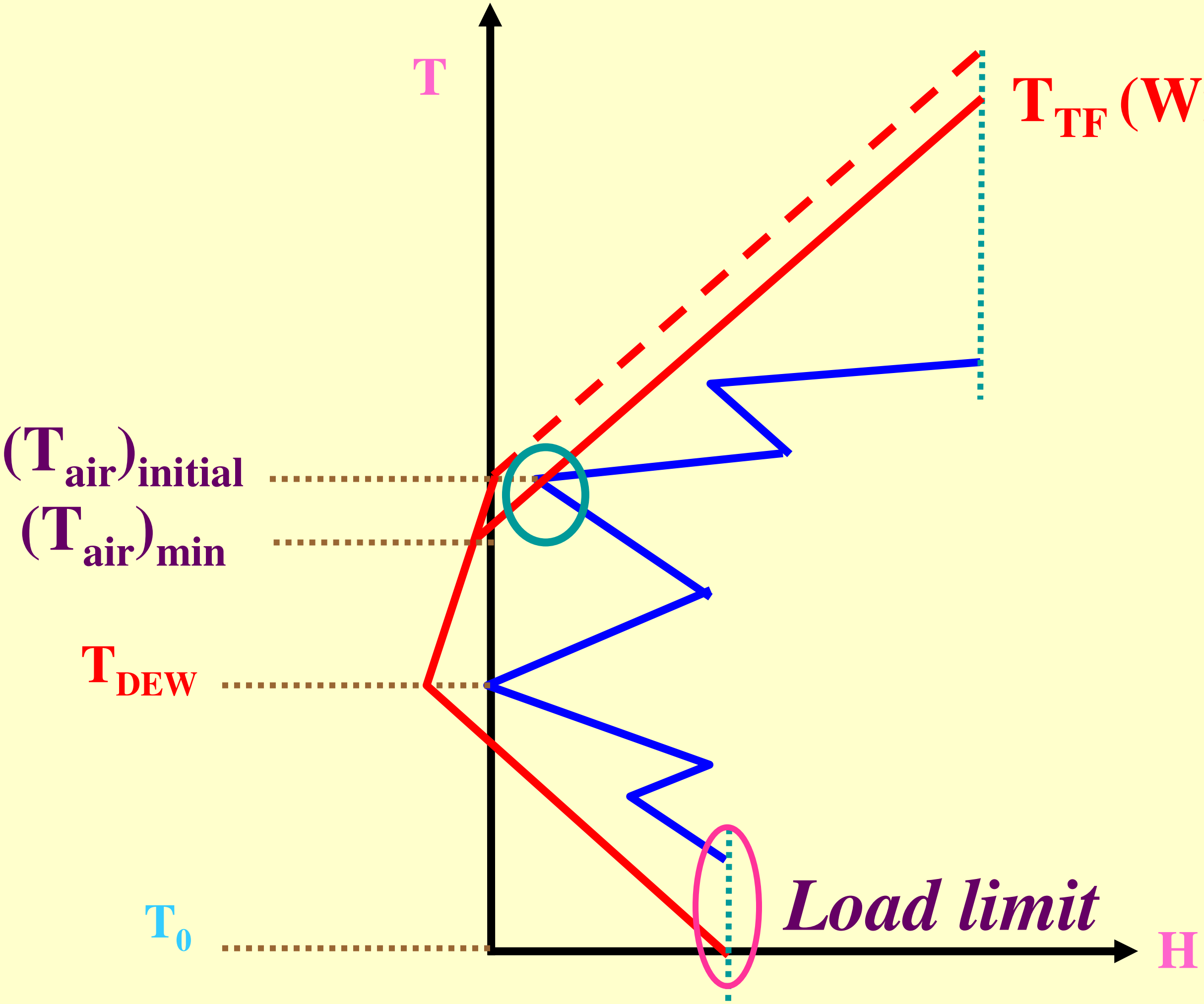
Decrease fuel flow until PGCC is limiting



Minimum fuel flow now set

Step 4

Back off from $(T_{air})_{initial}$



T_{air} = Minimum T_{air} that allows minimum fuel flow

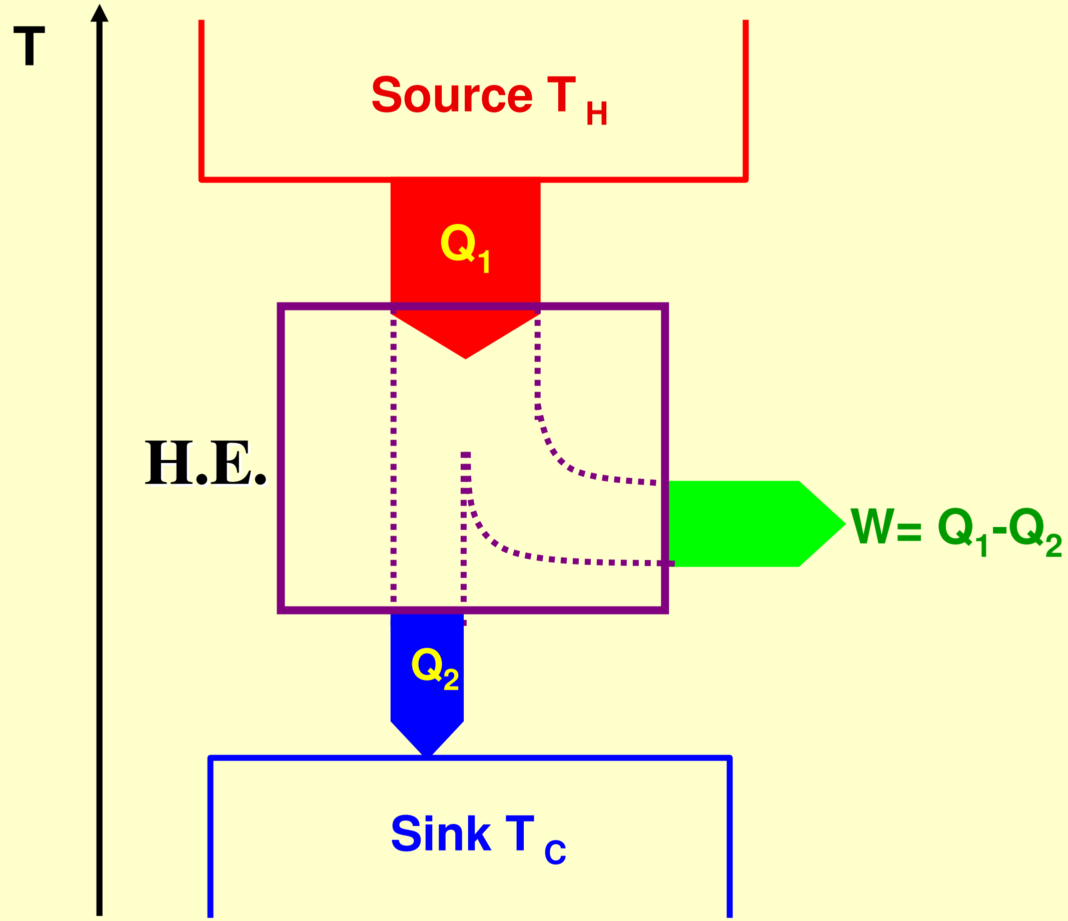
Homework 3

Following assignment is due to be returned in two weeks.

LECTURE 15

Heat Engines

Heat Engine Models



$$W_{\max} = Q_1 \left(1 - \frac{T_C}{T_H} \right)$$

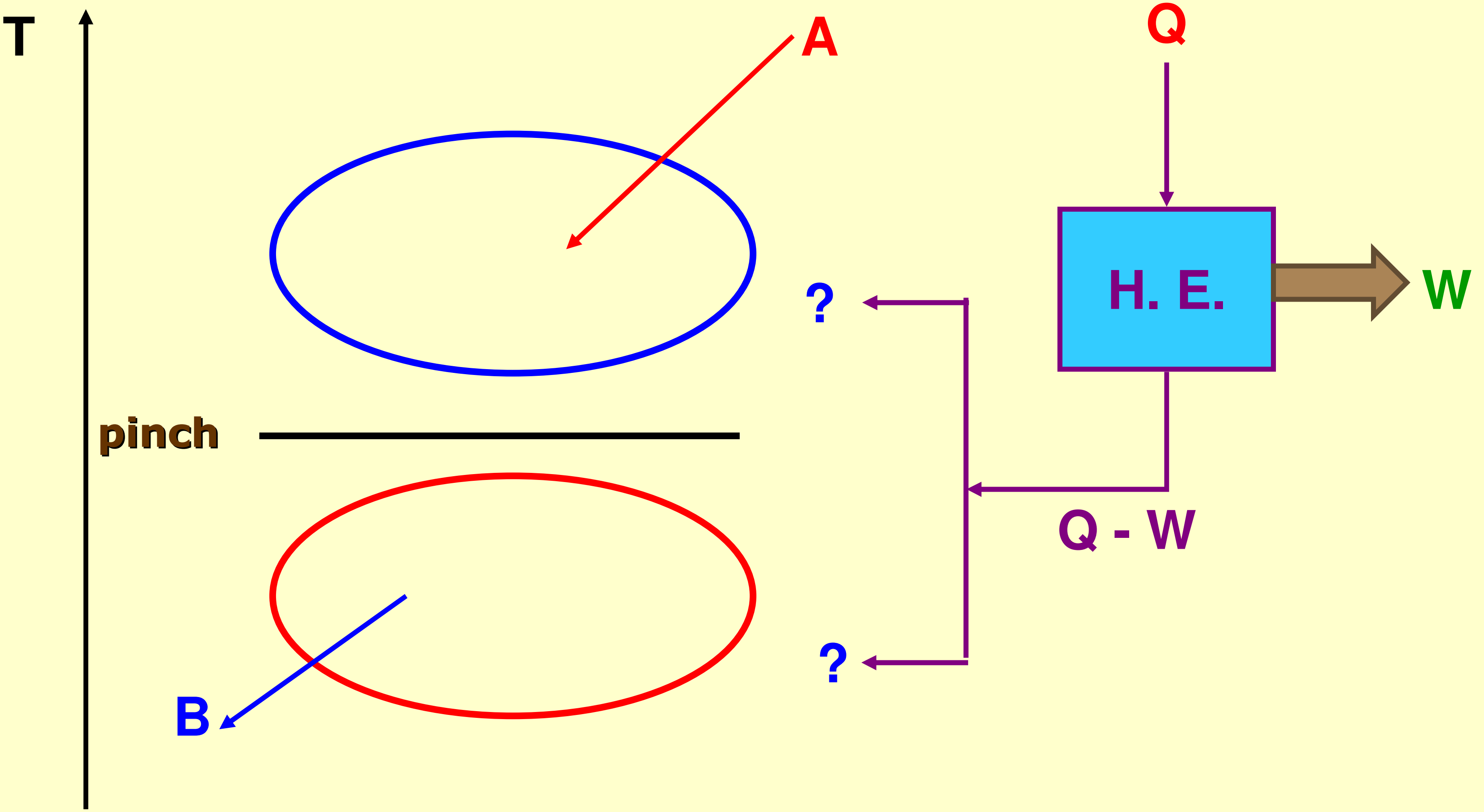
$$\left(1 - \frac{T_C}{T_H} \right) = \text{Carnot efficiency}$$

$$W_{\text{Real}} = W_{\max} \times \eta_m$$

$$\eta_m = \text{machine efficiency}$$

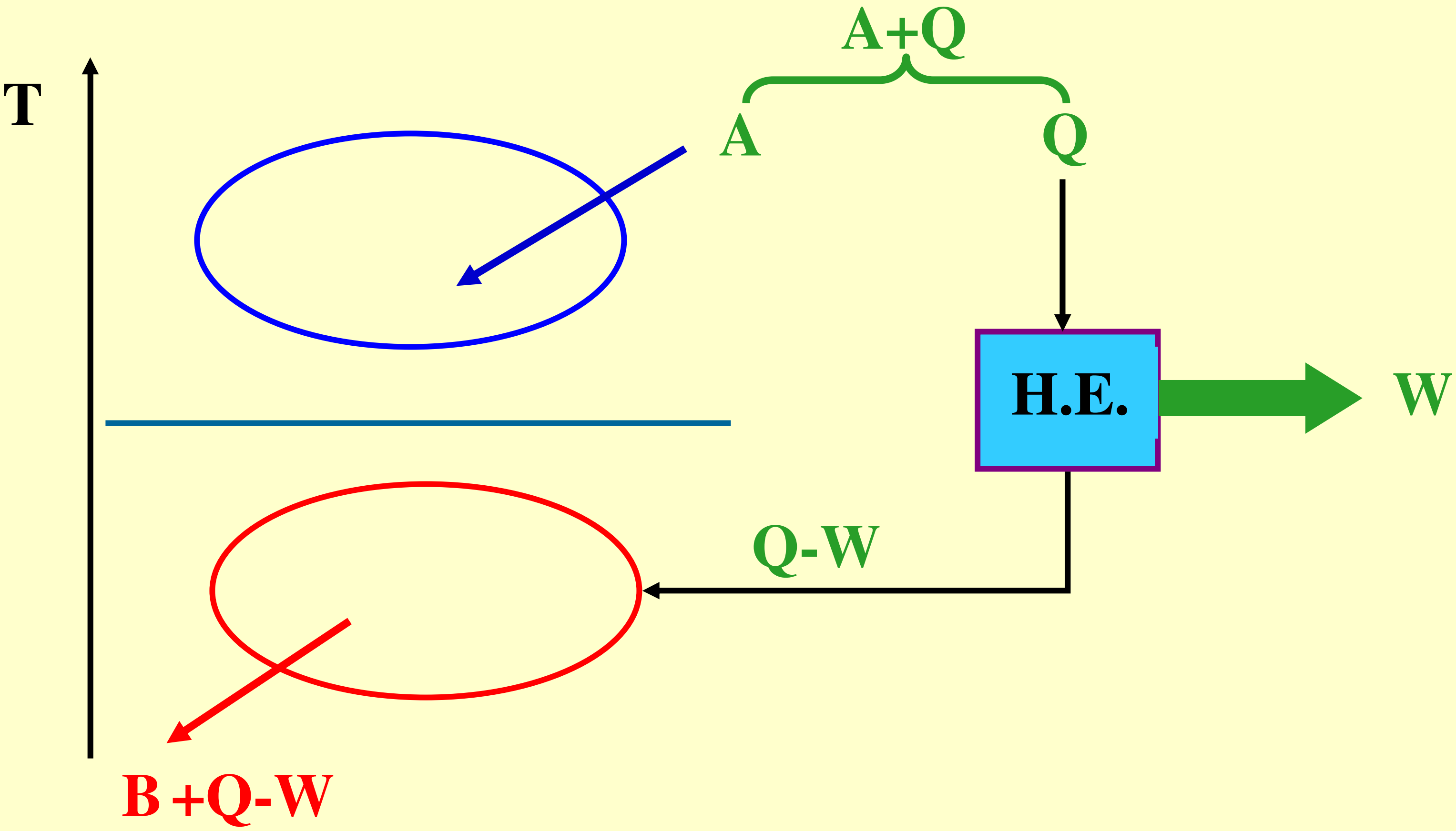
Common Heat Engines

- **Steam Turbines**
- **Gas Turbines**



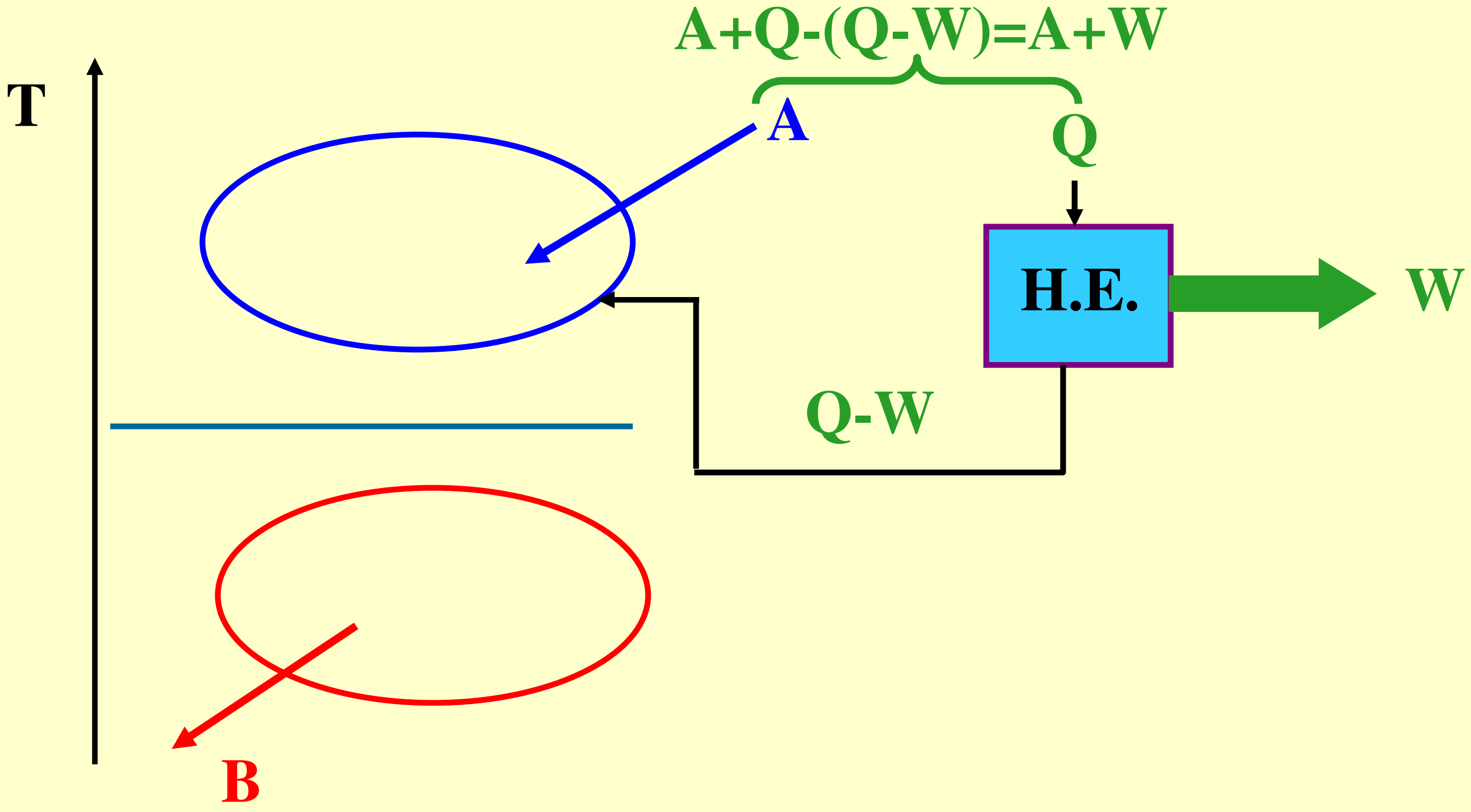
How should we integrate a heat engine?

If we integrate across the pinch



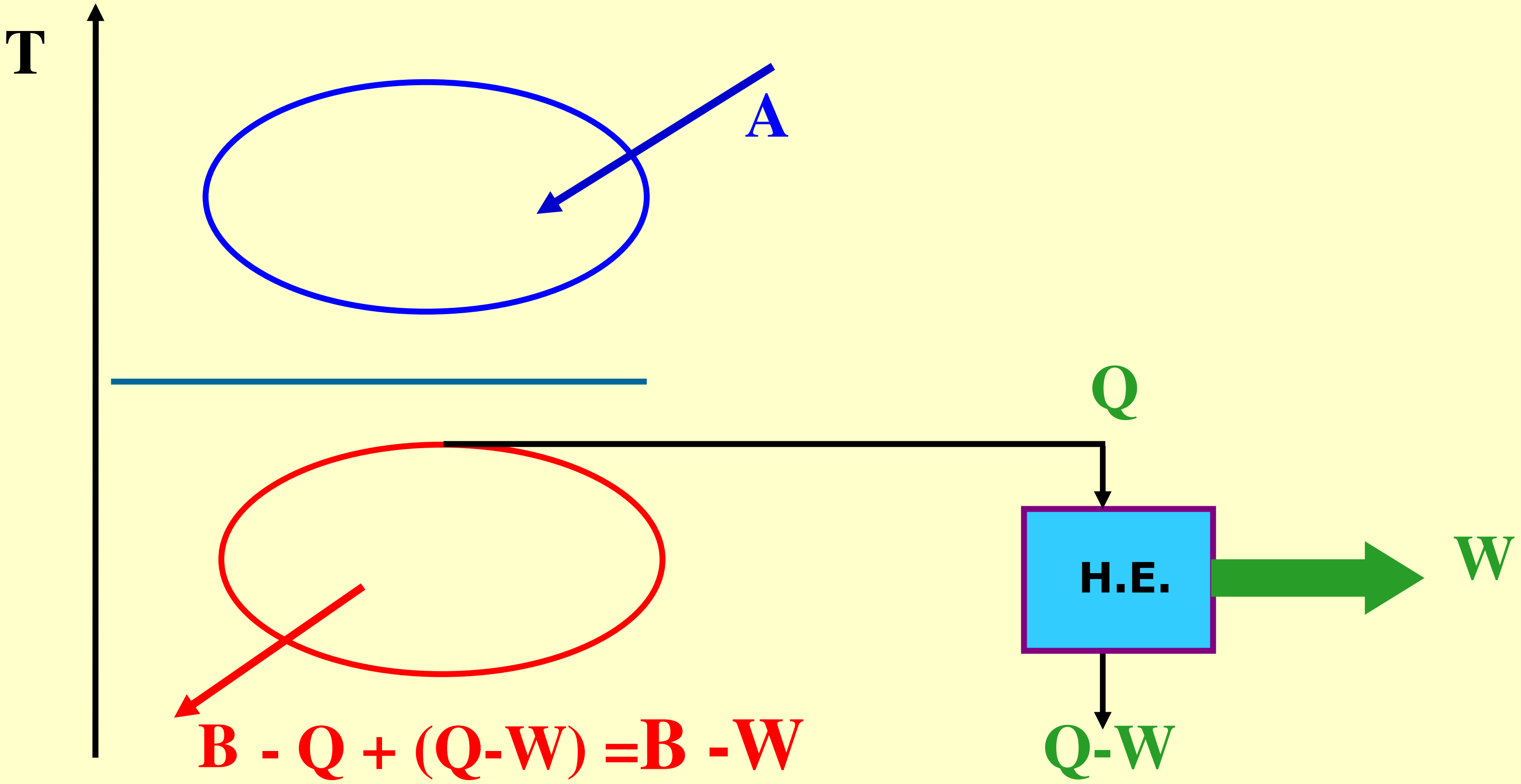
Waste of Capital and Energy

Integrate above the pinch



100% Conversion of Heat to Work

Integrate below the pinch



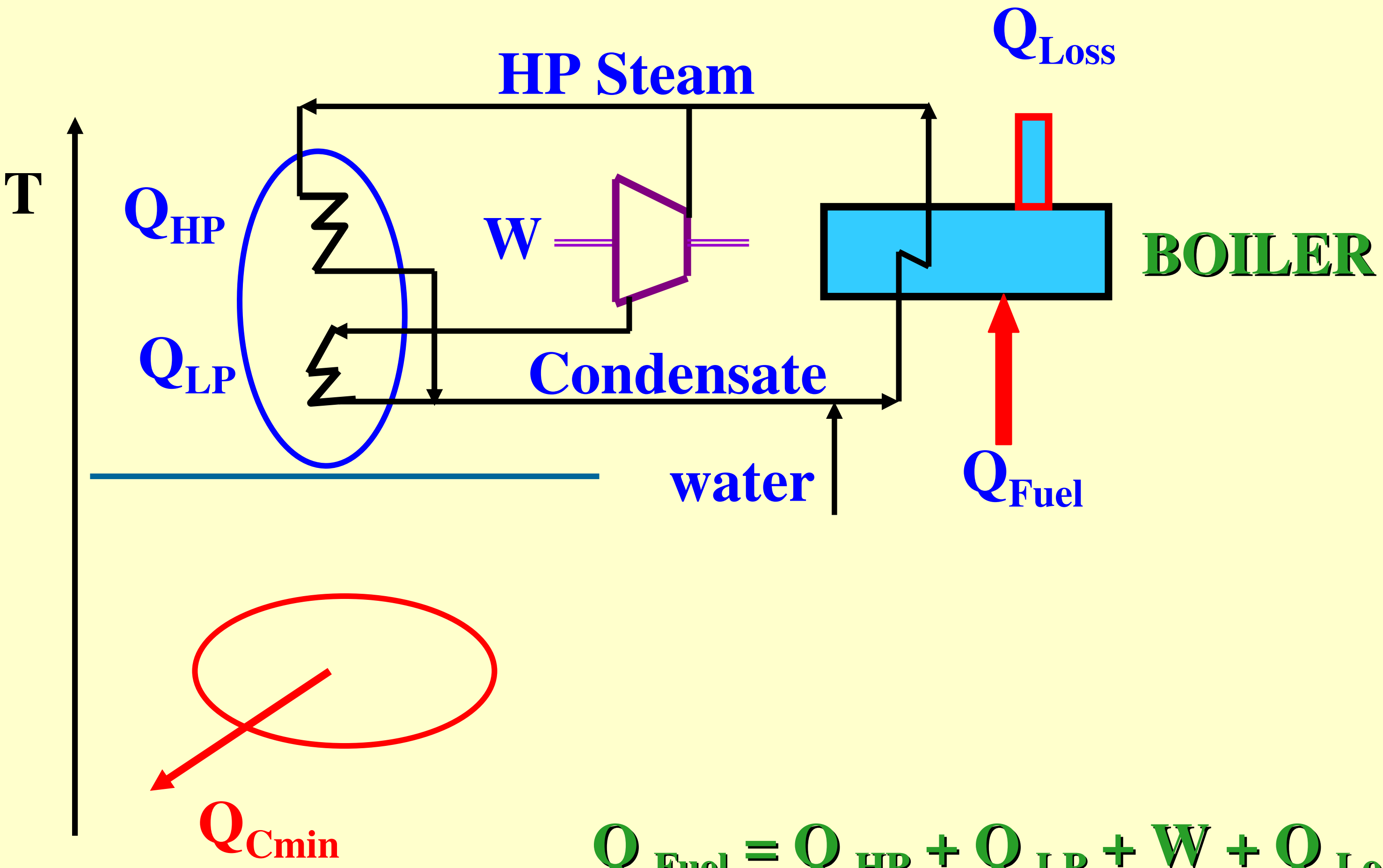
B - Q + (Q-W) =B -W

100% Conversion of Heat to Work

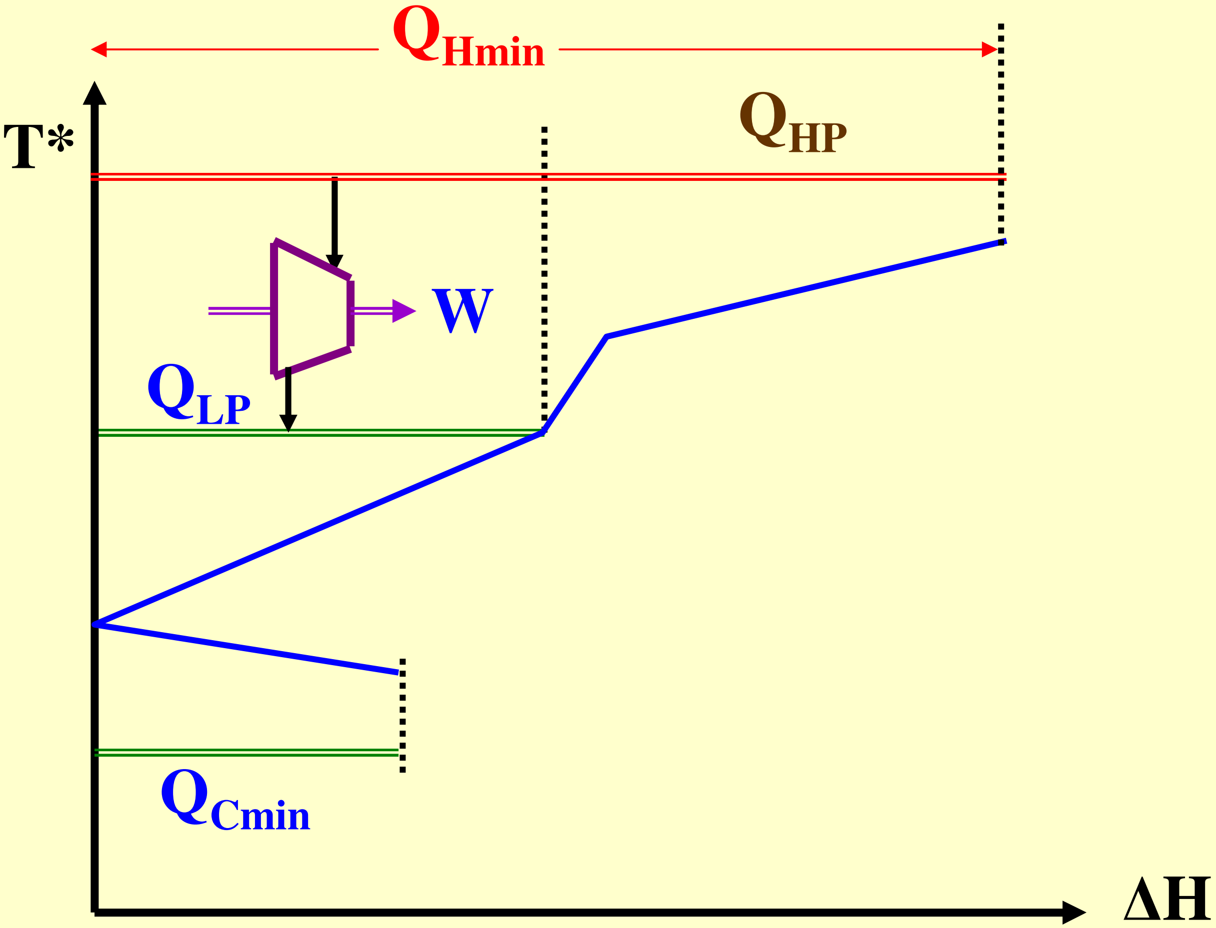
Appropriate placement of heat engine is

NOT ACROSS THE PINCH

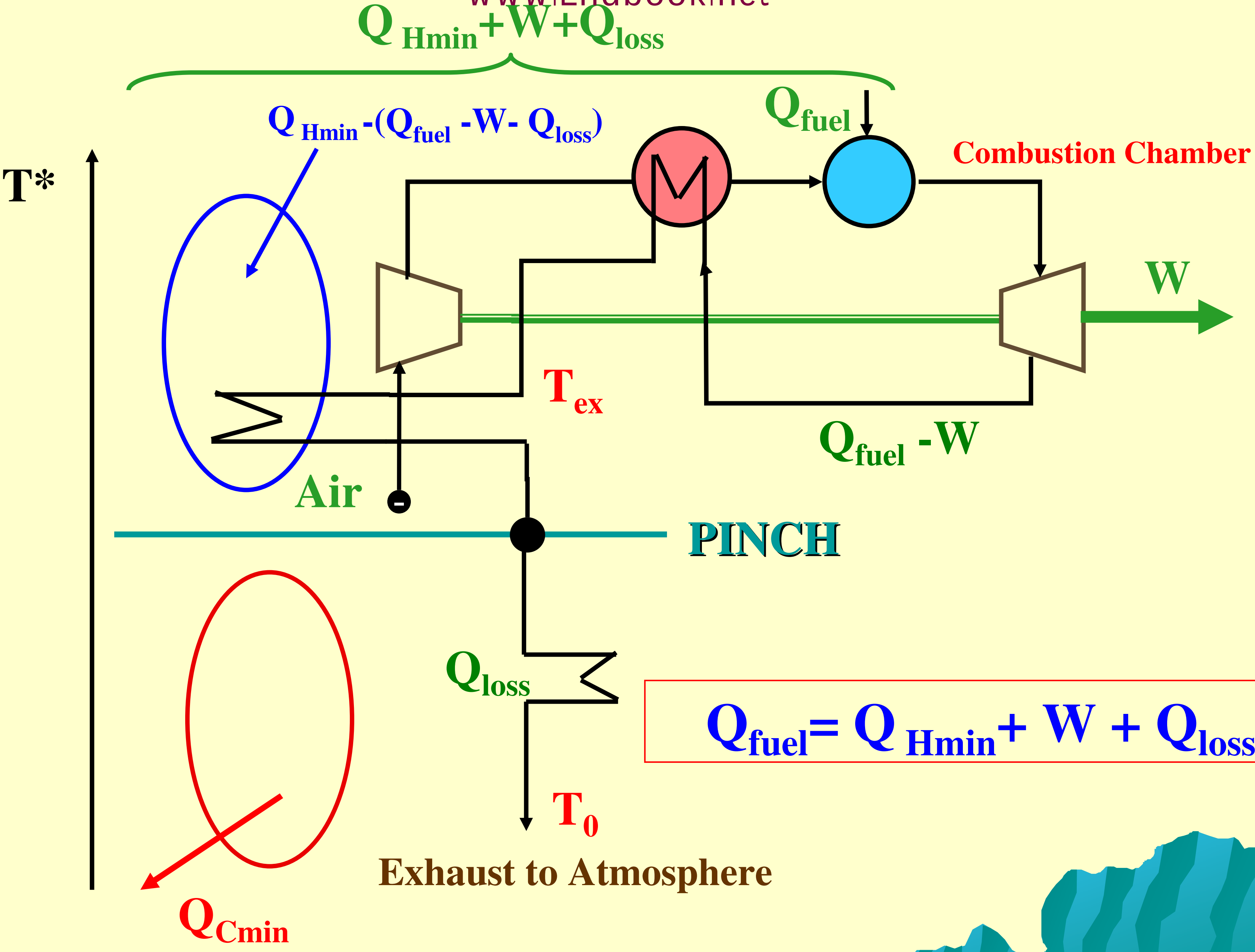
To target the thermal design, use the process grand composite curve and treat the heat engine like a utility



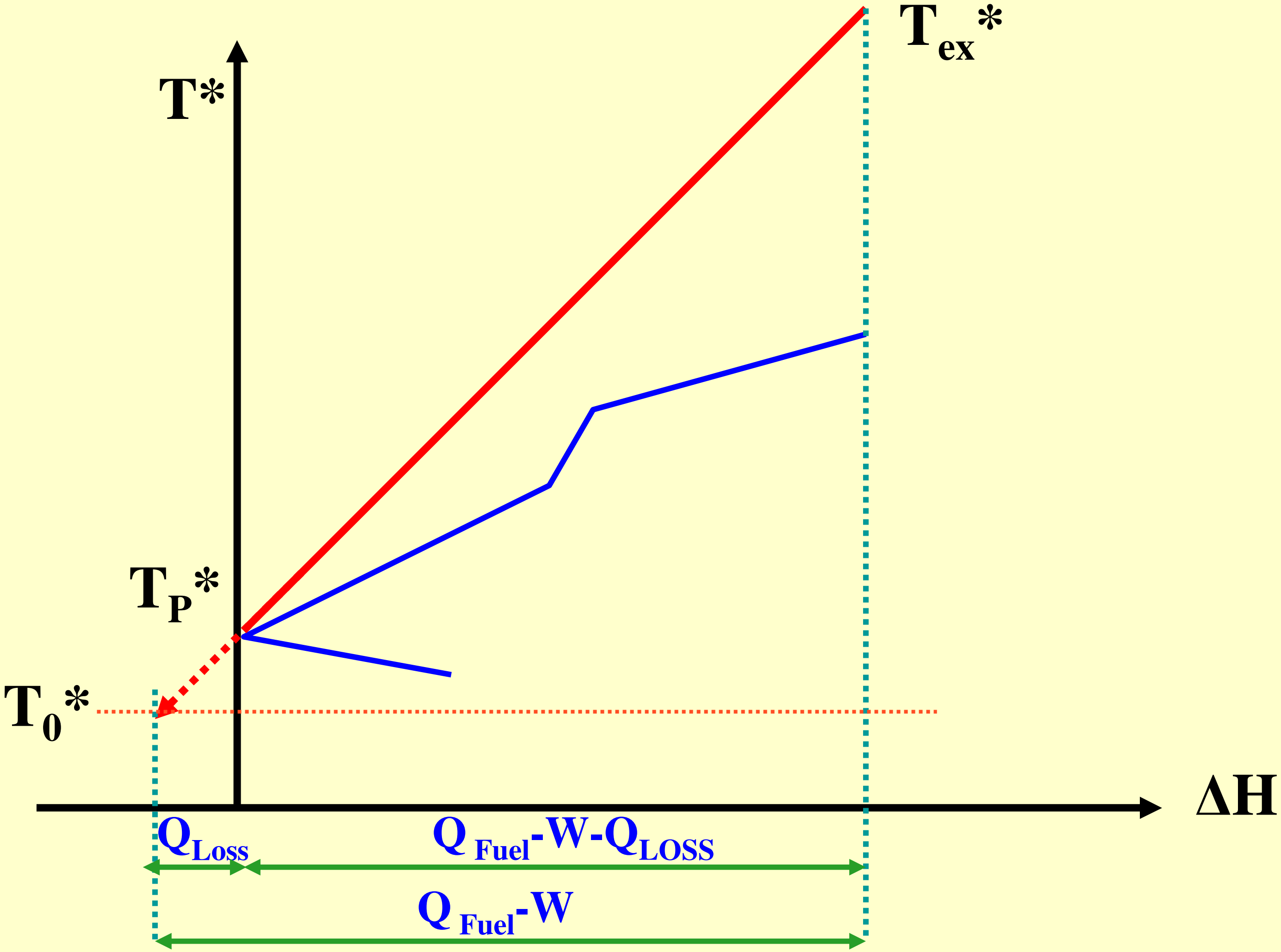
$$Q_{Fuel} = Q_{HP} + Q_{LP} + W + Q_{Loss}$$



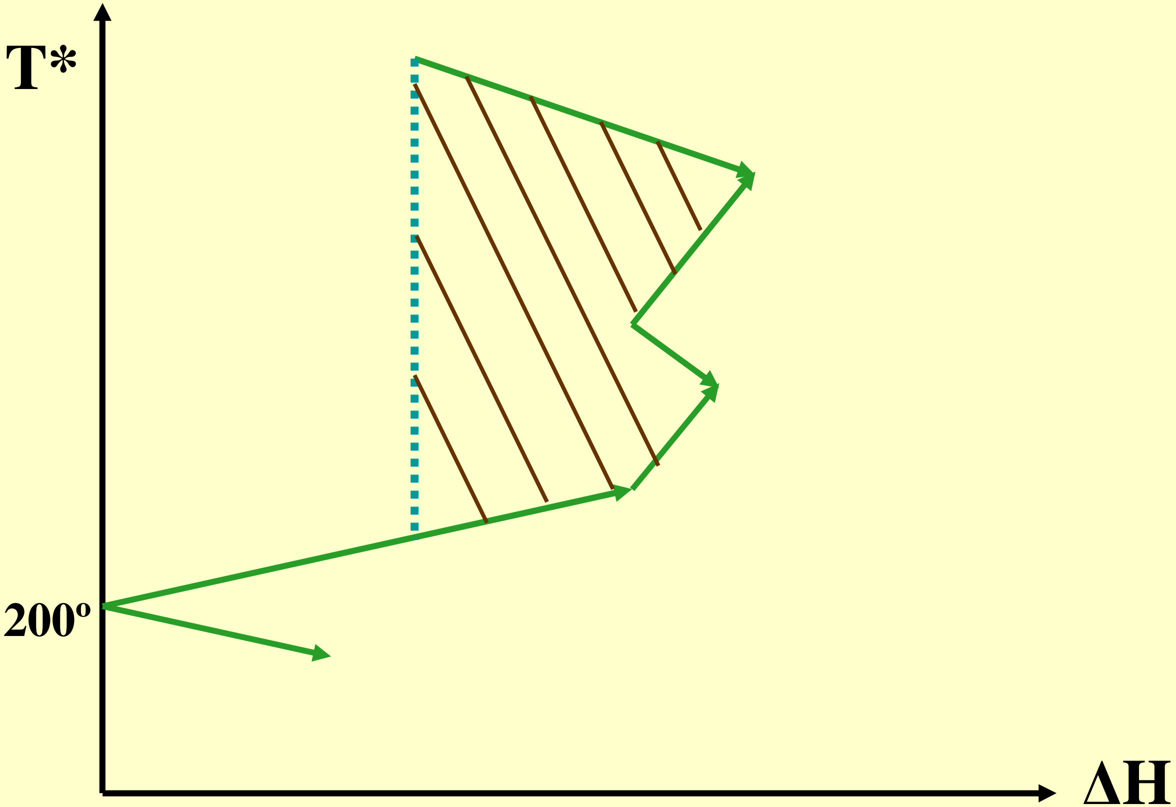
Integration of a steam turbine with the process



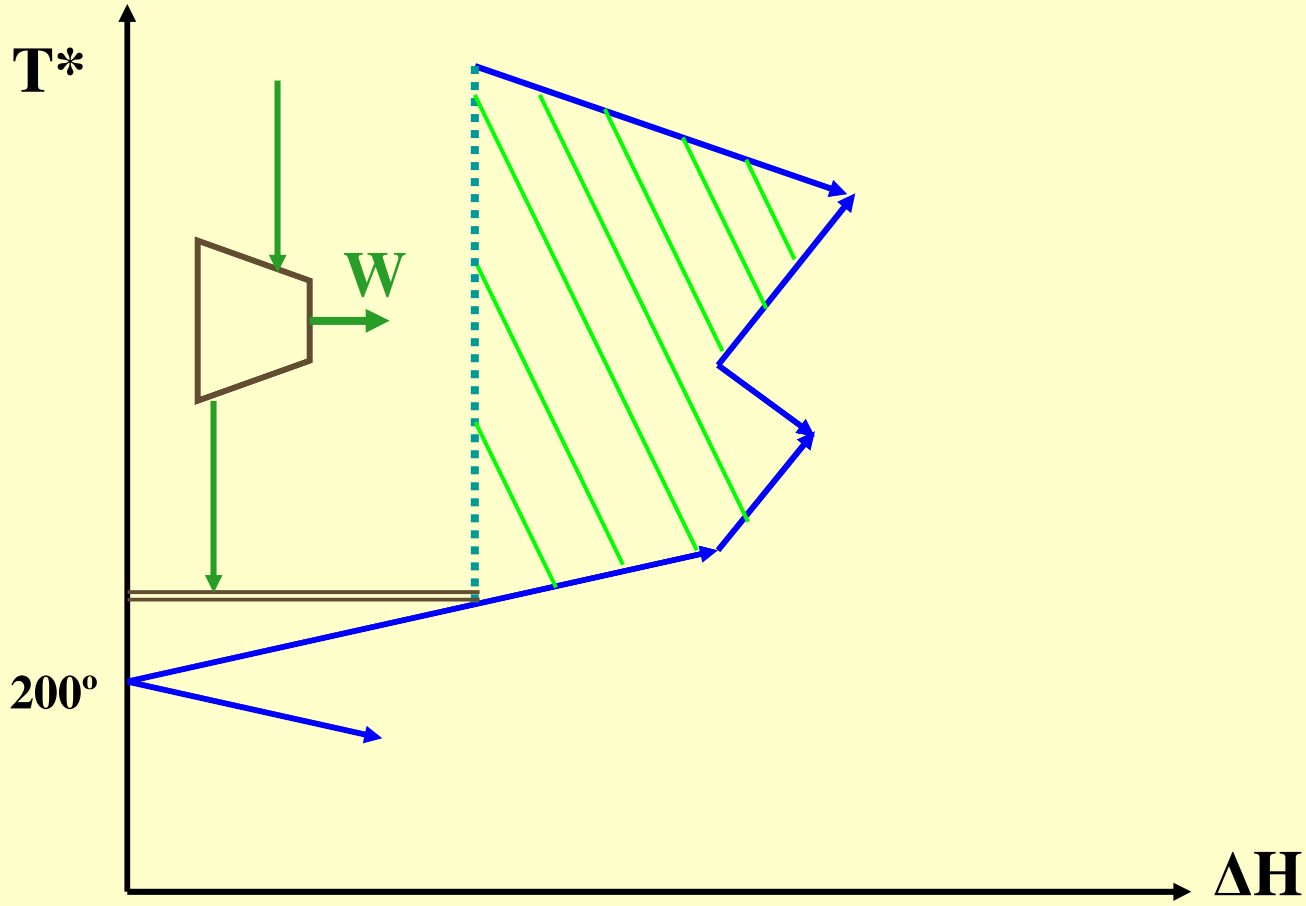
$$Q_{fuel} = Q_{Hmin} + W + Q_{loss}$$



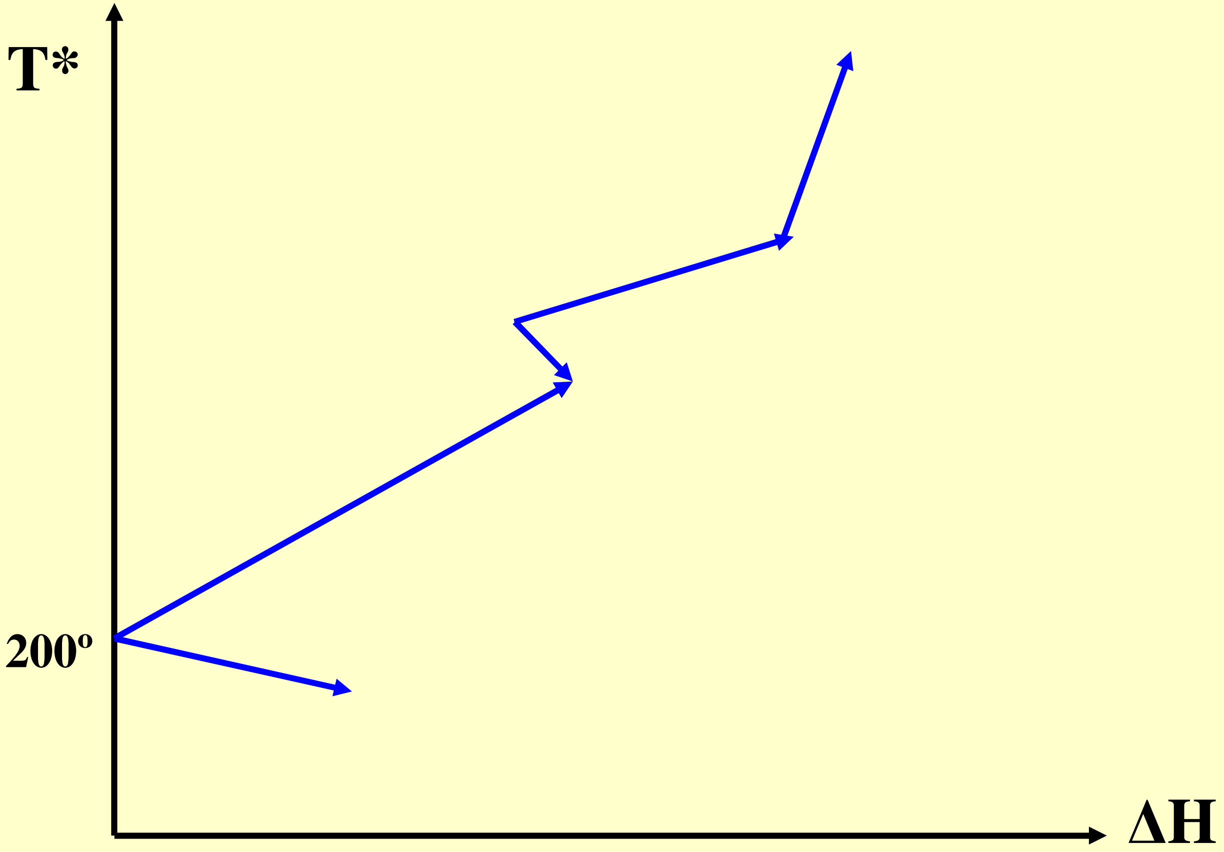
A gas turbine exhaust matched with process (same as flue gas)



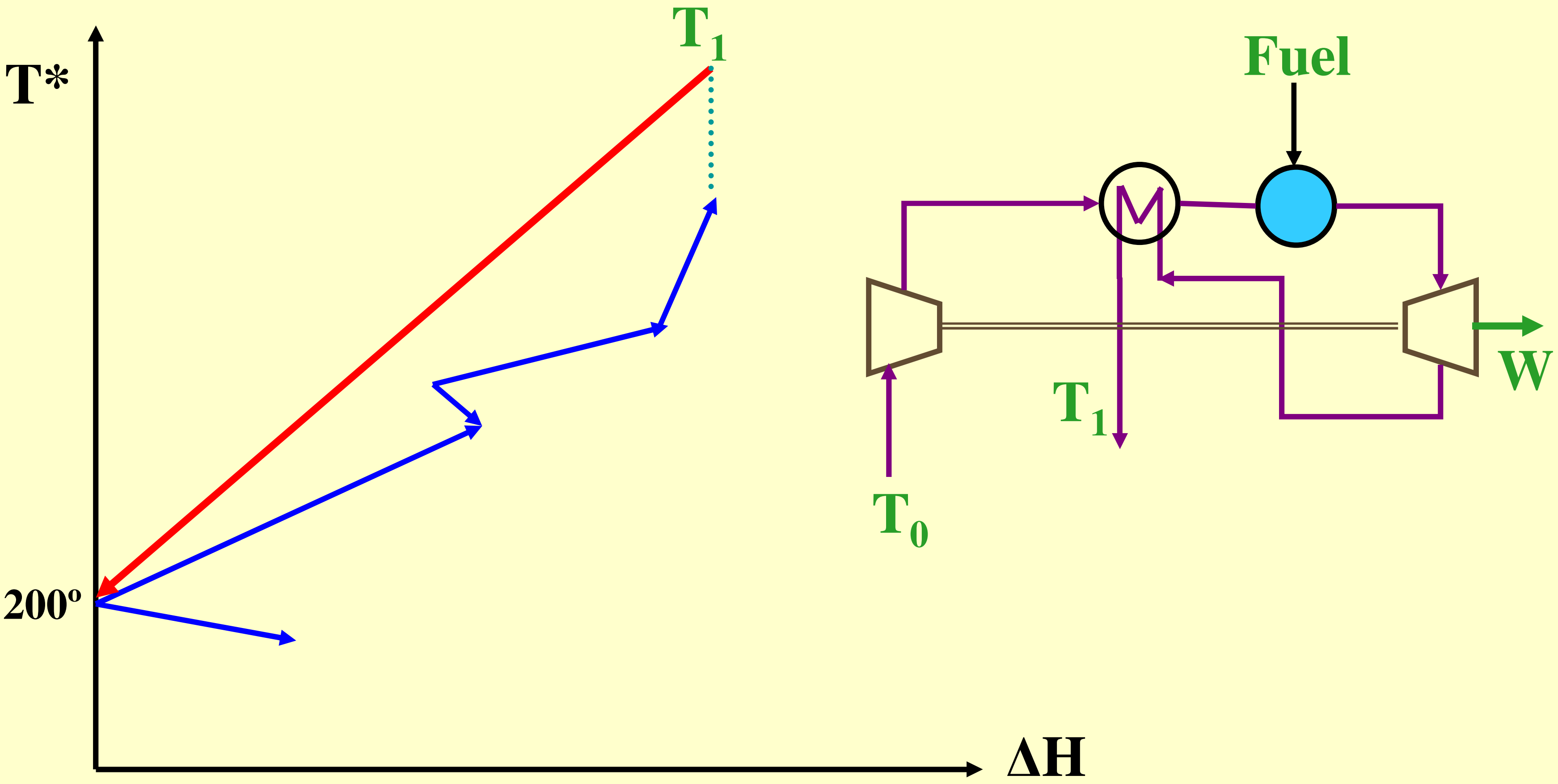
Question : Which CHP Scheme?



Answer : Steam Turbine!



Question : Which CHP Scheme?

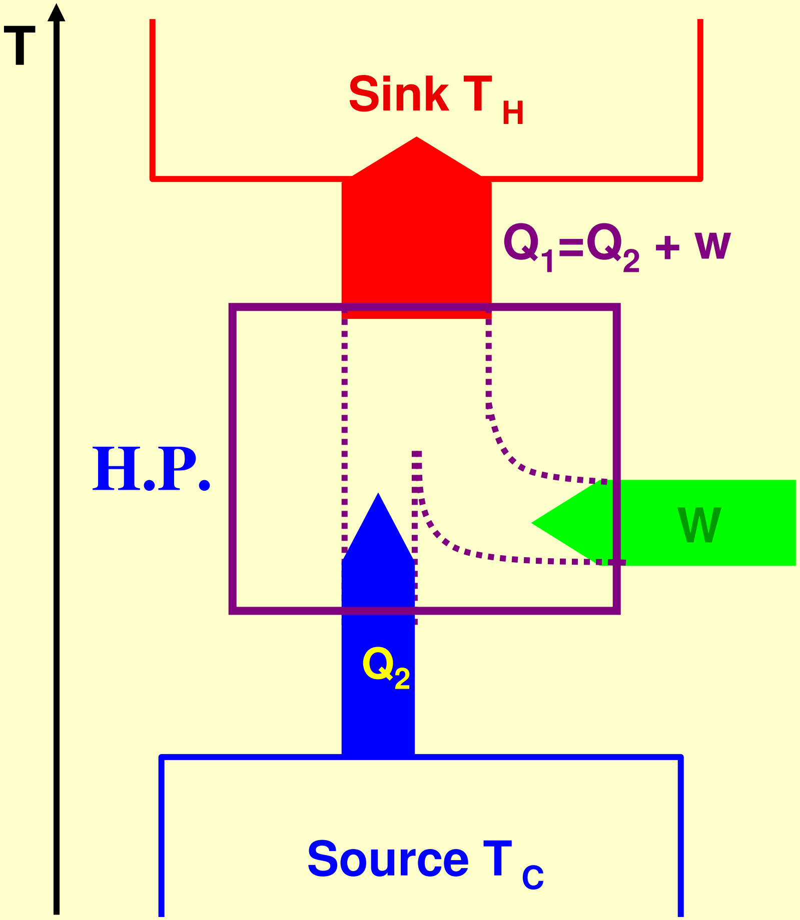


Answer : Gas Turbine!

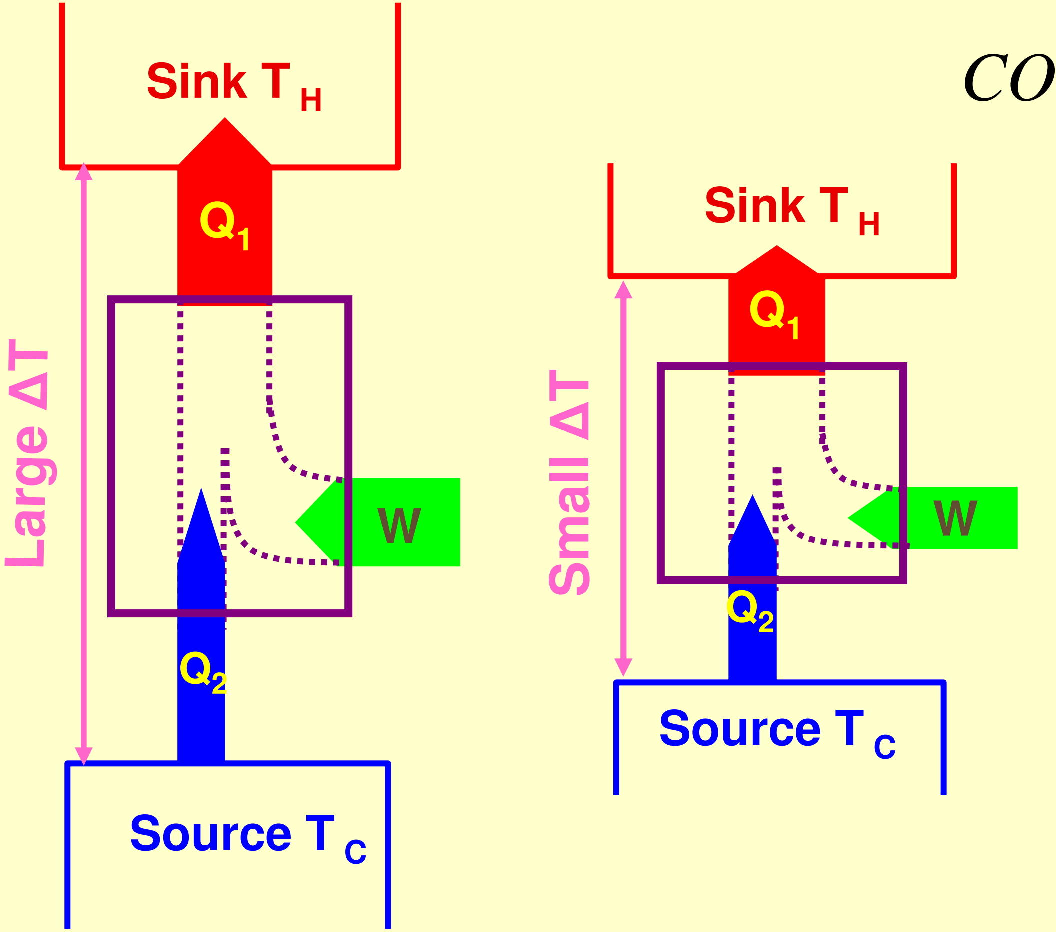
LECTURE 16

Heat pumps

Heat Pump Model



Coefficient of Performance

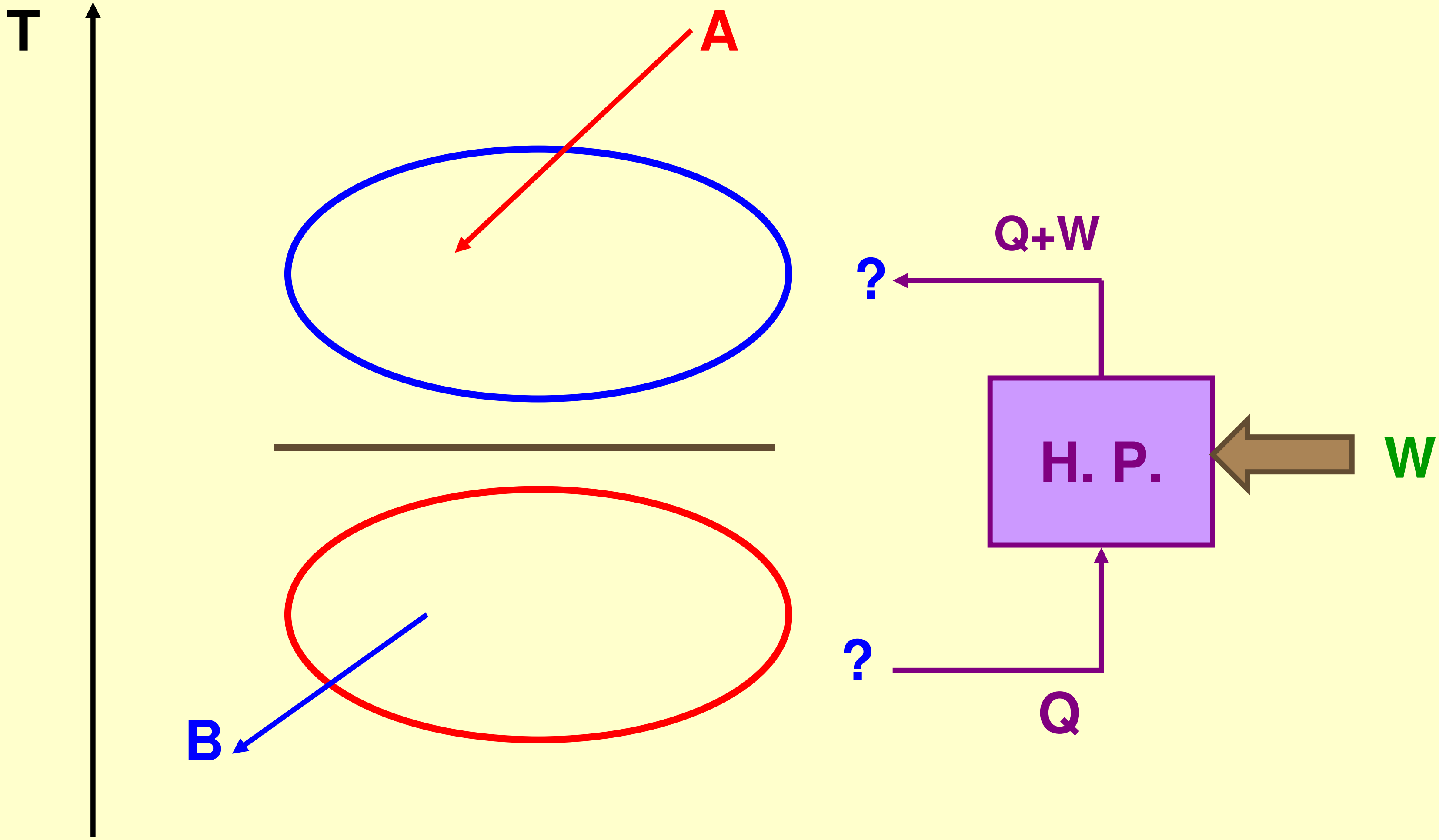


$$COP = \frac{Q_2}{W} \left\{ \begin{aligned} COP_{hp} &= \frac{T_H}{T_H - T_C} \\ COP_{ref} &= \frac{T_C}{T_H - T_C} \end{aligned} \right.$$

$$W_{hp} = \frac{Q_H}{\eta_m (COP)_{hp}}$$

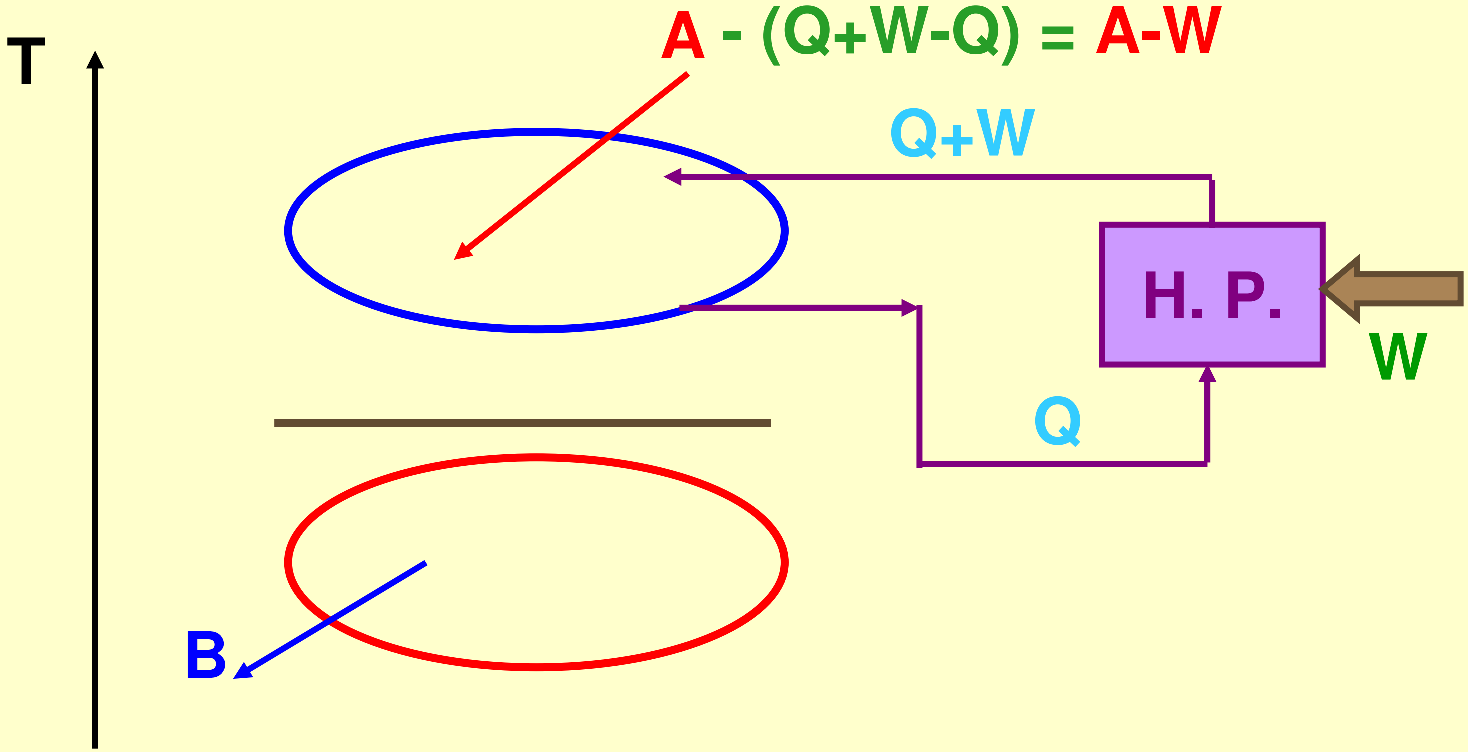
$$W_{ref} = \frac{Q_C}{\eta_m (COP)_{ref}}$$

η_m = machine efficiency



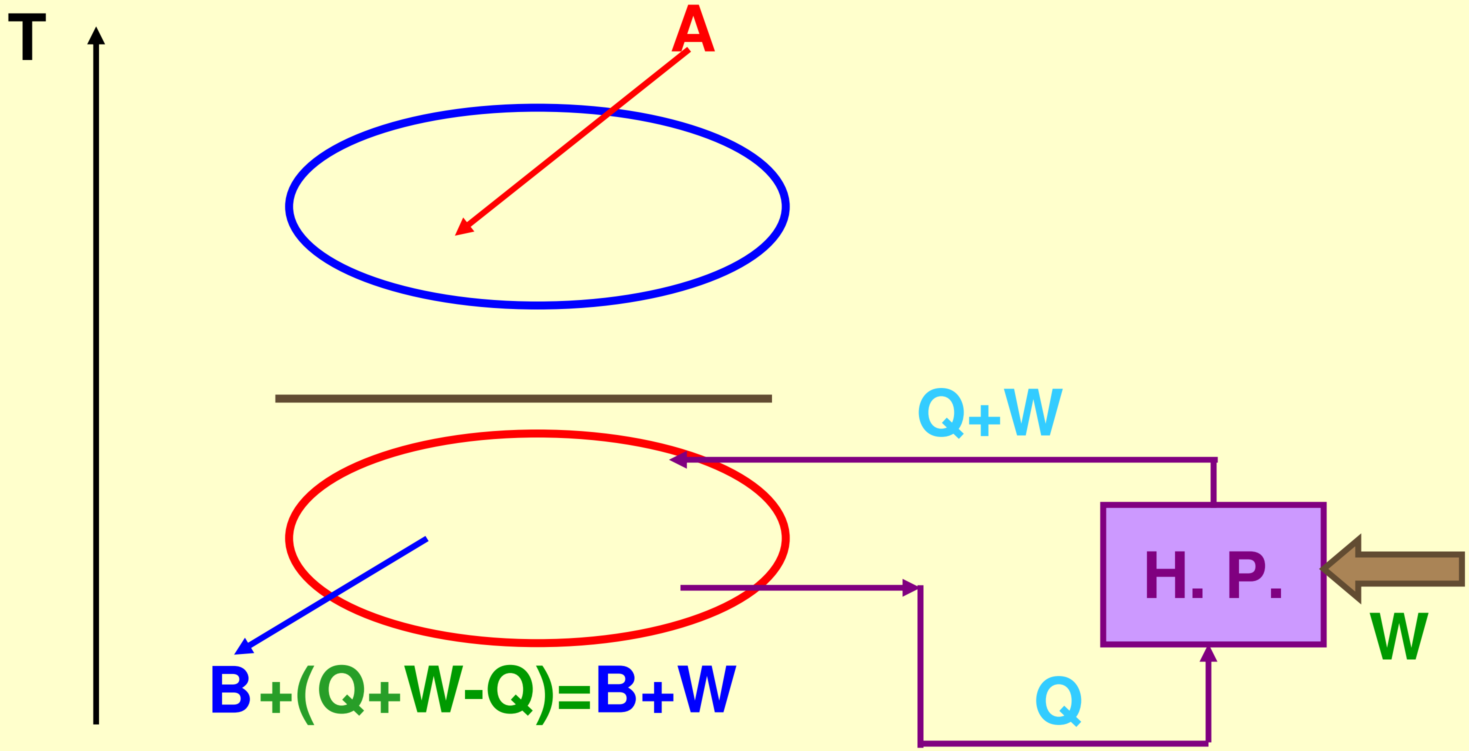
How should we integrate a Heat Pump?

Integrate above the pinch



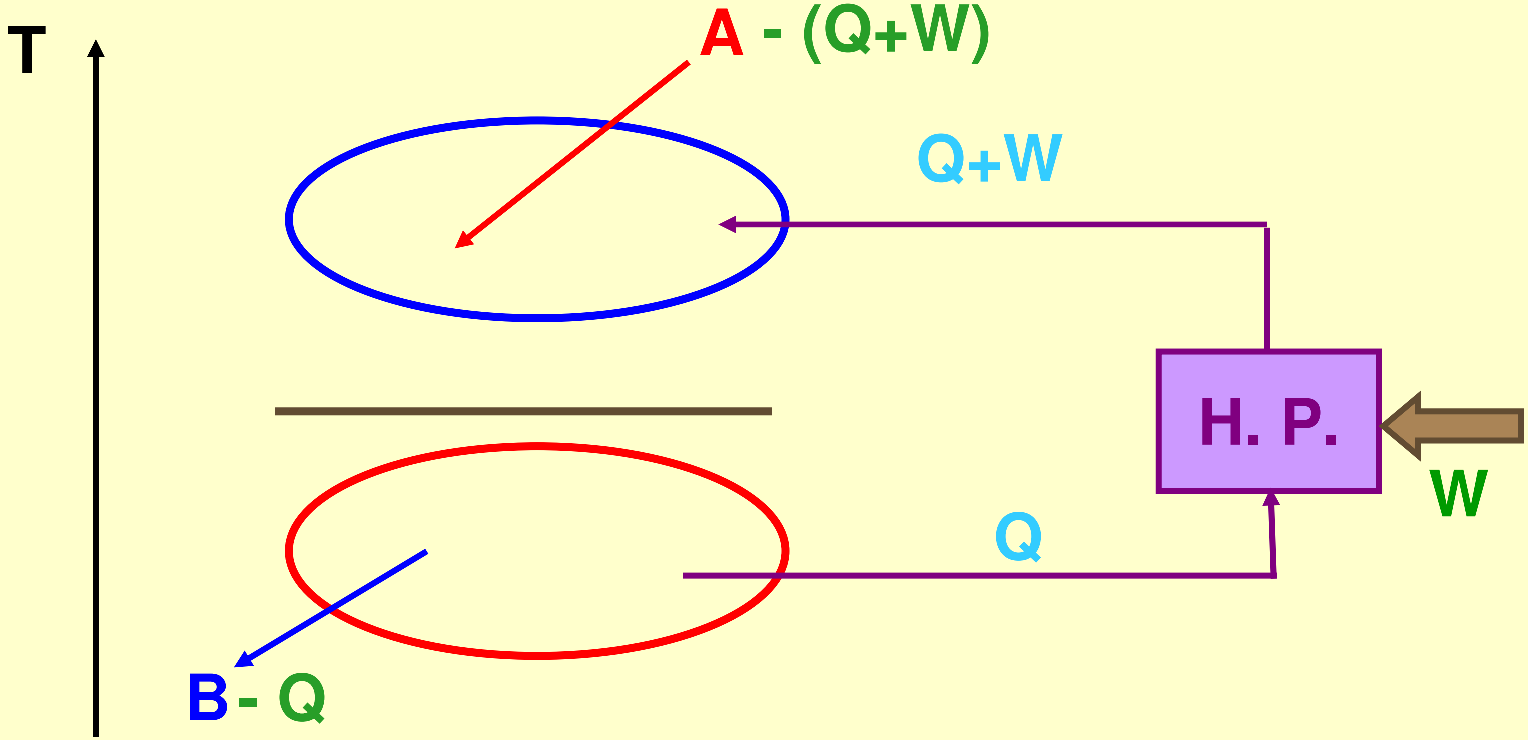
Power ⟶ Heat

Integrate below the pinch



Power → more cooling water

Integrate across the pinch



Save *Hot* and *Cold* Utility

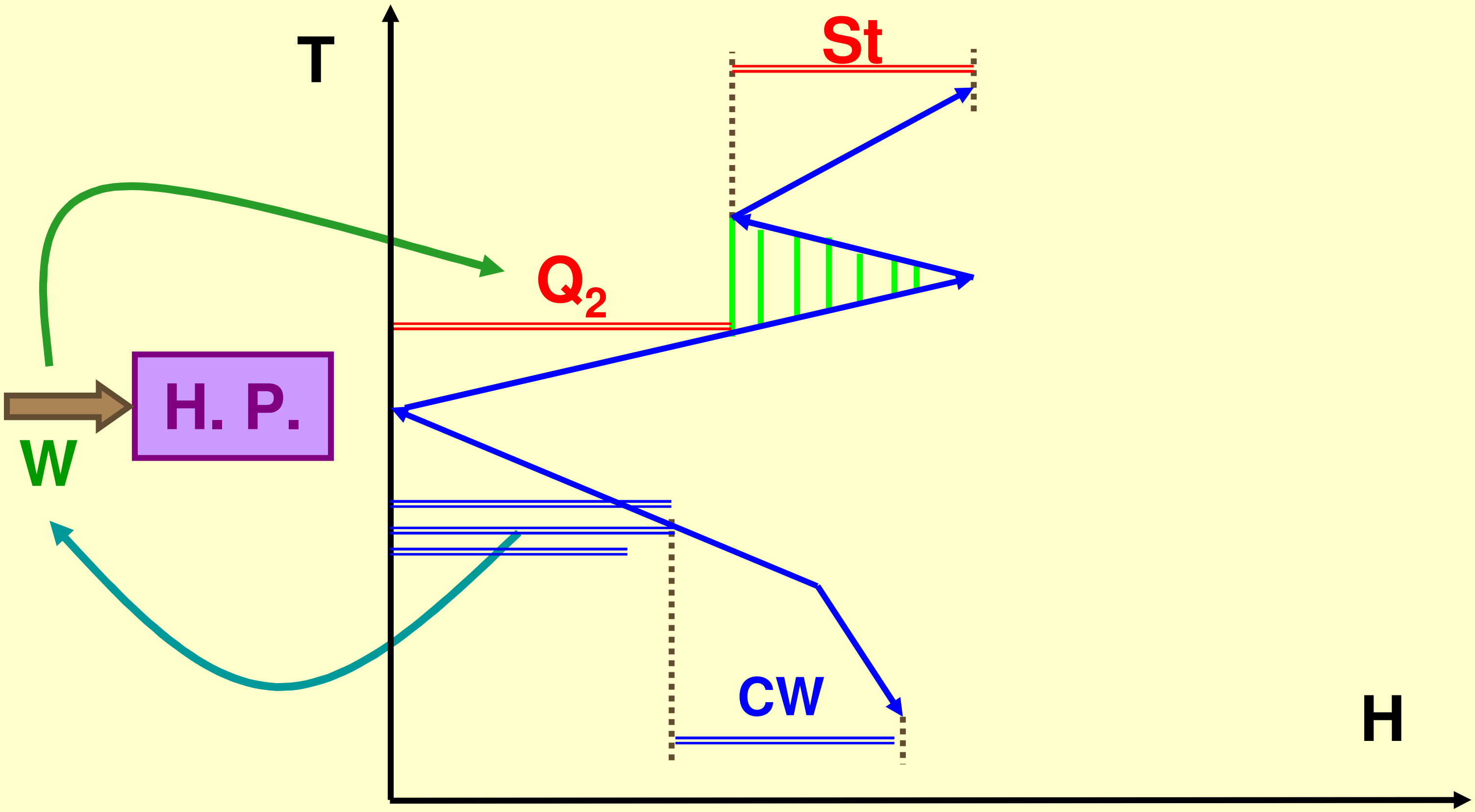
Appropriate Placement of Heat Pump is

ACROSS THE PINCH

To target the thermal design, use the

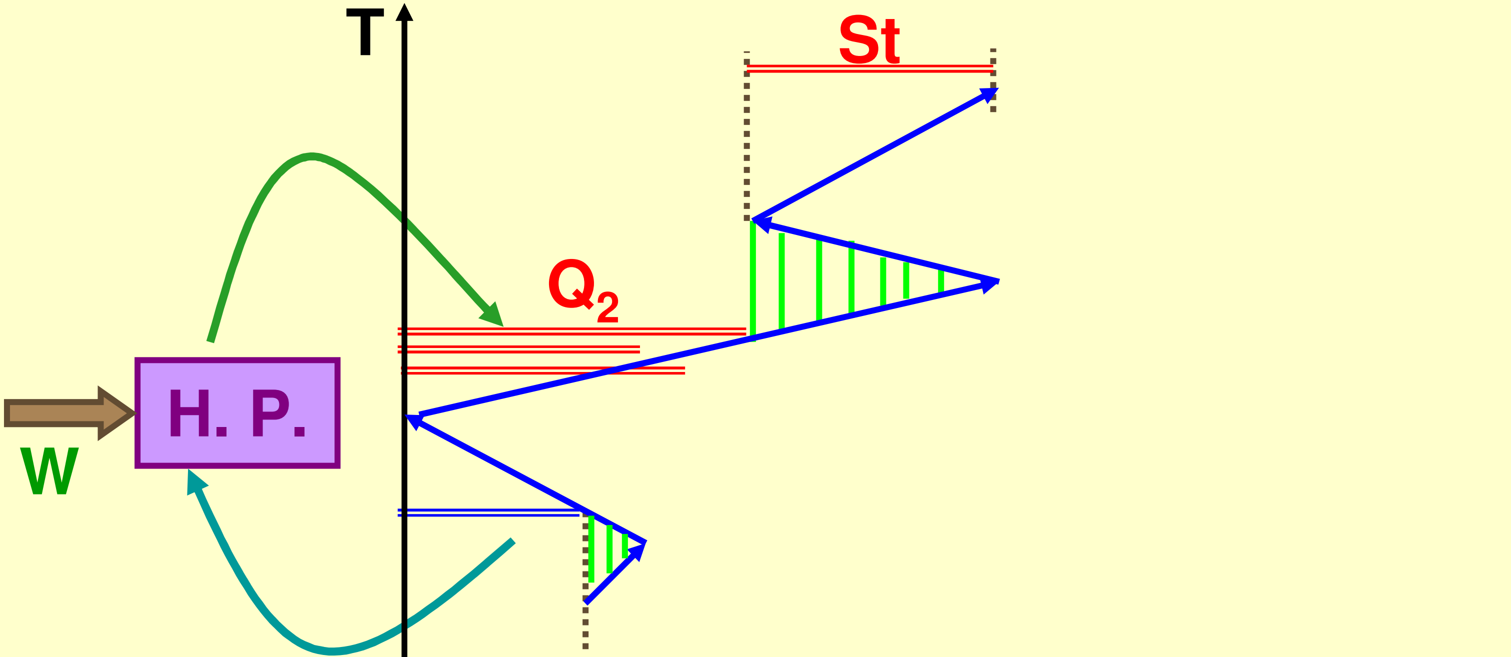
GRAND COMPOSITE CURVE

and treat the *Heat Pump* like a utility



If the hot side of *Heat Pump* is limiting

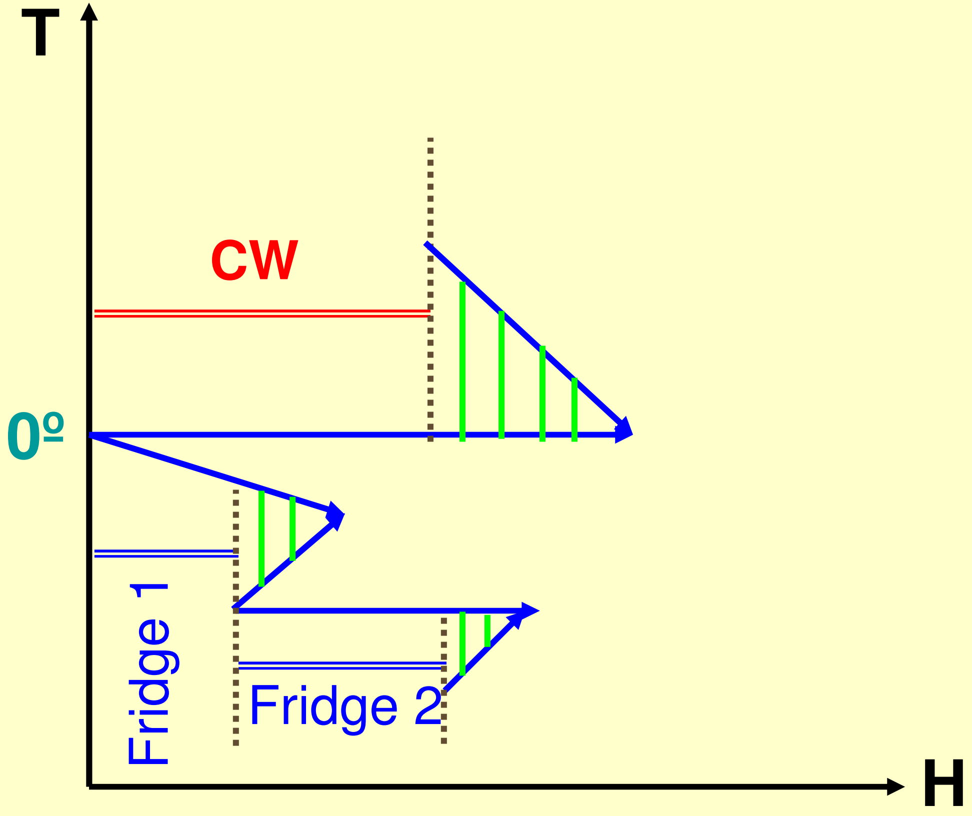
Find cold side temperature by iteration



If the cold side of *Heat Pump* is limiting,

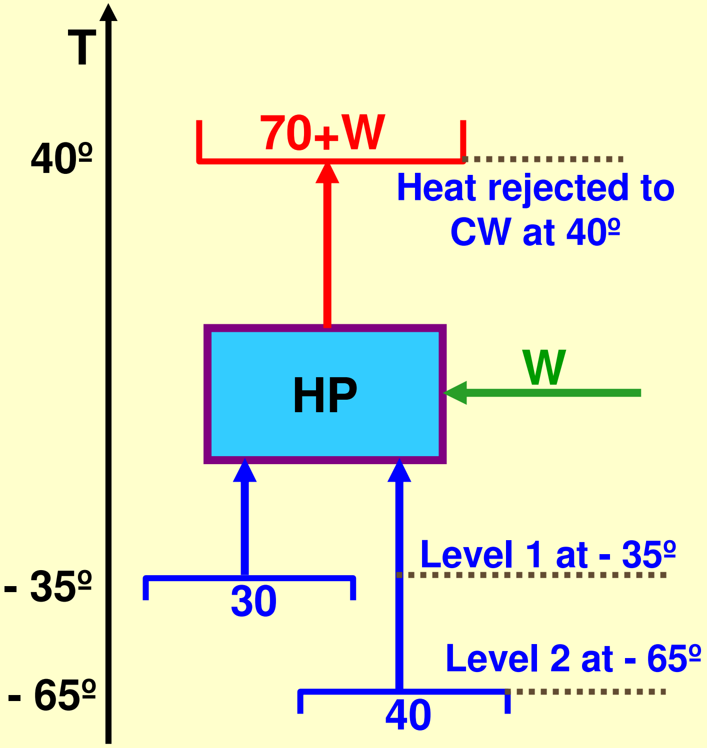
Find hot side temperature by iteration

And now, Let’s get more sophisticated…

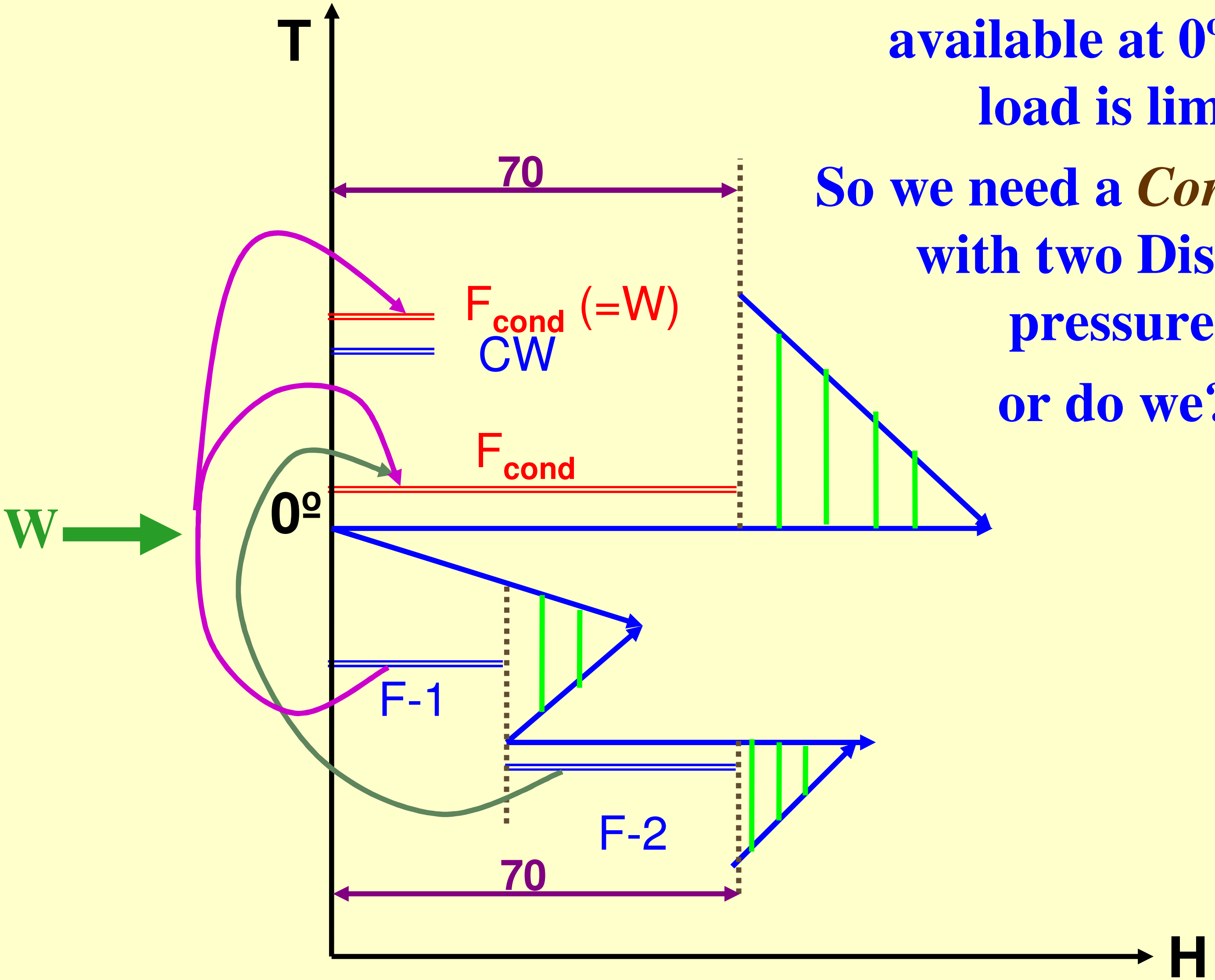


We can use cooling water as hot utility … but can we do better still?

Let's consider the fridge cycle



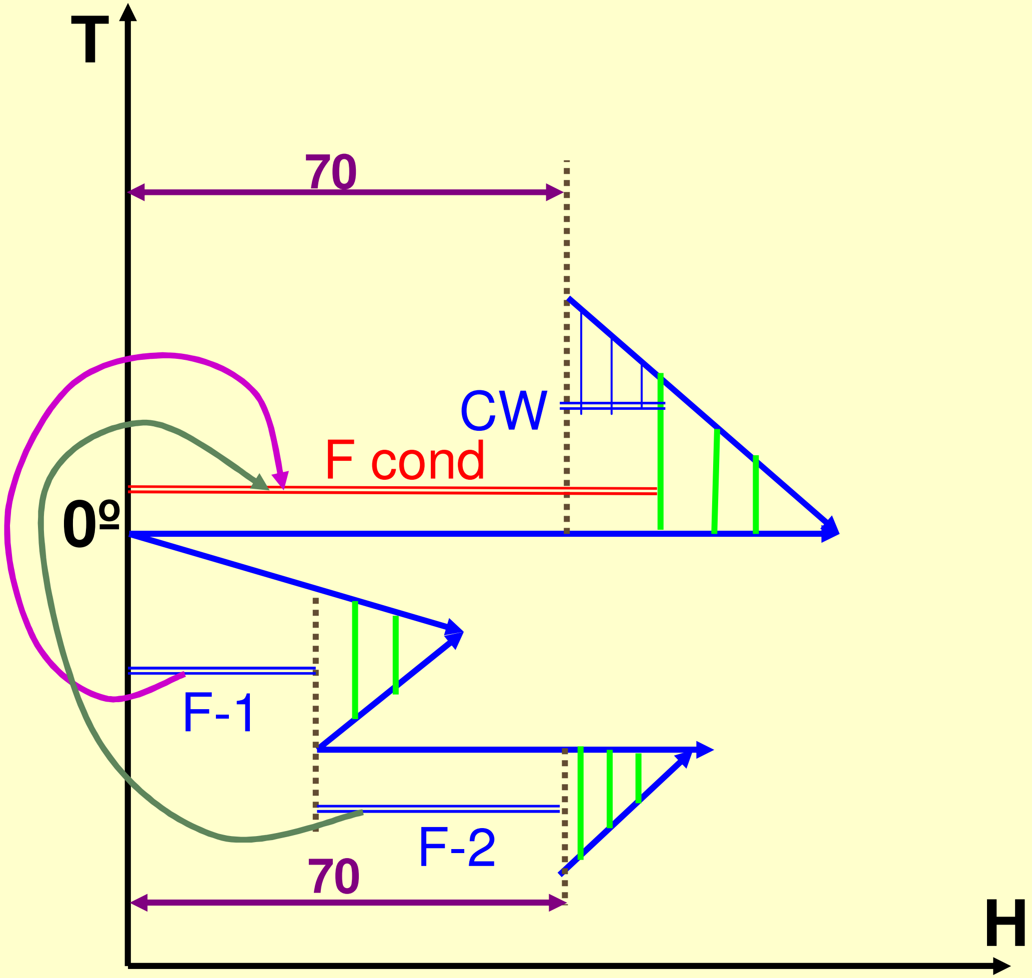
Do we have to Pump the heat all the way up to 40ºC ?



There is a nice Heat Sink available at 0º, but its load is limited

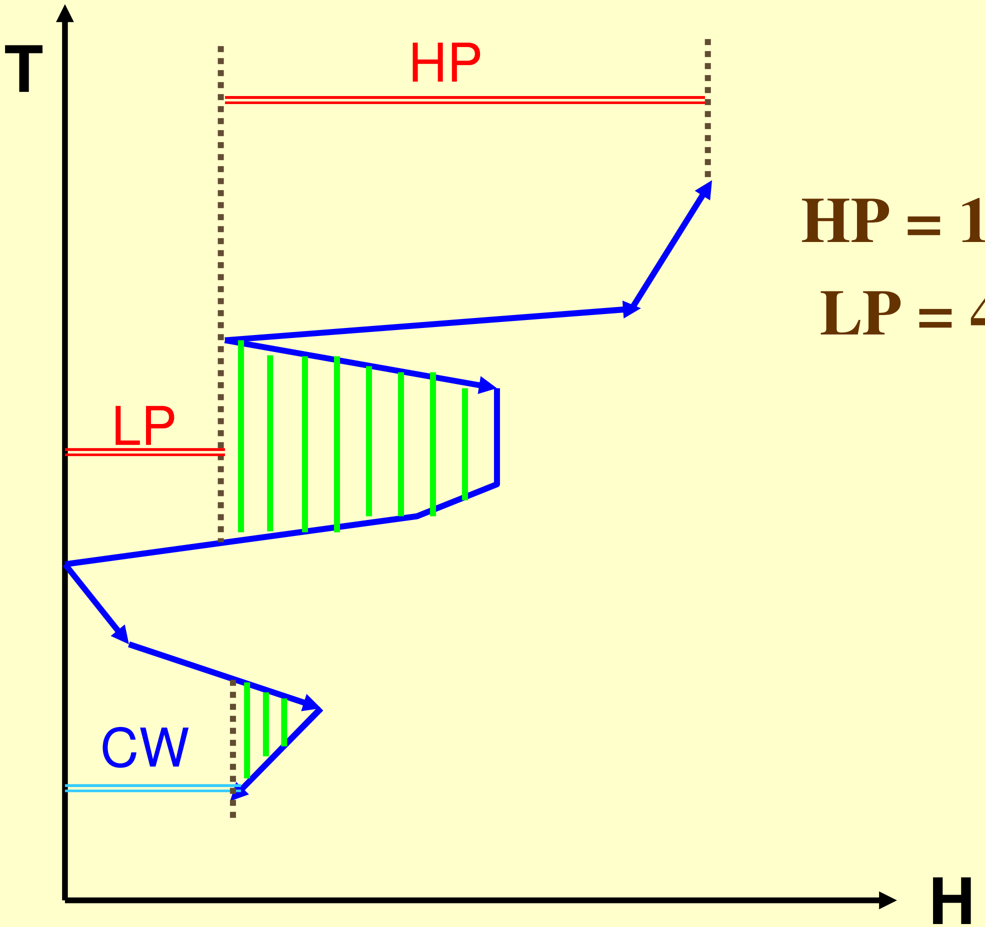
So we need a *Compressor* with two Discharge pressure …

or do we?


T
70
CW
F cond
0º
F-1
F-2
70
H

Do we ever integrate a heat pump not across the pinch?

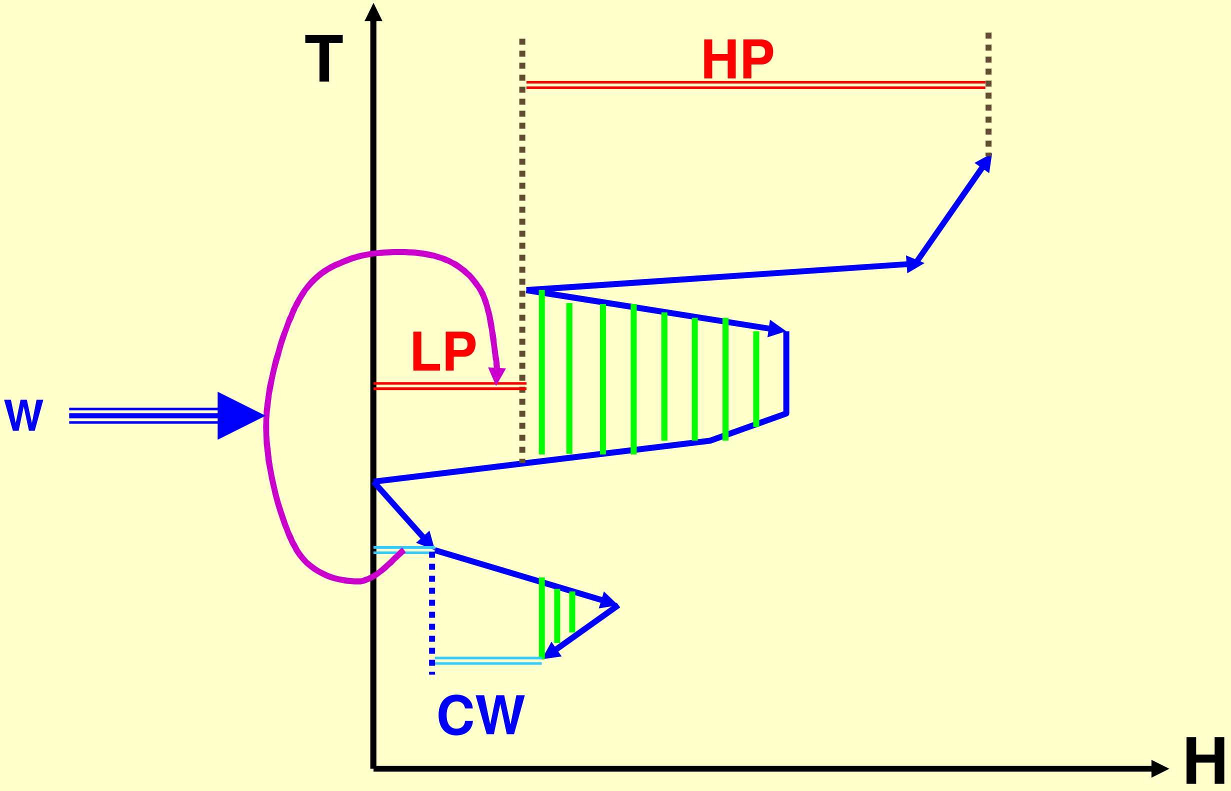
Consider the following case



HP = 15 $ / ton

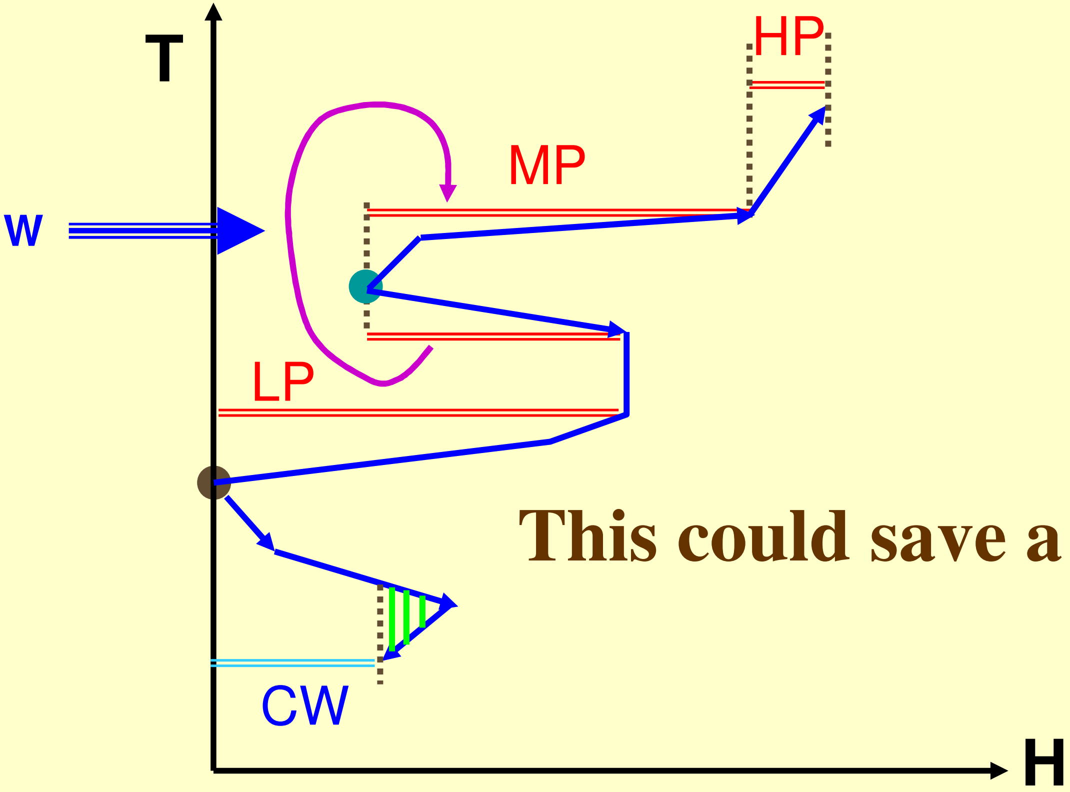
LP = 4 $ / ton

Any case for heat pumping?



Answer : NO

- ✓COP is poor
- ✓LP steam is cheap anyway



This could save a lot of money

Note:

The *Heat Pump* may not be across the *process pinch*, but across the *utility pinch*

Question:

Have we just violated the appropriate placement principle?

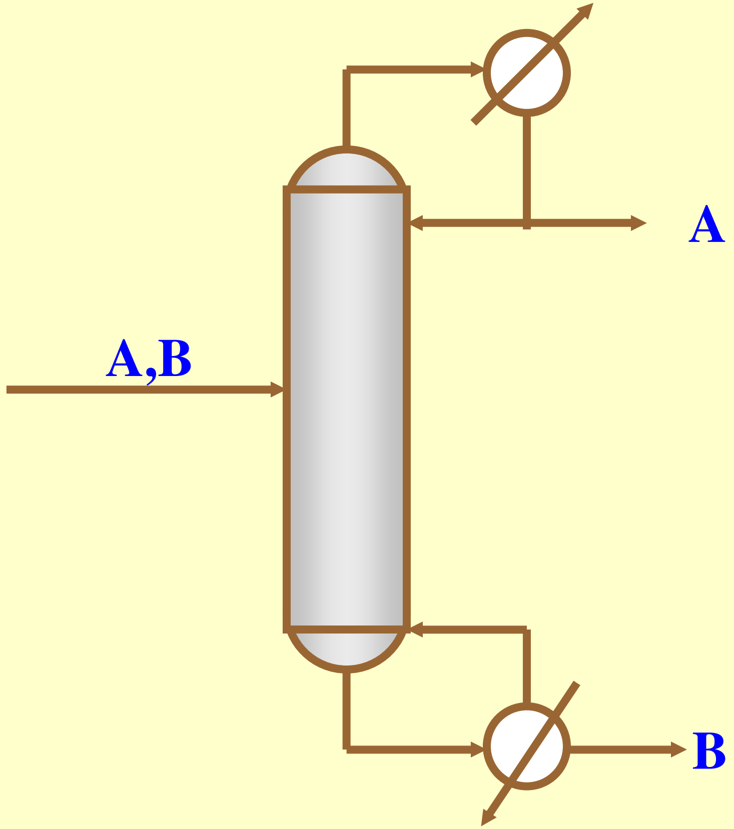
Answer:

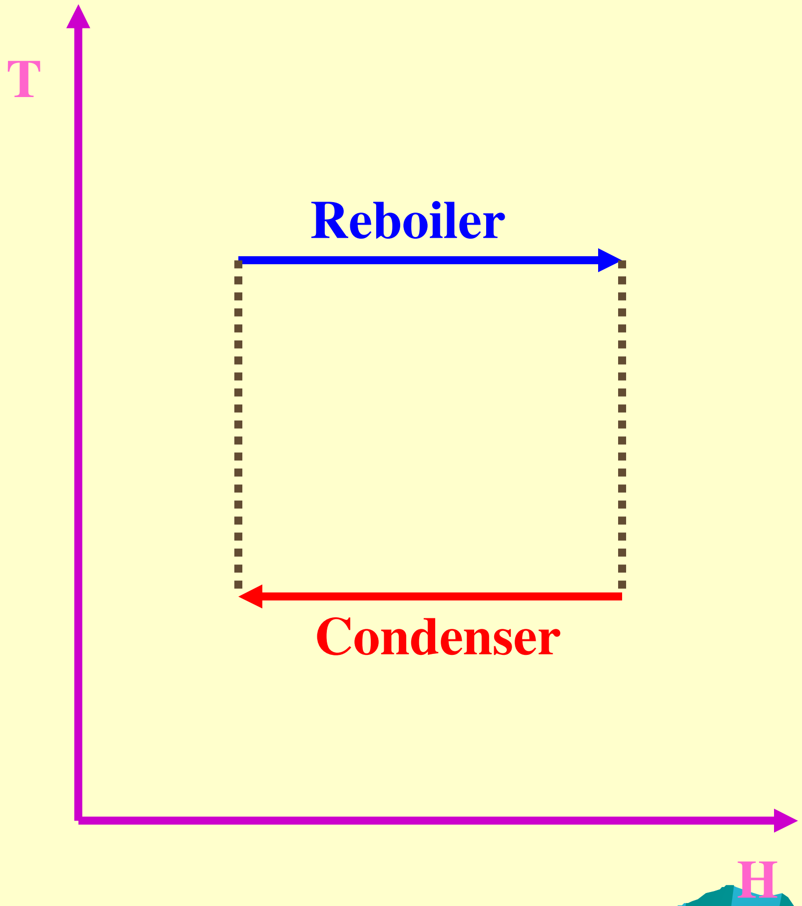
No, we have placed a *HEAT PUMP* across a *UTILITY PINCH*

LECTURE 17

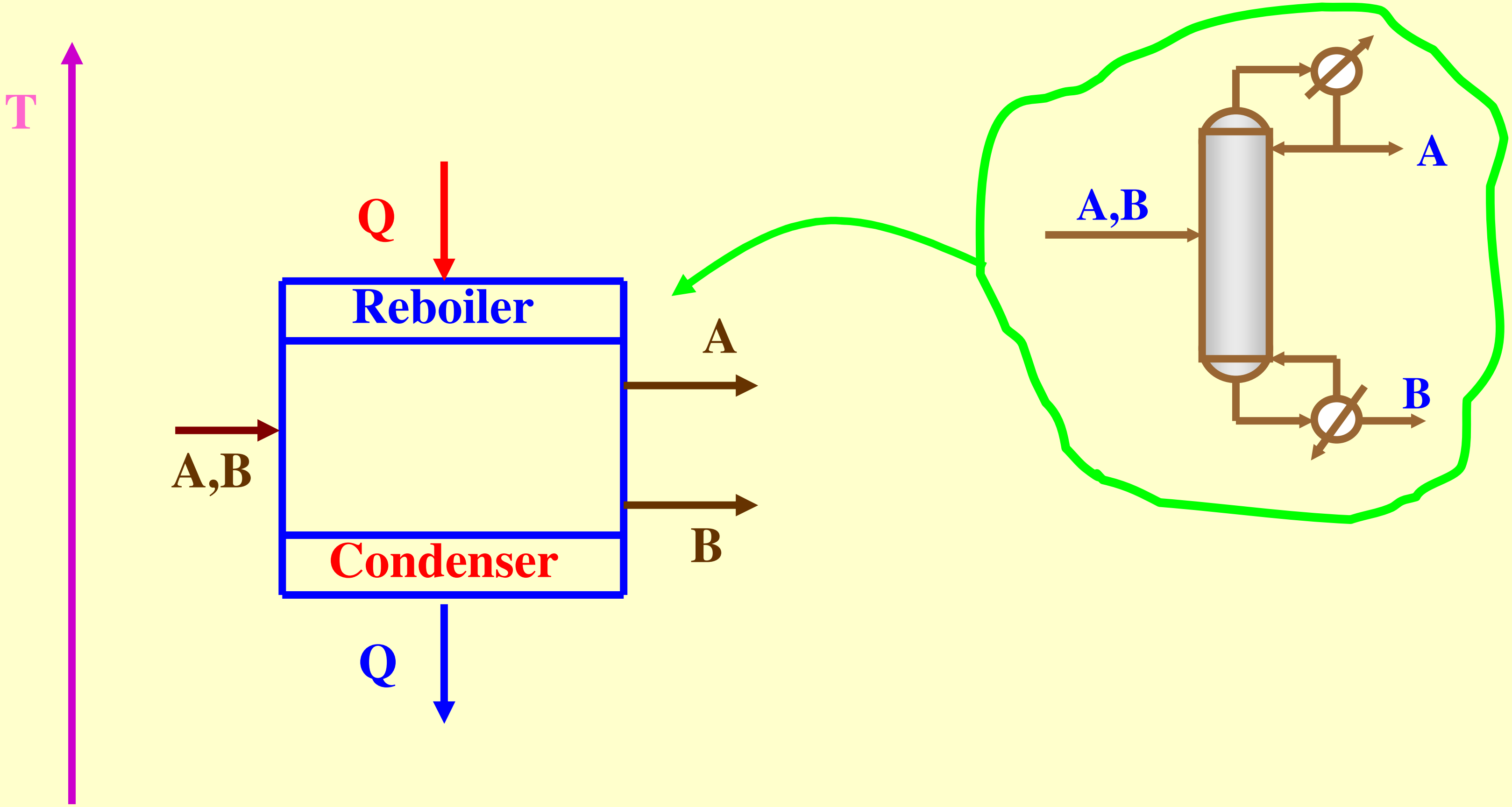
Distillation

Distillation Column



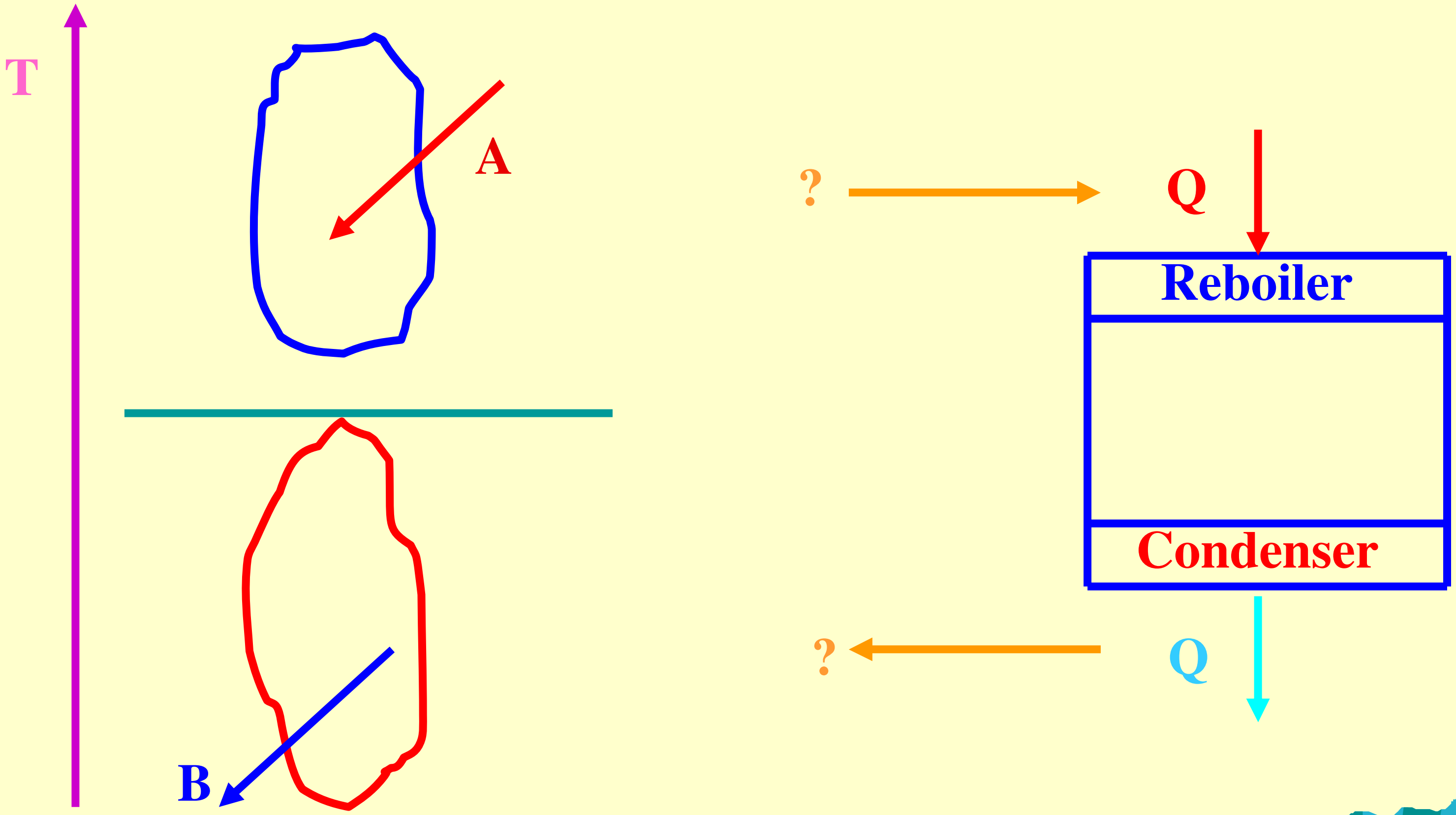


Distillation Column Model

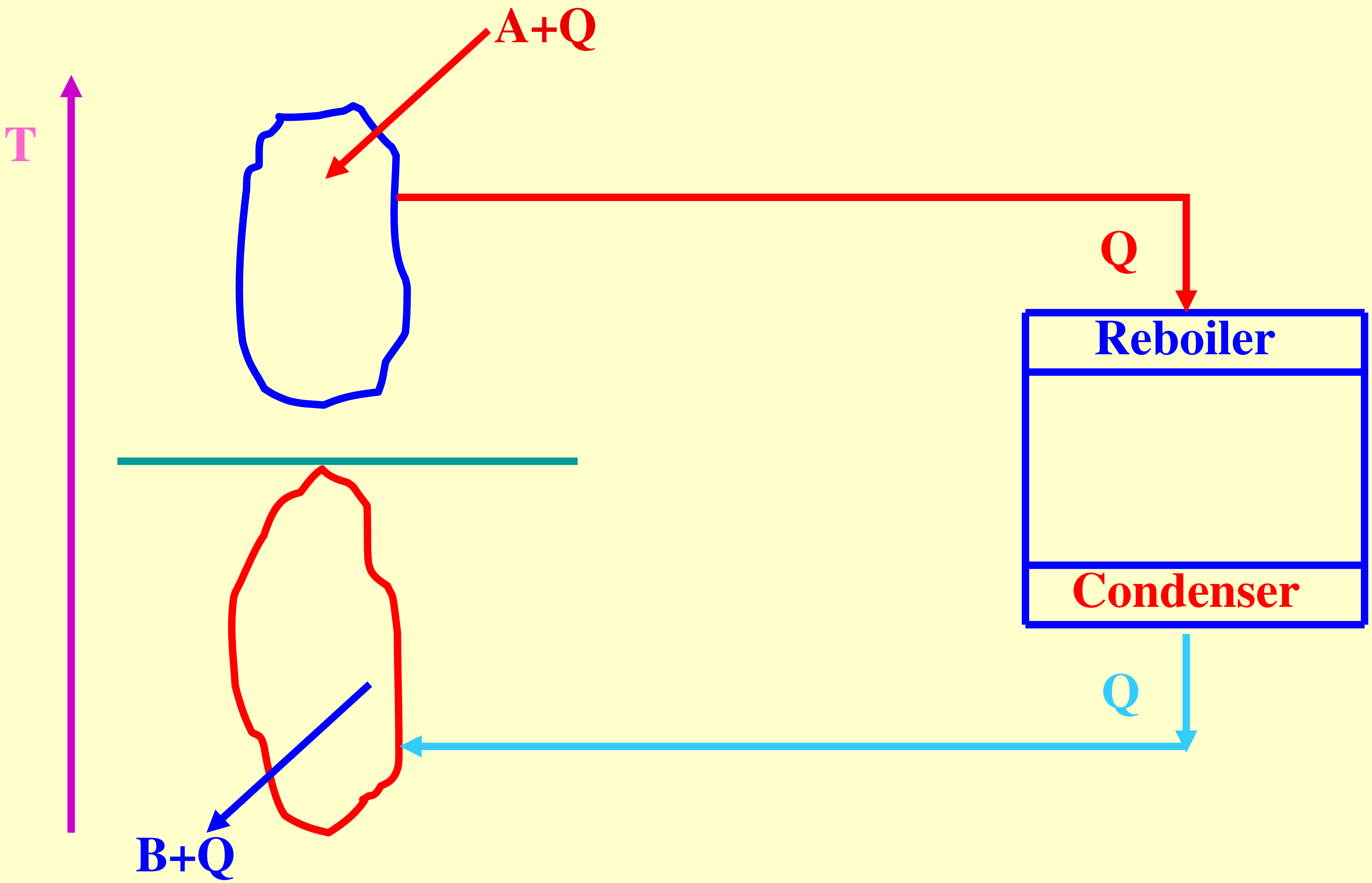


“ Separation Engine”

How Should We Integrate a Distillation Column?

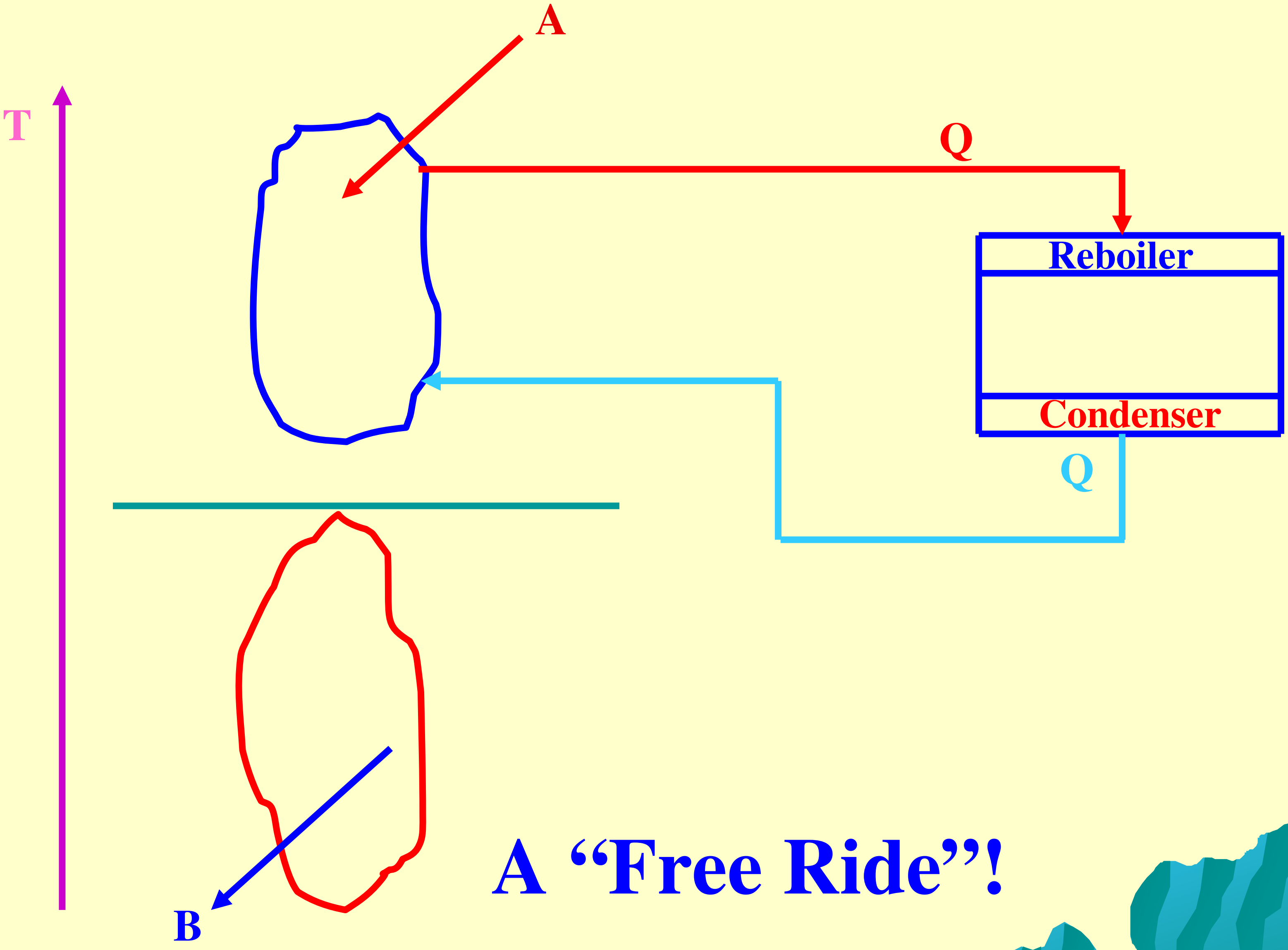


Integrate across the pinch



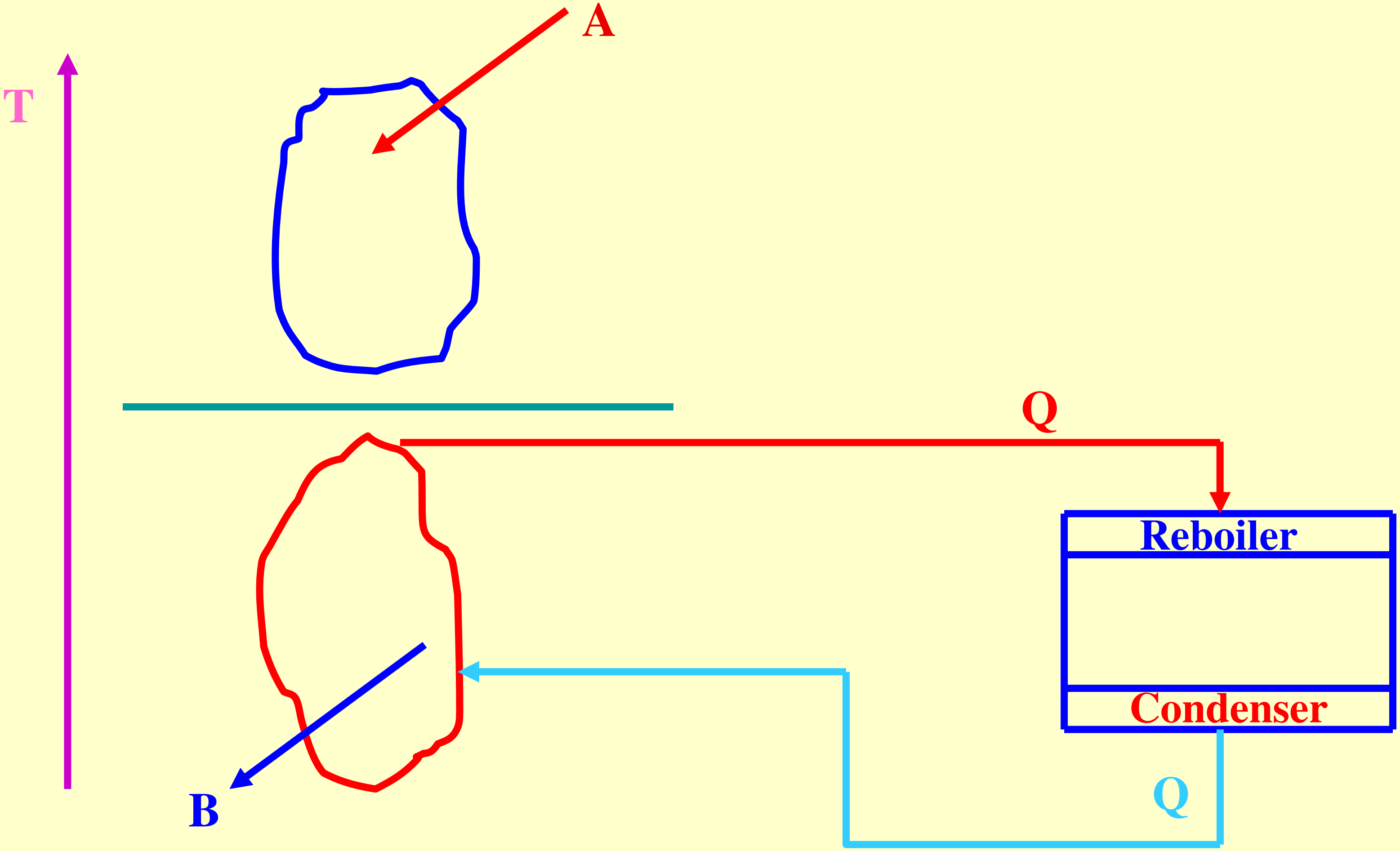
Why Integrate?

Integrate above the pinch



A “Free Ride”!

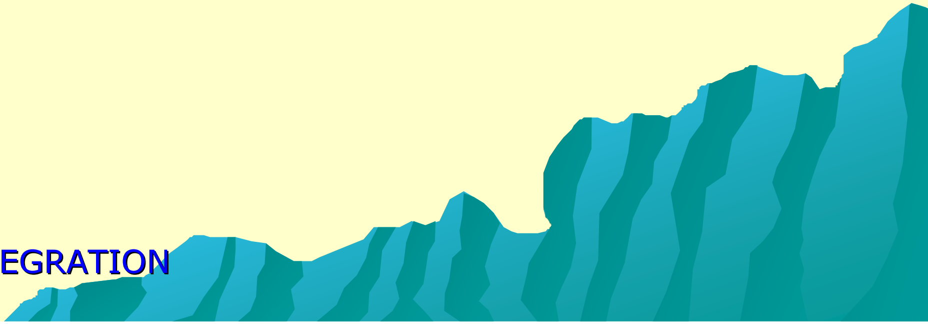
Integrate above the pinch



A "Free Ride"!

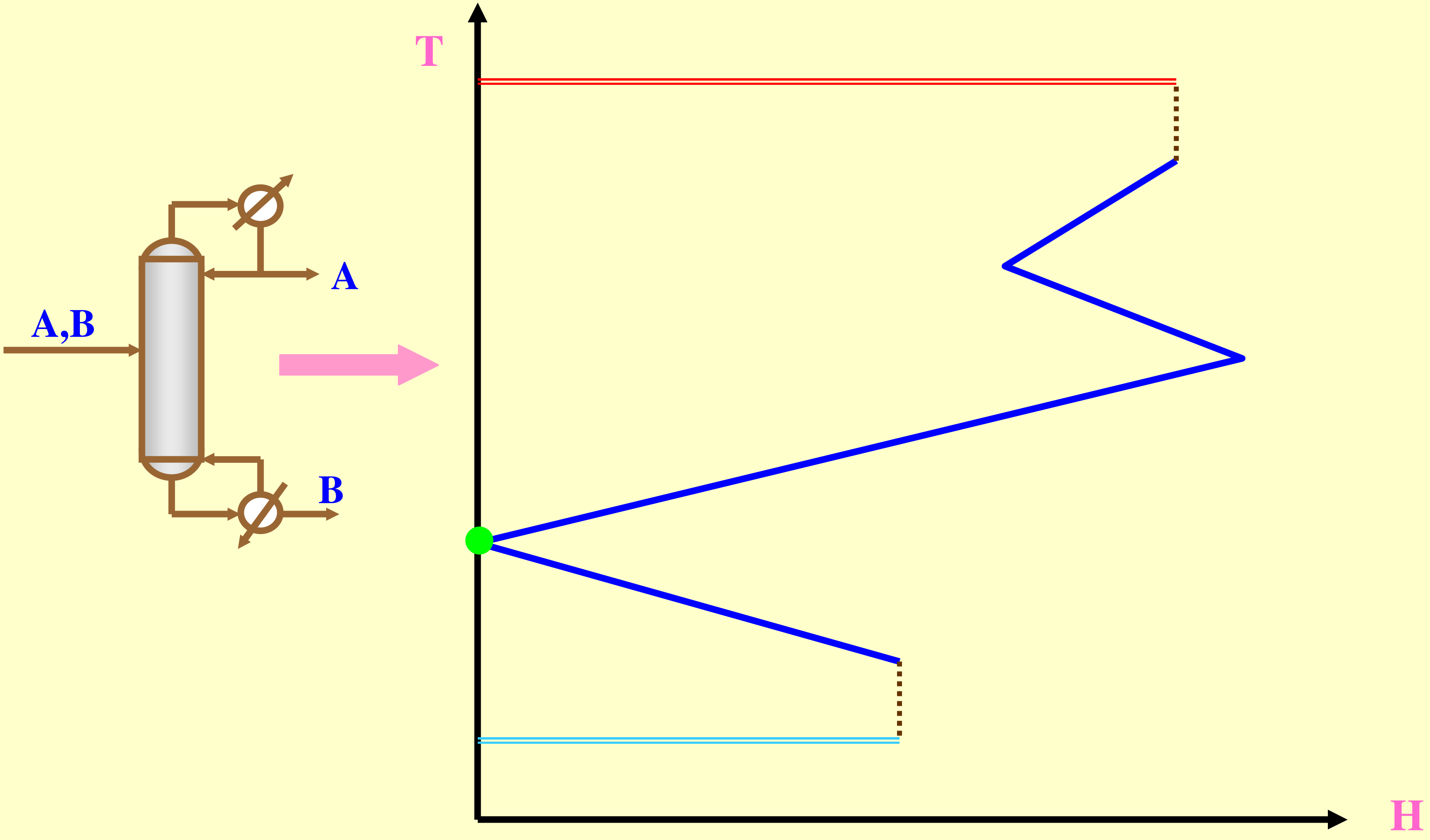
Appropriate Placement of Columns :

NOT ACROSS THE PINCH

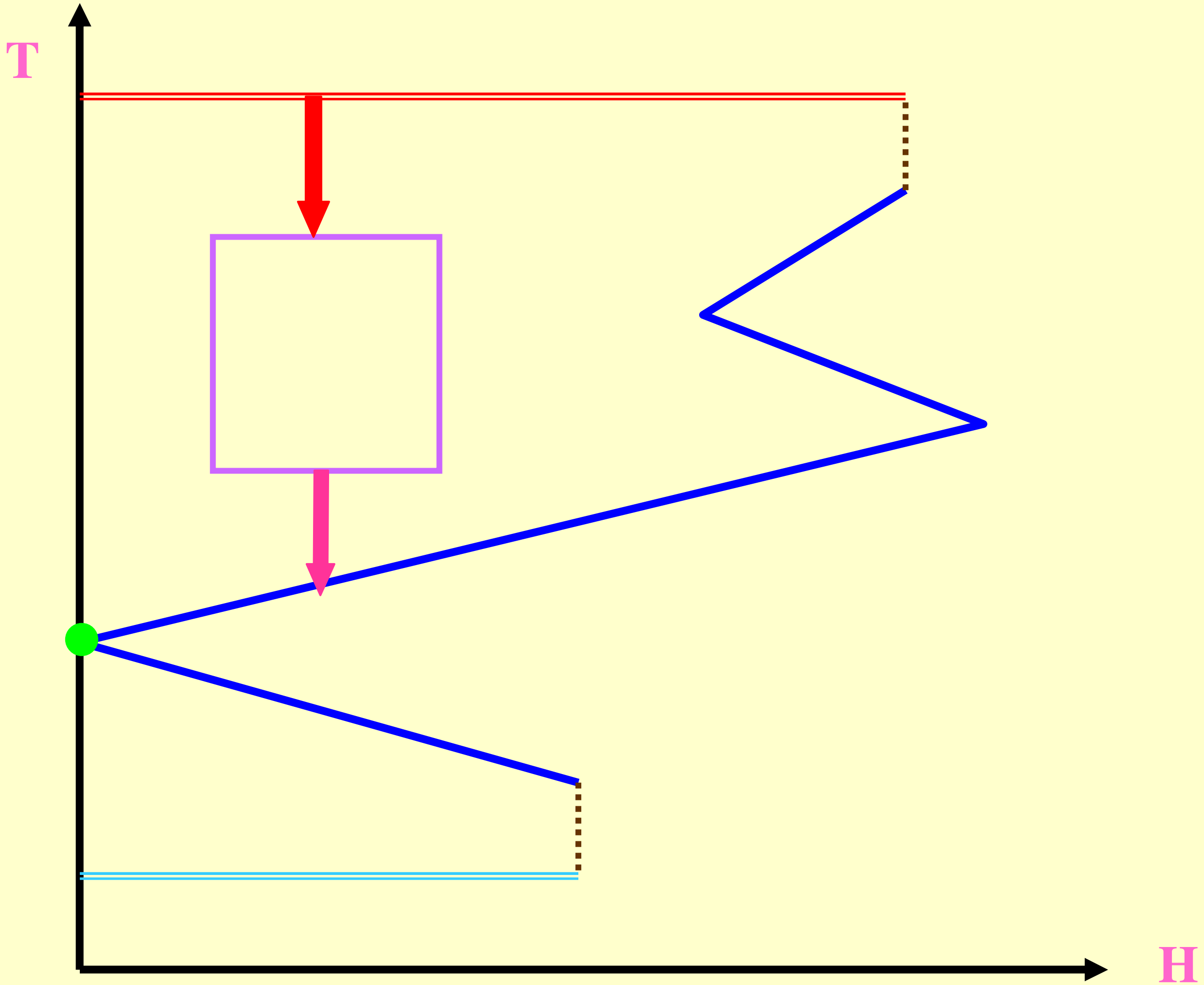


How can we integrate the column with the process appropriately?

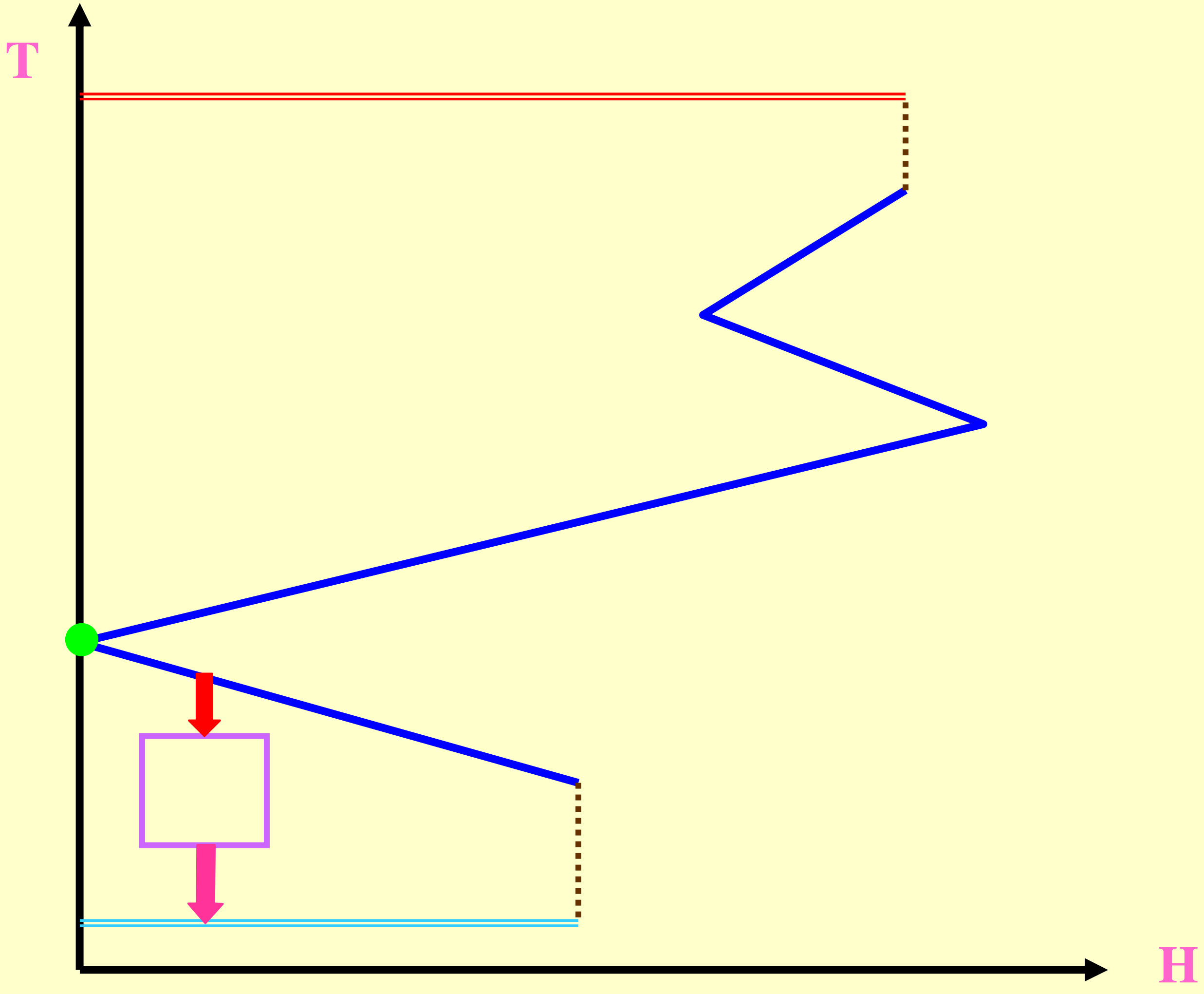
Use the background process grand composite curve and treat the column as utility …



Will the column fit the process?

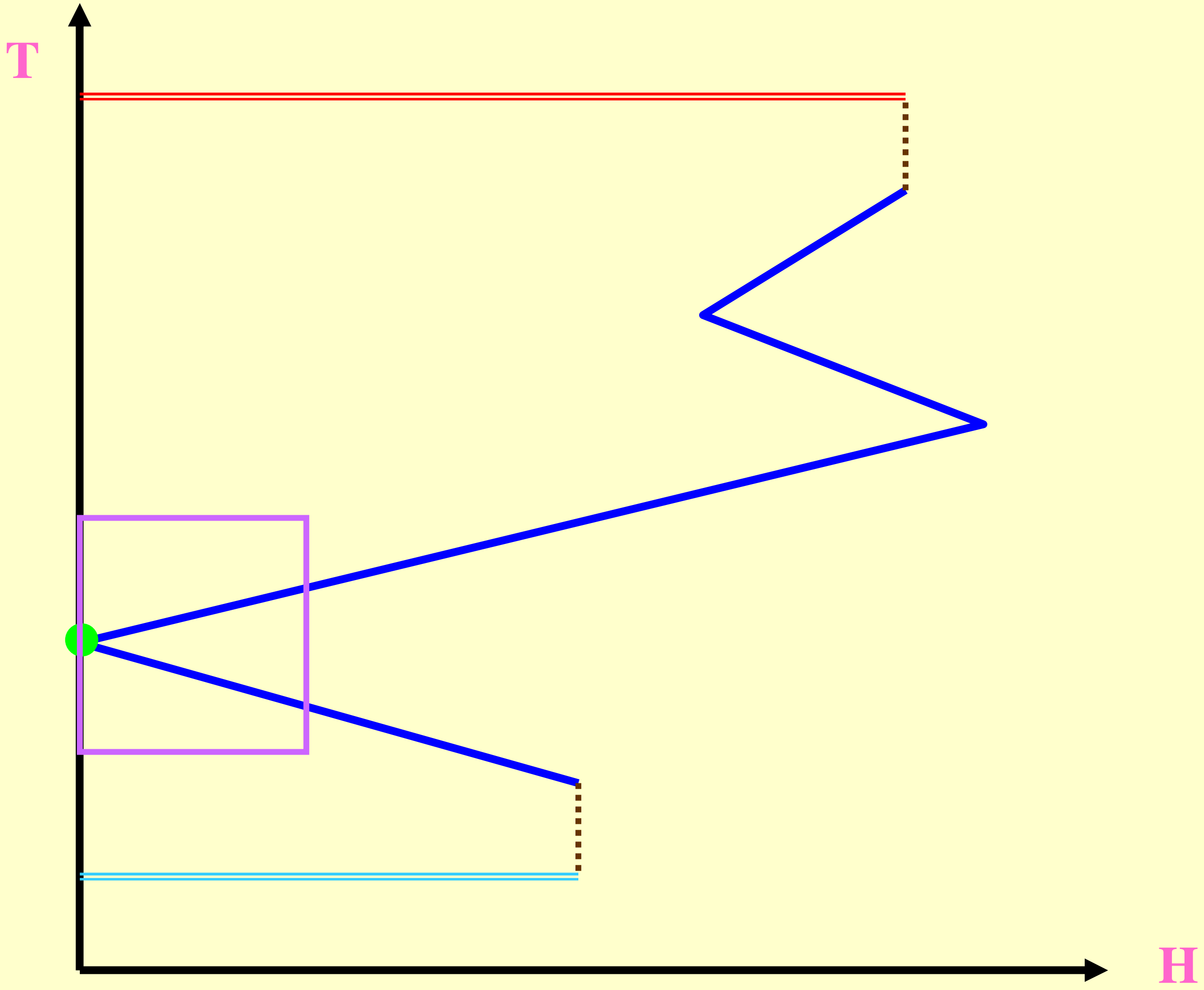


This column fits!

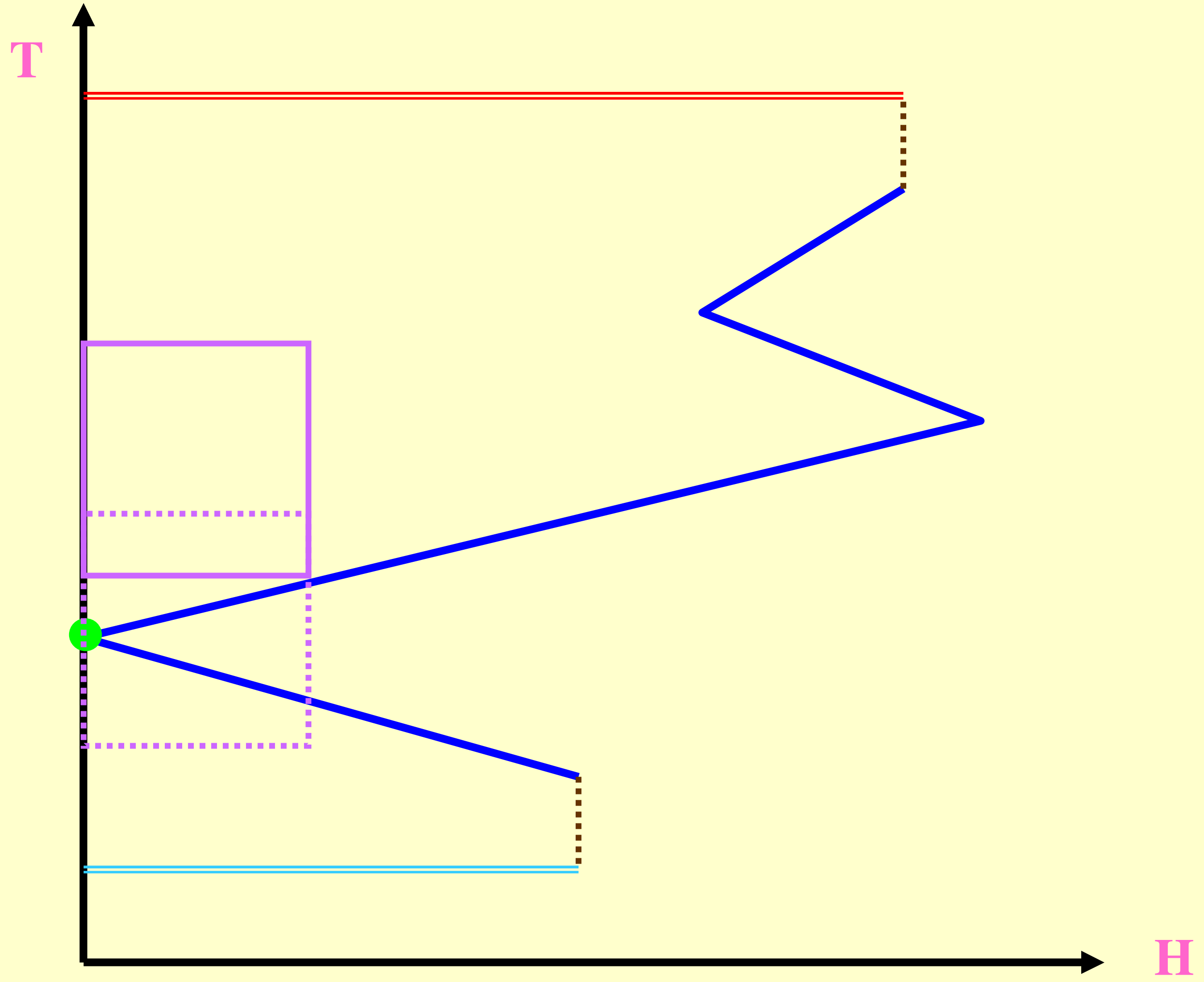


This one fits too!

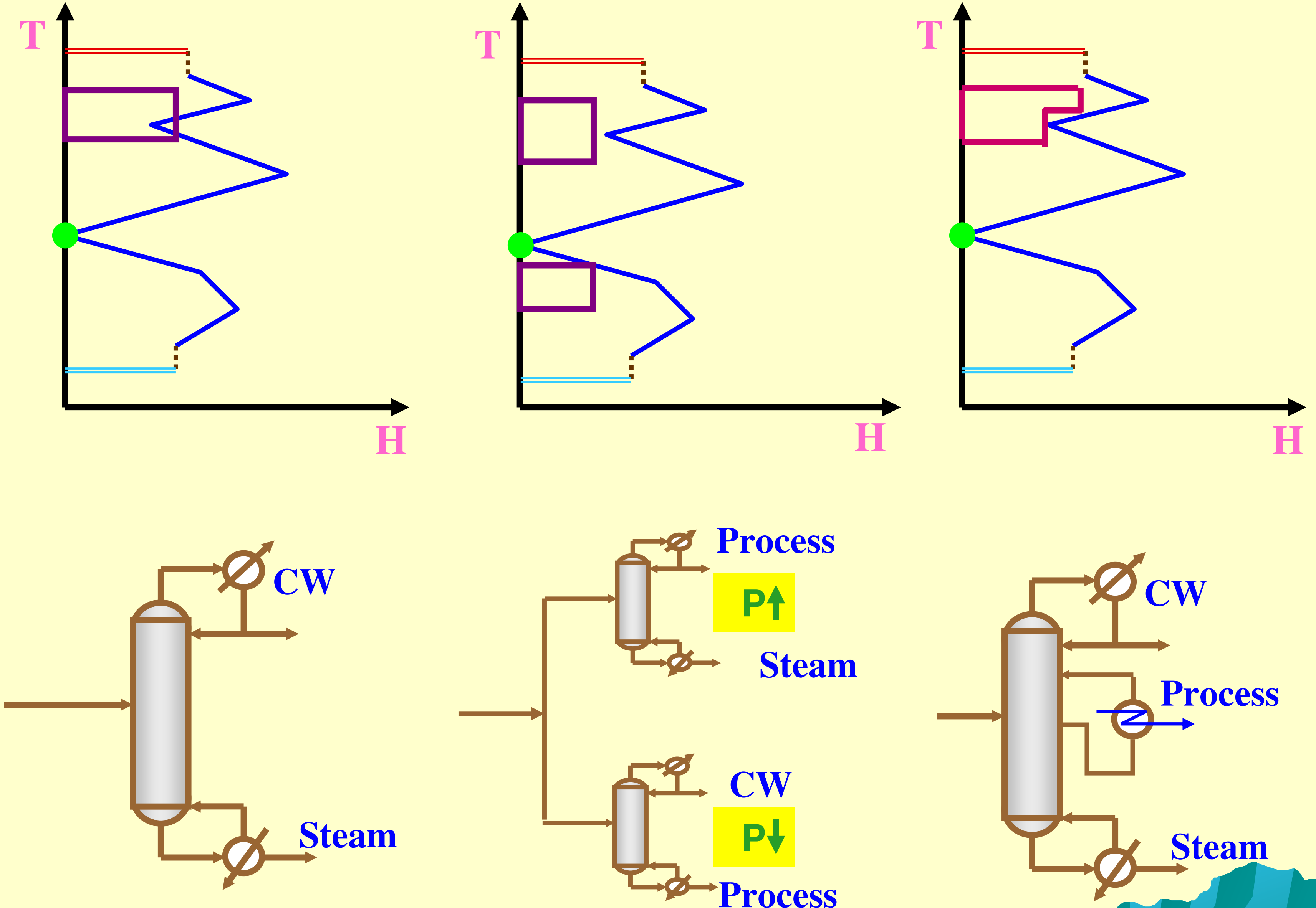
What if the column does not fit?



Column Across the Pinch - does not fit



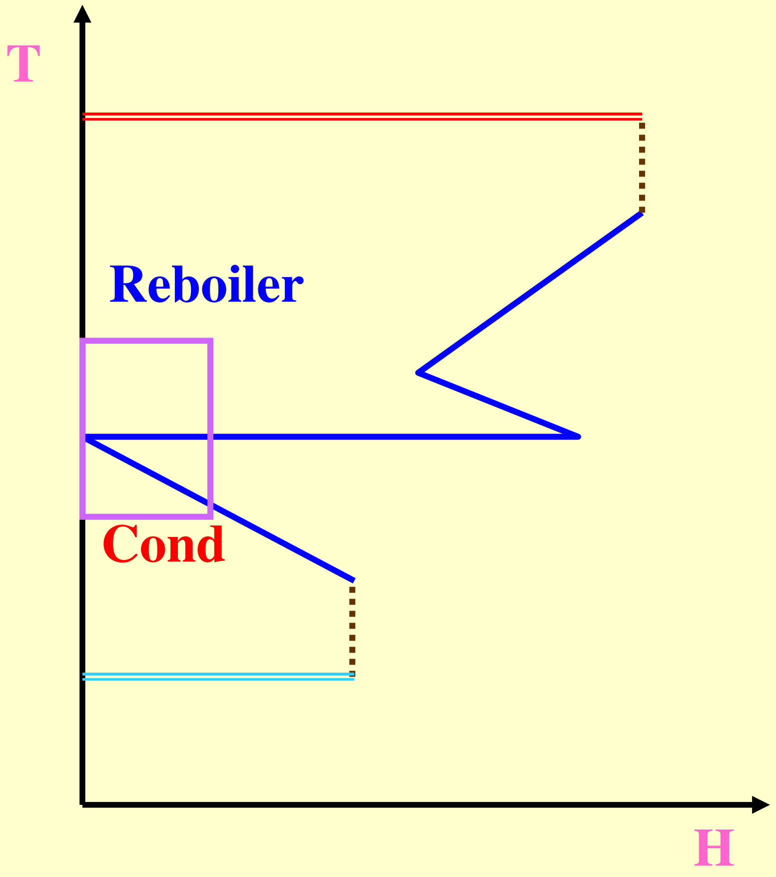
Shift the Column (Change the Pressure)

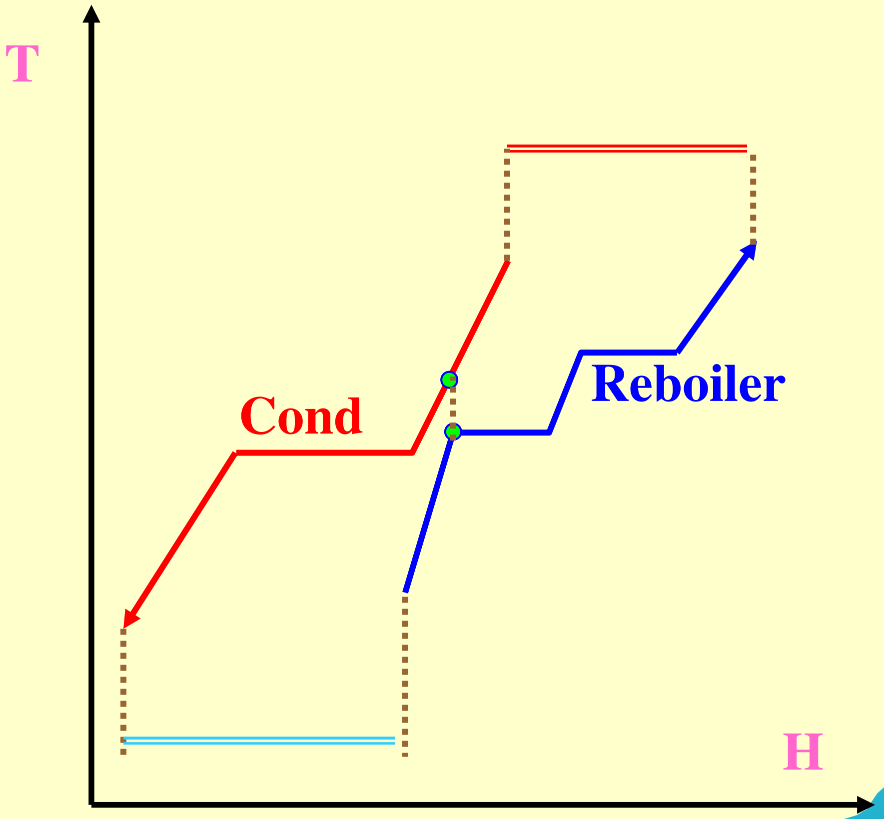

T
H
T
H
T
H
CW
Steam
Process
P↑
Steam
CW
P↓
Process
CW
Process
Steam

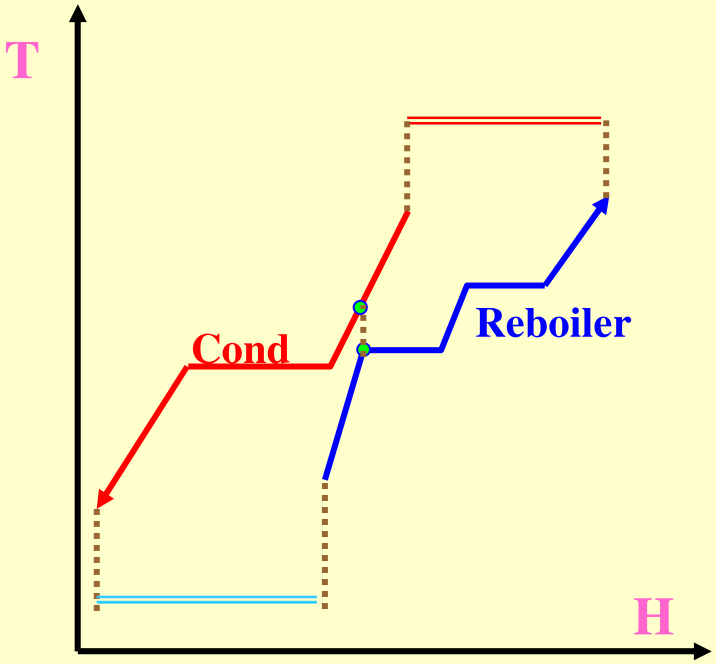
Appropriate Column Placement And…

- ✓ **Capital Cost**
- ✓ **Control**
- ✓ **Double Effect**
- ✓ **Vapor Recompression**

1. Column across the Pinch

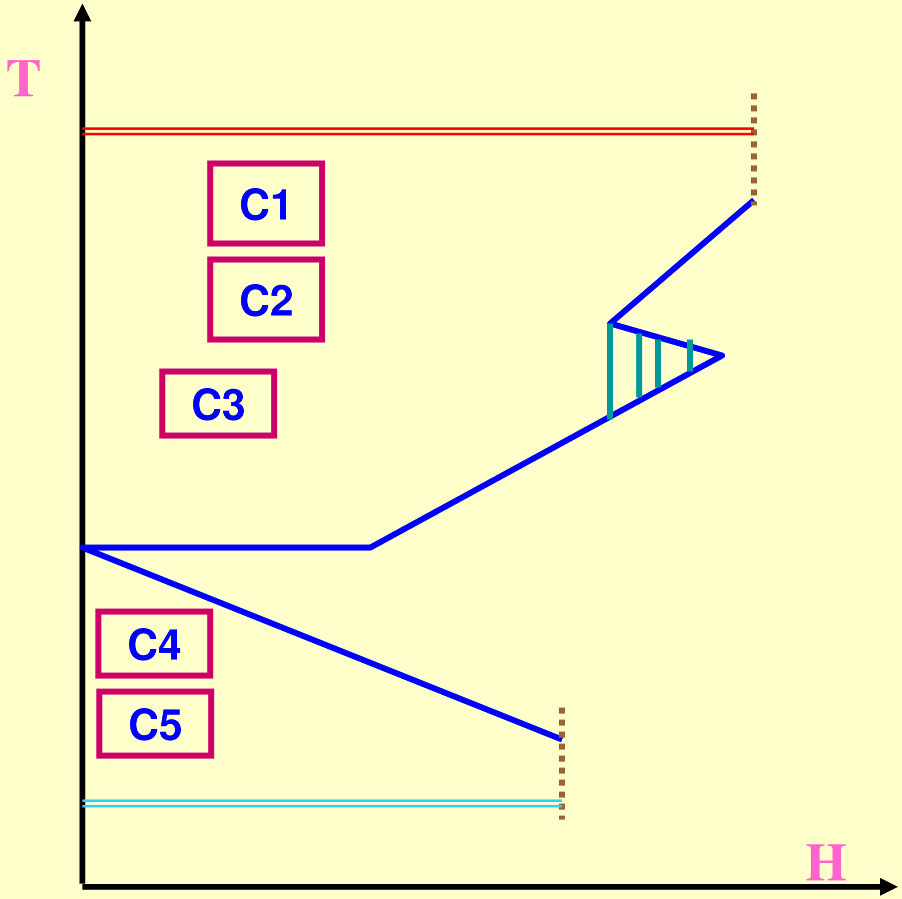






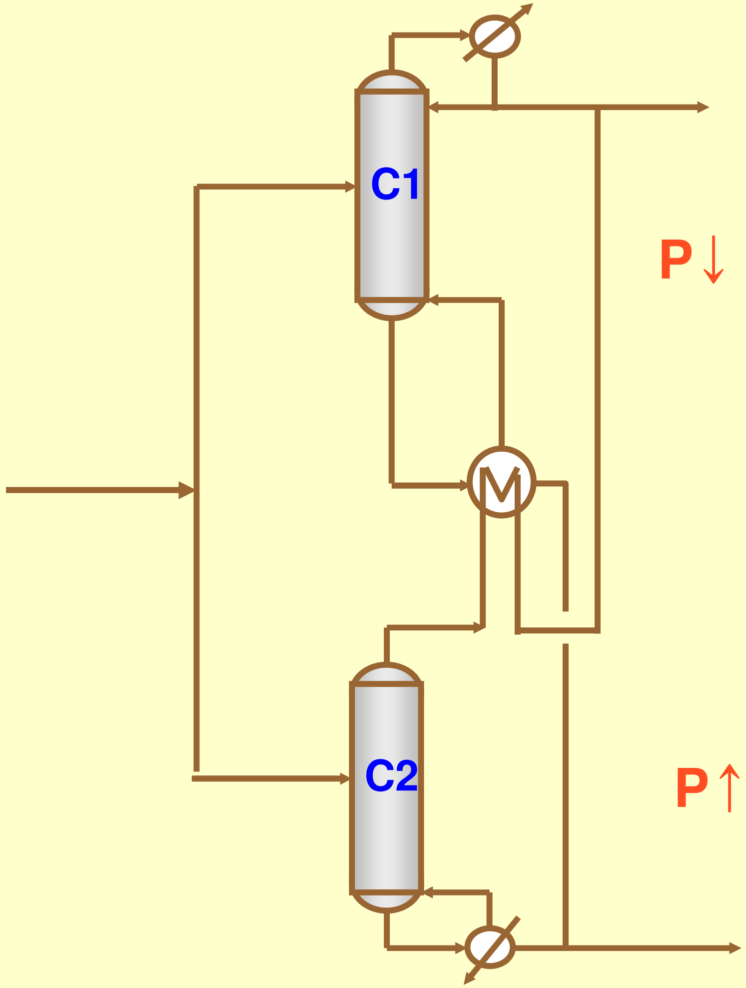
Increase pressure ⇨both “condenser” and “ reboiler” temperature increase

We have a useful diagram

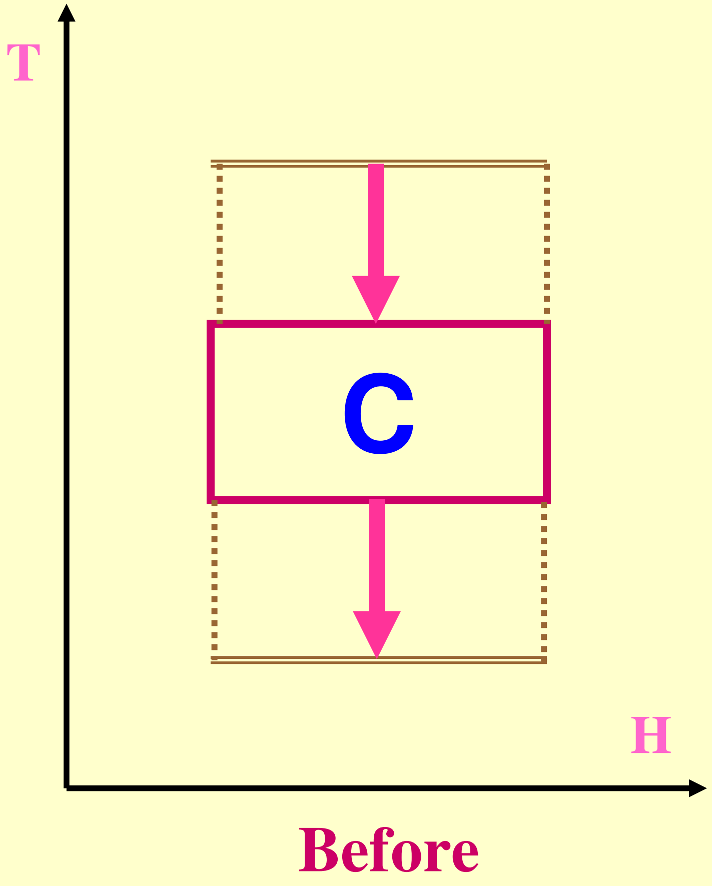


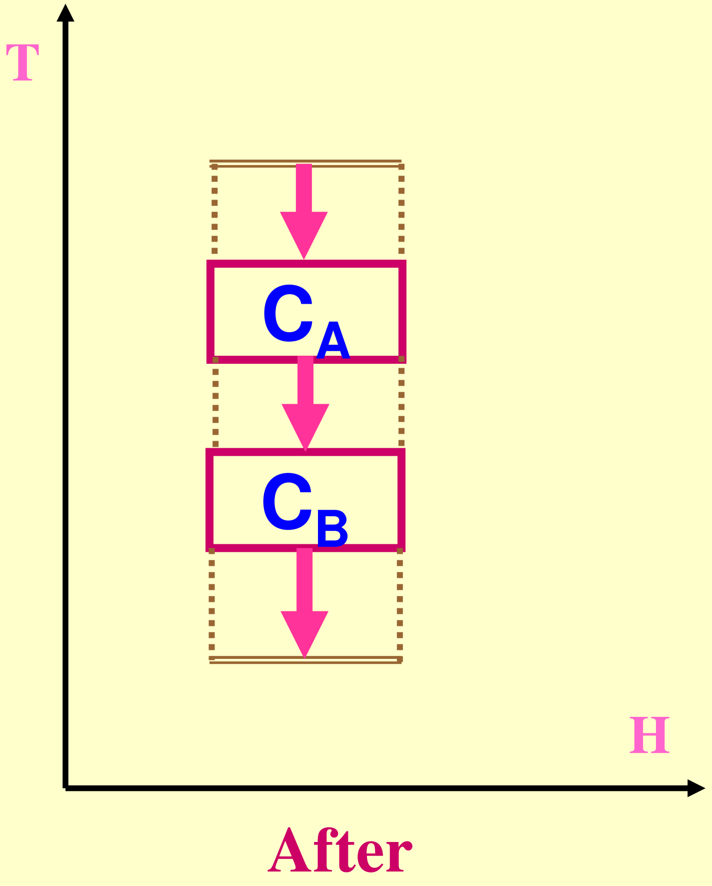
All columns are appropriately placed…

Double - Effect



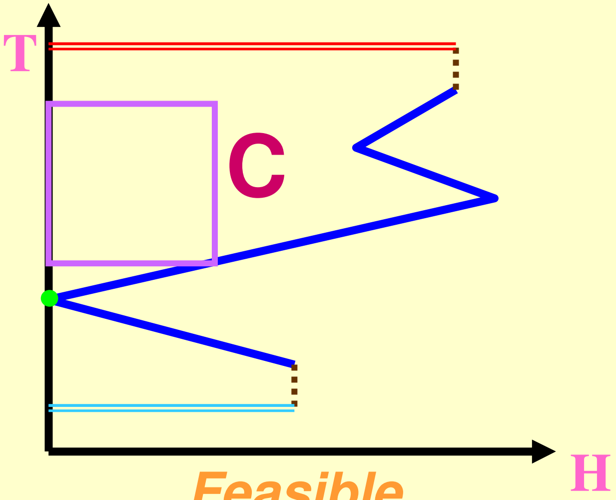
Stand-Alone Column Optimization ⇒ Double Effect



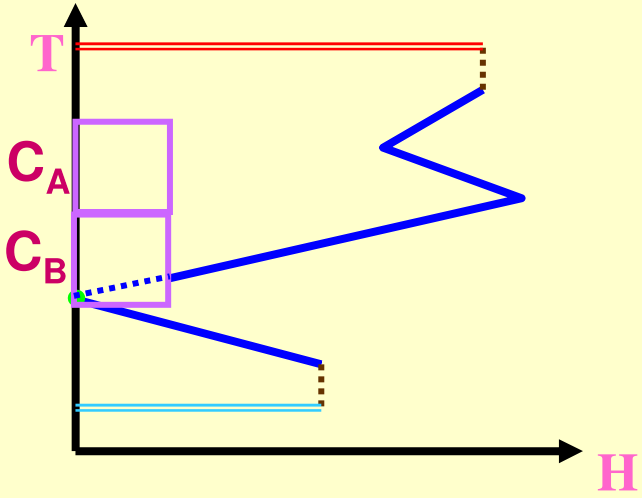


In isolation, we have saved energy …

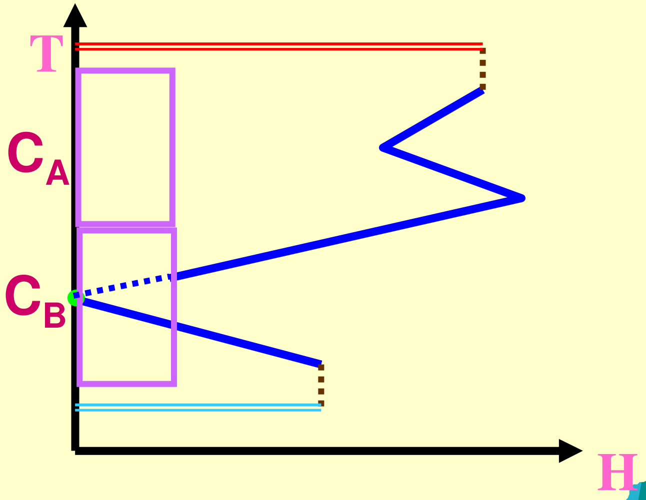
But What if ?



Feasible



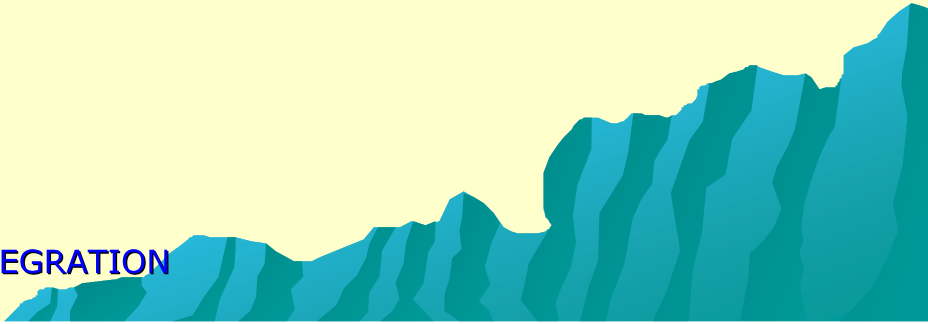
Not Feasible (product decomposition)



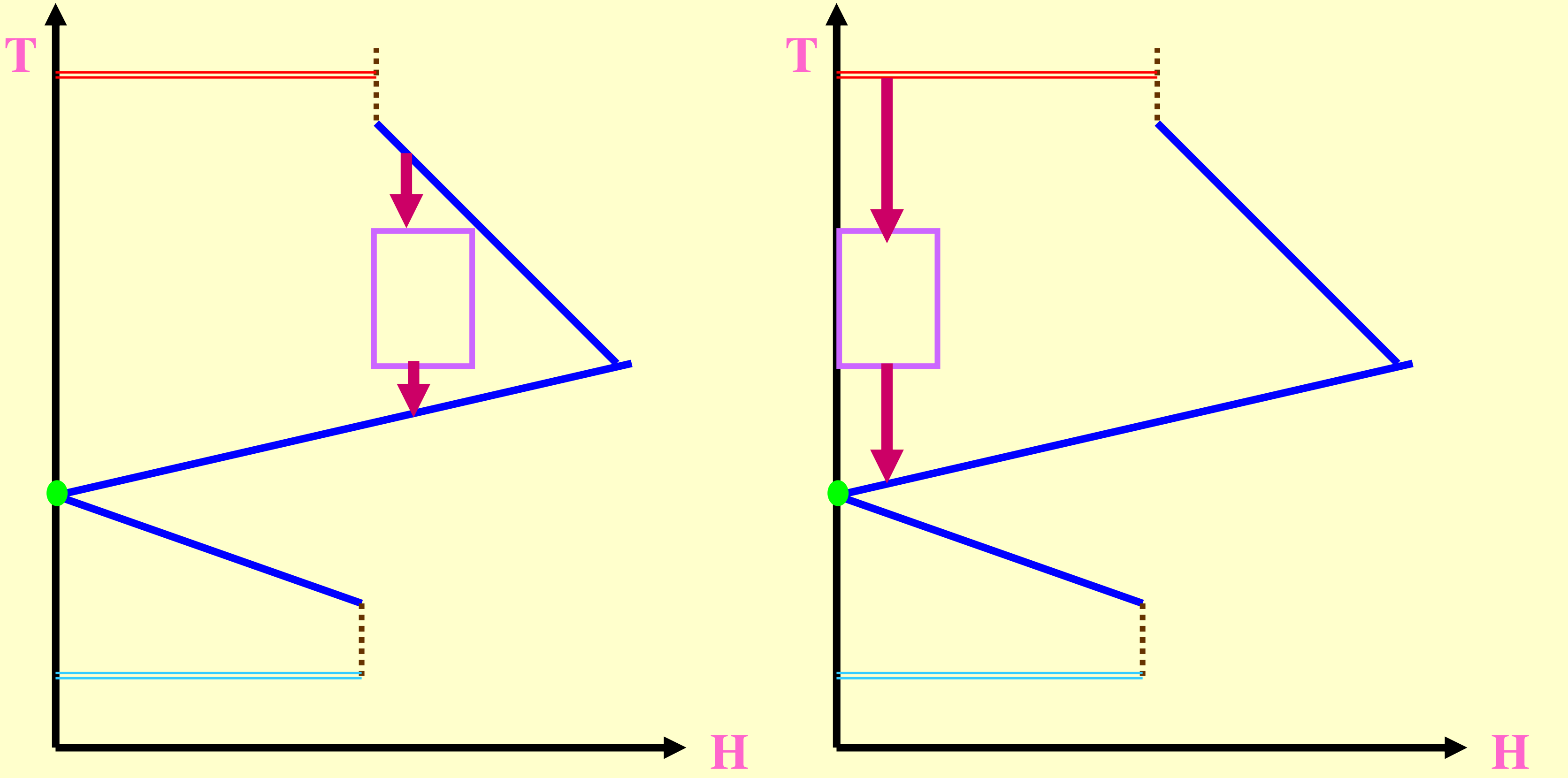
Not Favorable (refrigeration)

Conclusion

Do not “*optimize*” your column before you have understood the process context



Control

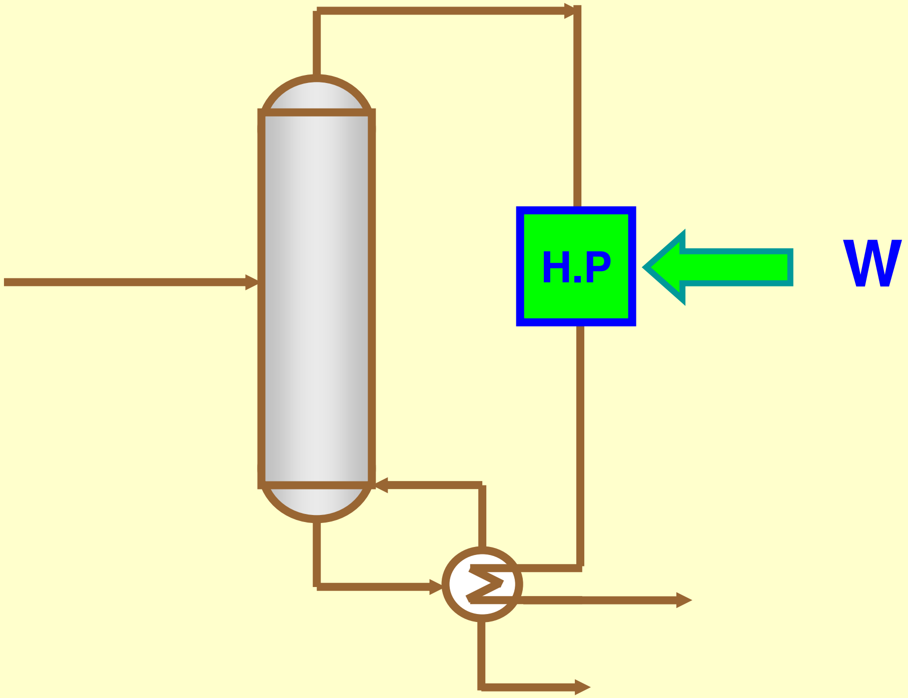


This Fits **But** This is easier to control

Control - Conclusion

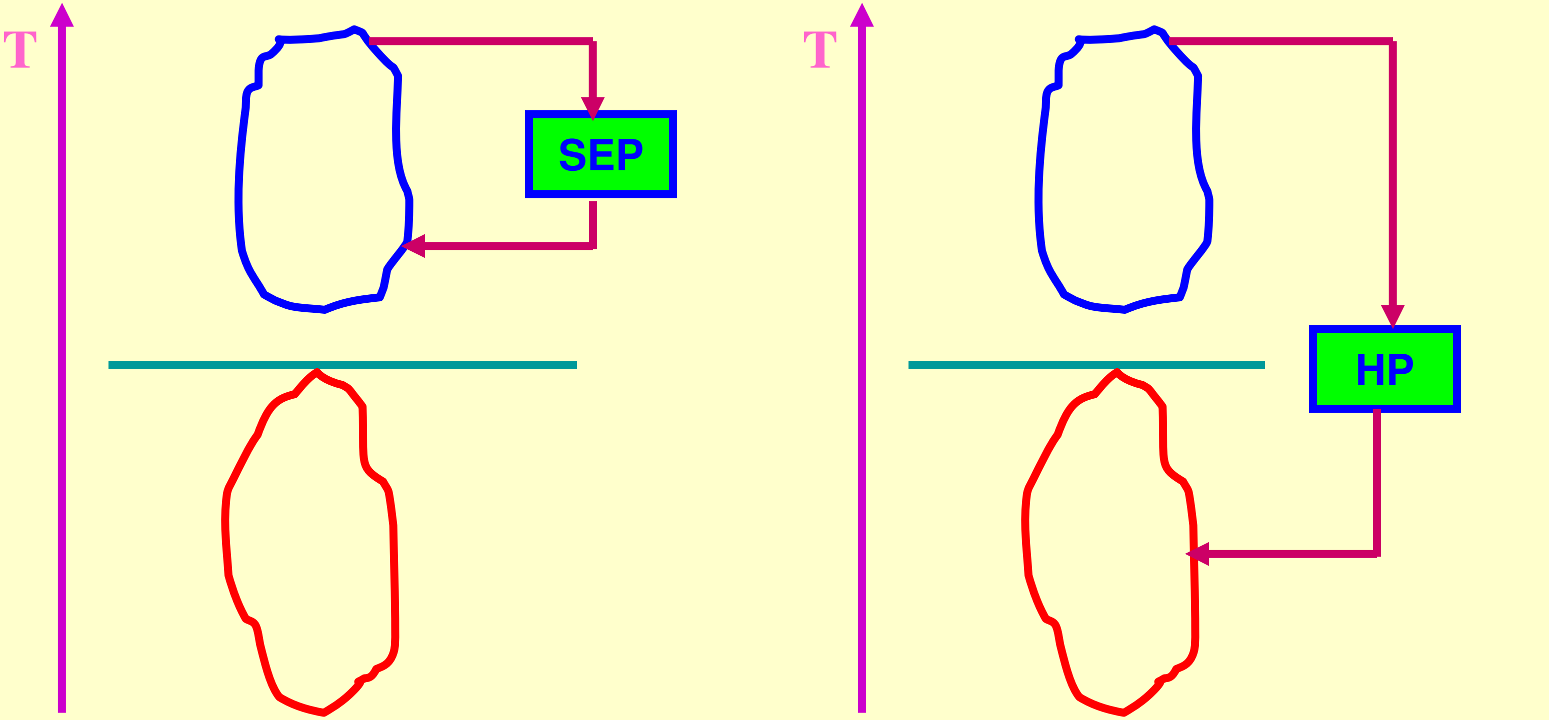
In principle, it is enough to integrate the reboiler *OR* the condenser

Vapor Recompression



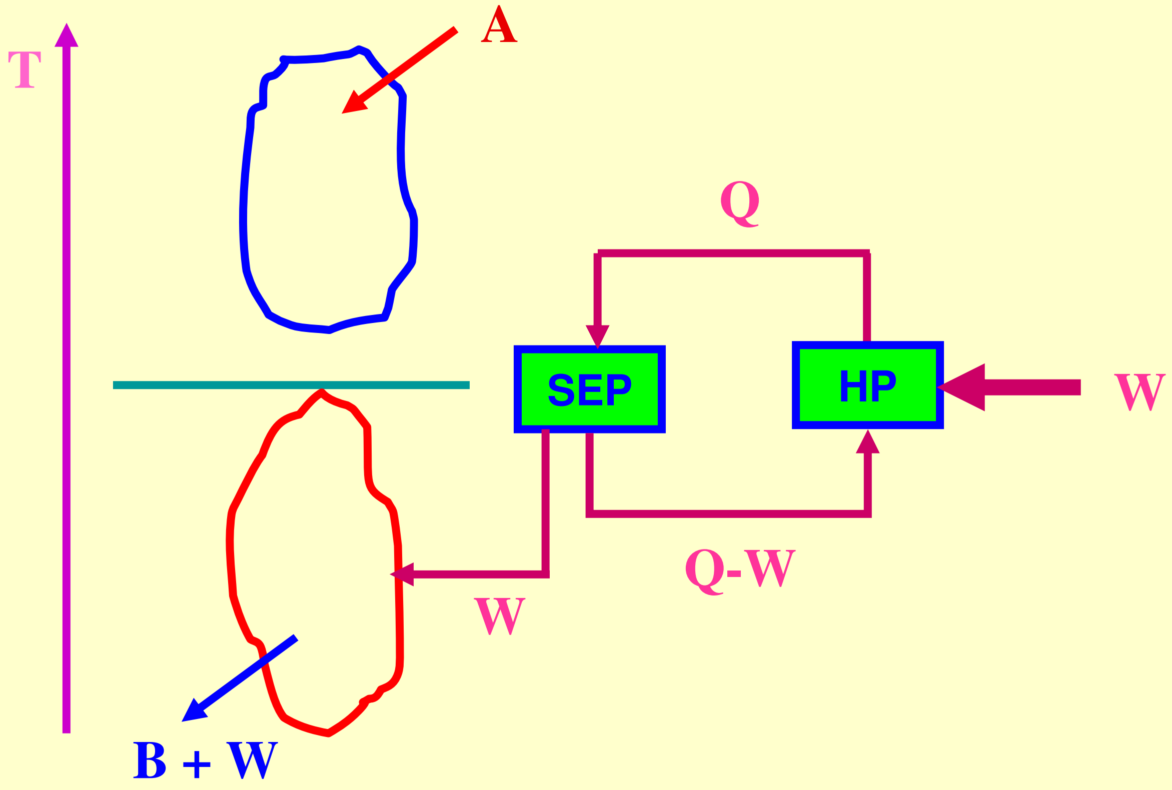
Distillation Column

Stand Alone Column Optimization: Vapor Recompression



Appropriate placement of heat pumps and columns are incompatible.

There, only if the column *HAS* to be inappropriately placed …



…. Will there be a case for vapour recompression

Conclusion

Do not "*optimize*" your column before you have understood the process context