458.401 Process & Product Design

14

Pinch Technology (1)

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Introduction

- Constraints on the design, e.g.,
  - Distillation tower with 400 equilibrium stages and diameter of 20 m for two components with similar volatility
- Limitations imposed by the first and second laws of thermodynamics
  - Close approach between hot and cold streams in a heat exchanger requires a large heat transfer area
  - Approaching R_{min} increases the number of equilibrium stages
- Whenever the driving forces for heat or mass exchange are small, the equipment needed for transfer becomes large and it is said that the design has a __________
- Pinch (point): A point where the driving force for energy or mass exchange is a ____________

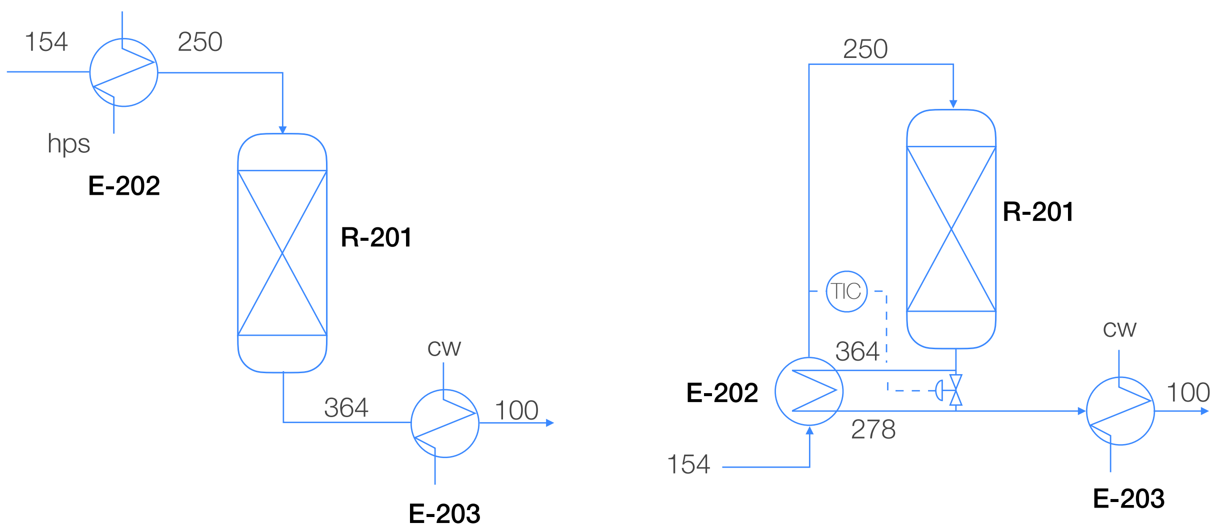
Pinch Technology

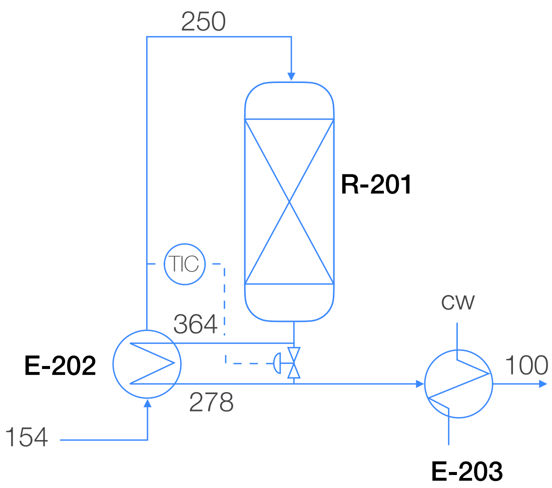
- Defines where the pinch exists and uses the information at the pinch point to design the whole network
- We focus on the implementation of pinch technology to heat-exchanger networks (HENs)
- Design of a HEN that consumes minimum amount of utilities and requires the minimum number of exchangers (MUMNE)
    - May not be optimal in an economic sense, but represents a feasible solution and will often be close to the optimum

Heat Integration

To find matches between heat additions and heat removals within the process

Example 15.1 DME Reactor





The CW utility is reduced and the HPS is eliminated

E-203 is smaller; E-202 is also smaller since his condenses at 254°C

	No Heat Integration	With Heat Integration
Fixed capital investment	$346,000	$244,600
Cost of utilities	-$210,000/yr	-$36,820/yr
( )	-$1,636,000	-$471,000

10-yr plant life and a 10% discount rate

Design Strategy

1. Utility requirements are minimized. Use interior heat exchangers to keep utilities from auxiliary network minimum. “Minimum Utility” or “Maximum Energy Recovery (MER)” targets. - OPEX
2. Then allow the number of HX to be reduced (toward minimum) and allow the need for utilities to rise - CAPEX

Note) When fuel / energy costs are relatively high, the minimum annual cost solution will lie near networks having the minimum utilities.

Steps to solve MUMNE problem

1. Choose a minimum approach temperature. This is part of a parametric optimization, because for every minimum approach temperature a different solution will be found
2. Construct a temperature interval diagram
3. Construct a cascade diagram and determine the minimum utility requirements and the pinch temperatures
4. Calculate the minimum number of heat exchangers above and below the pinch
5. Construct the heat-exchanger network

Example 15.2

Hot streams require cooling; cold streams require heating

Stream No.	Condition	Flowrate $\dot{m}$(kg/s)	C_p (kJ/kg°C)	$\dot{m}C_p$ (kW/°C)	T_{in} (°C)	T_{out} (°C)	$Q_{available}$ (kW)
1	Hot	10.00	0.8	8.0	300	150	1200
2	Hot	2.50	0.8	2.0	150	50	200
3	Hot	3.00	1.0	3.0	200	50	450
4	Cold	6.25	0.8	5.0	190	290	-500
5	Cold	10.00	0.8	8.0	90	190	-800
6	Cold	4.00	1.0	4.0	40	190	-600
Total							-50

Net enthalpy change is 50; This does not mean that only 50 kW is needed from a hot utility.
One should consider the 2nd law of thermodynamics

ΔT_{min}

- You need a driving force for heat to move in your heat exchanger
- The area required for the HX will depend on the size of the driving force
- There must be a finite temperature difference between the two streams in the HX.
- We will choose a ΔT_{min} = 10 °F or 10 °C
- ΔT_{min} = gets smaller, less lost work in the process
- ΔT_{min} = gets bigger, smaller heat exchangers

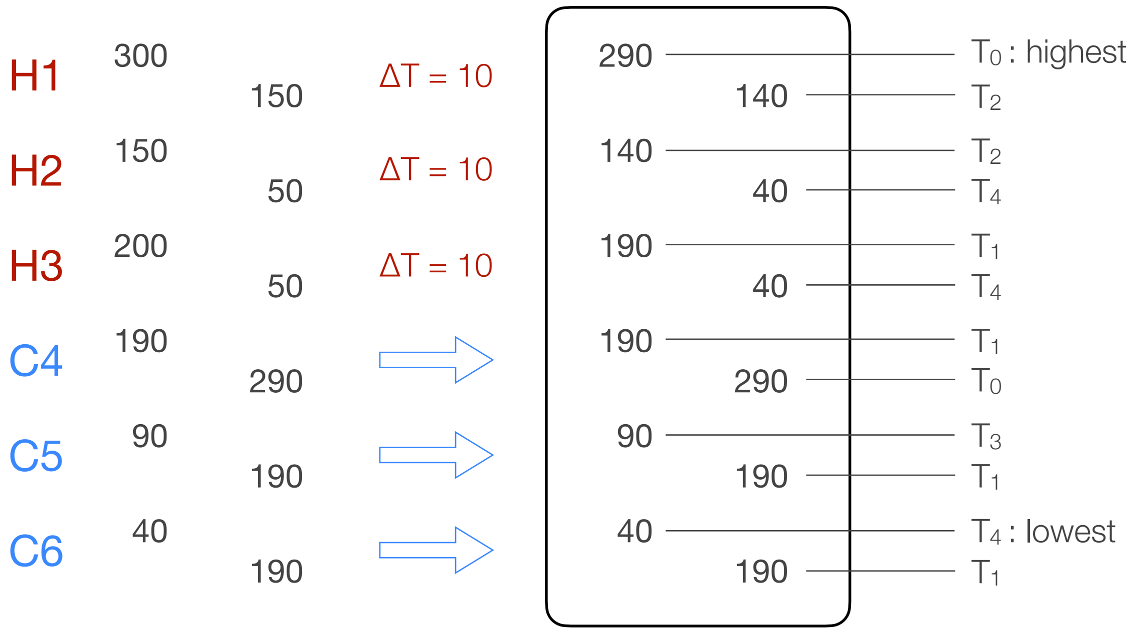
Step 1: Choose a Minimum Approach Temperature

- The smallest temp. difference that two streams leaving or entering a heat exchanger can have
- Typically 5°C ~ 20°C; We choose (   )°C for this problem.

Step 2: Construct a Temperature Interval Diagram

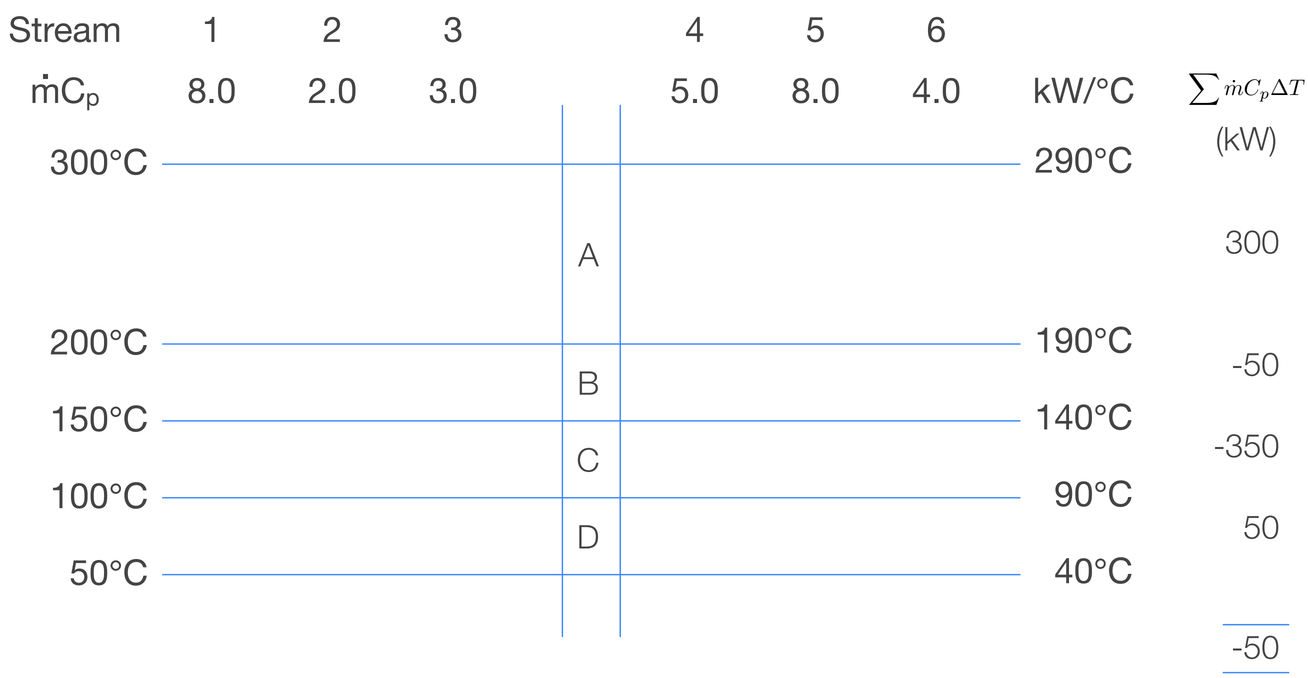
- Hot streams on the left-hand side; cool streams on the right
- The left- and right-hand axes are shifted by the minimum temp. difference
- Arrows indicate the direction of temperature change
- The net amount of available energy from all the streams in a given temp. interval is given in the right-hand column; (+) for excess energy and (-) for energy deficit
- With the cold streams shifted down by the ΔT_{min}, energy can flow from L to R within a given temp. interval without violating the 2nd law of thermodynamics.

We begin by making a semi-arbitrary choice to adjust the HOT stream temperatures (down) by 10°C (to ensure that ΔTmin = 10°C is maintained). Then look at all of the temperatures anywhere in the system



- There are five temperatures in play… So there are ___ temperature intervals to be considered.
- Draw 4 boxes [290 - 190] , [190 - 140], [140-90], and [90-40]. Look at the first interval. How many streams exist in [290-190]?
  - There are ______ streams, ___ and ___. Exchange between hot and cold is possible.
  - H1 has mCp = 8 and C4 has mCp = 5 and the temperature interval is 290-190 = 100
  - So, 8 x 100 - 5 x 100 = 300 of Q is *removed* in this interval
- Heat flows downhill. So let this Q go to the next box.
- Now, look at [190 - 140] … H1, H3, C5, and C6 are present in this interval
  - _______ (added from the previous interval) + 50 x (8 + 3 - 8 - 4) = 250
- Carry on like this…

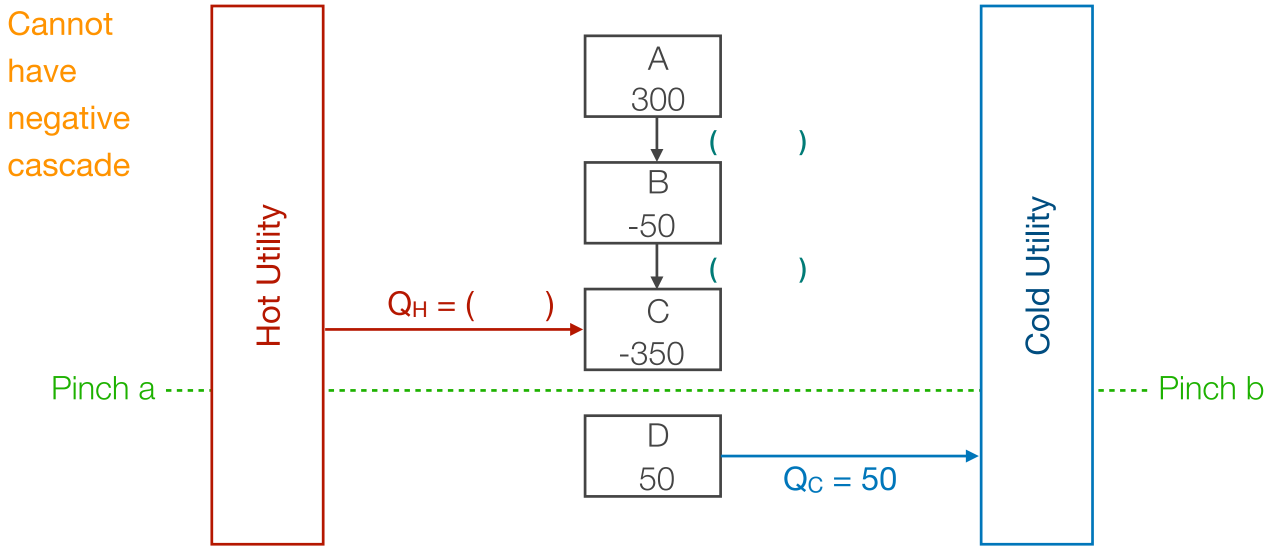
Temperature Interval Diagram



Step 3: Construct a Cascade Diagram

- The diagram simply shows the net amount of energy in each temperature interval
- Excess energy (+) can be cascaded down to the next temperature level; ________ upward (cannot go against the T gradient)
- You can find, if any, there is point in the diagram at which no more energy can be cascaded down (line a - b)
- Line a - b is termed the pinch zone or pinch temperature
- By following this procedure, the minimum energy is transferred from the hot utility to the process and from the process to the cold utility

Cascade Diagram

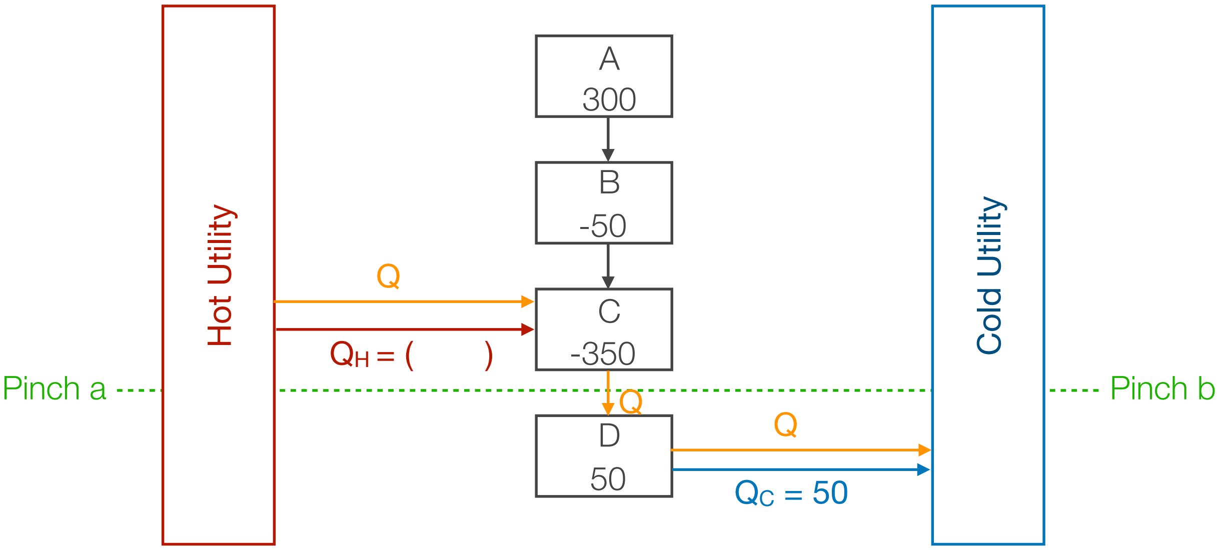


The minimum utility requirements: ( ) kW from the hot utility and 50 kW to the cold utility

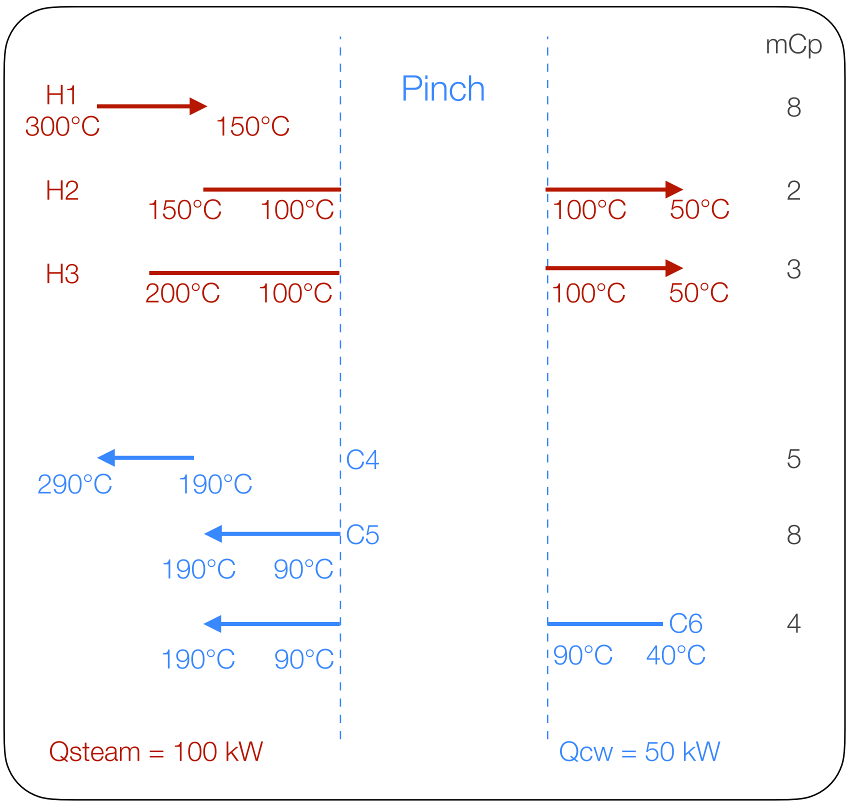
Pinch

- Extra heat added at the start means extra heat removed at the finish. This is a bummer, but it must be done (thermodynamics!)
- The location that now has a zero residual is called the PINCH. Think of this as the limit that just barely accomplishes the needs of the system.
- Boxes A, B, C are independent from Box D… “no heat flows across the pinch.”
- Intervals A, B, and C are above the pinch.
- Interval D is below the pinch.

Cascade Diagram



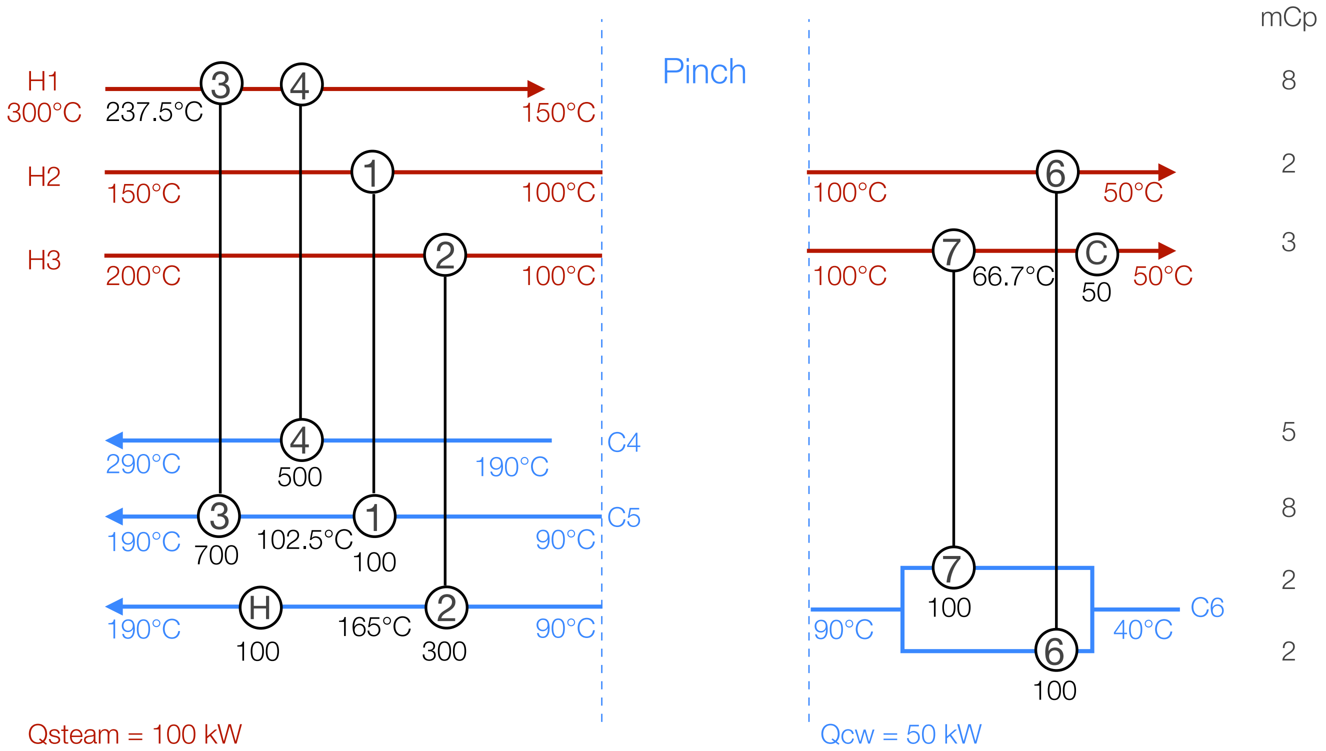
Do not transfer heat across the pinch zone. It is wasted!



This shows a nice way to visualize the idea of not crossing the pinch — you will want to think about this as two separate regions. The HOT streams hit the pinch at 100°C and the COLD streams hit the pinch at 90°C (recall that we selected ΔT_{min} = 10°C)

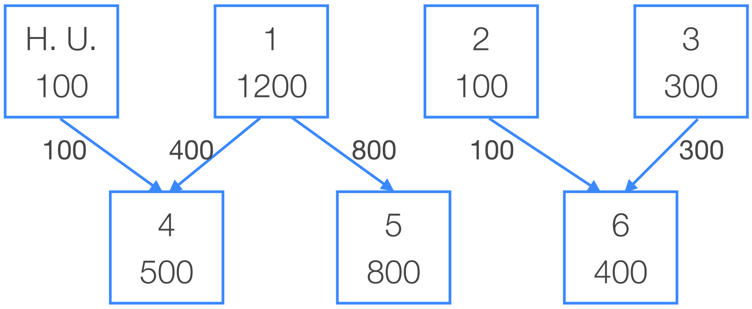
- You should be able to do all cooling down to ______°C without using any cooling water.
- You should be able to do all heating up to _____°C without using any system.

One Successful Configuration

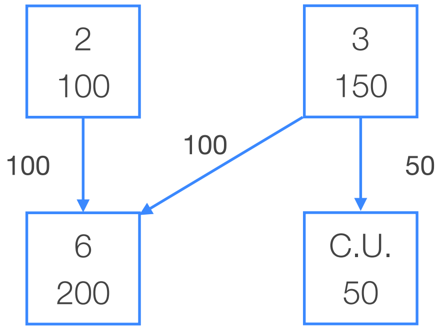


Step 4: Calculate the Minimum # of Heat Exchangers

- Above the pinch
  - Draw boxes representing the energy in each process stream
  - Hot utility at the top
  - Indicate the energy transfers by lines
  - One line = one heat exchanger
- Below the pinch
  - Same above
- If there is no exact match between groups of hot and cold streams as in the "above-the-pinch problem" in our example, the following relationships can be written:
  - Min. No. of exchangers = No. of hot streams + No. of cold streams + No. Utilities - 1



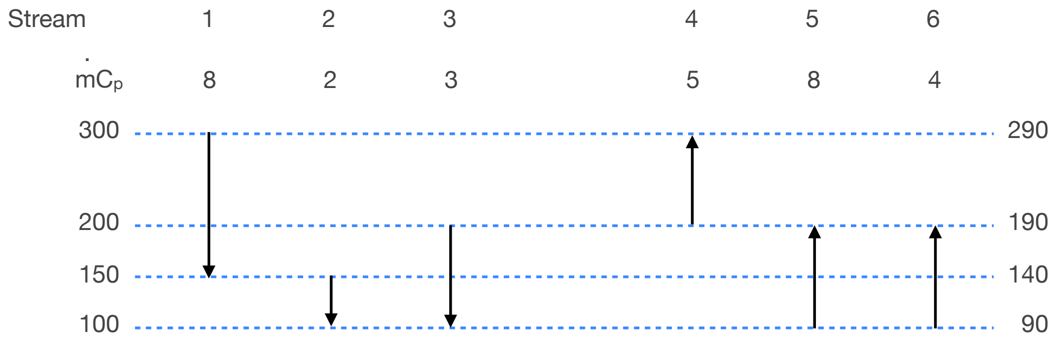
Above the pinch. Minimum # of Exchangers = 5

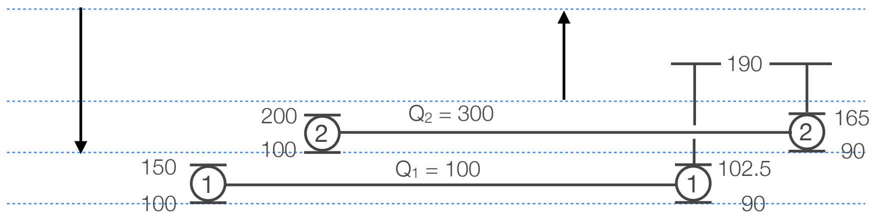


Below the pinch. Minimum # of Exchangers = 3

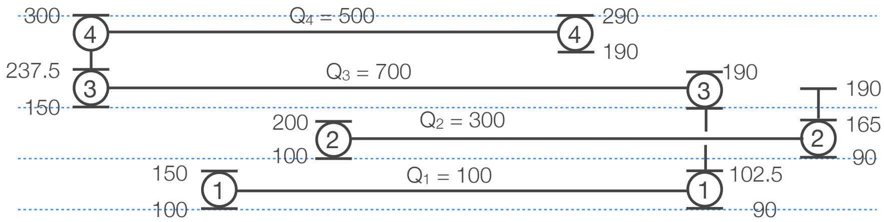
Step 5: Design the HEN

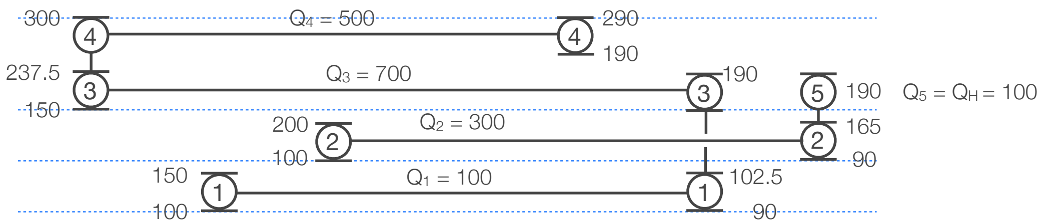
- Above the pinch
  - Draw the temperature interval diagram above the pinch.
  - Start by matching hot and cold streams at the pinch and then move away from the pinch
  - The stream matches will not necessarily be the same as in Step 4, because 2nd law of thermo. and 10°C approach constraint were not considered in Step 4.
- Design at the pinch
  - Match streams such that ______________ to ensure that ΔT_{min} is not violated
  - In the figure of next page, streams 2-5, 3-6 or 2-6, 3-5 can be matched.
  - Exchange as much heat as possible
- Design away from the pinch
  - Remaining hot streams with the remaining cold streams
  - ______________ does not necessarily hold away from the pinch; however, do not violate the following constraints:
    - A minimum approach temperature (10 °C)
    - Only five exchangers are used for the design above the pinch as calculated in Step 3
    - Heat is added from the coolest possible source





Stream 5: 2 x (150-100) = 8 x (T - 90); T = ________

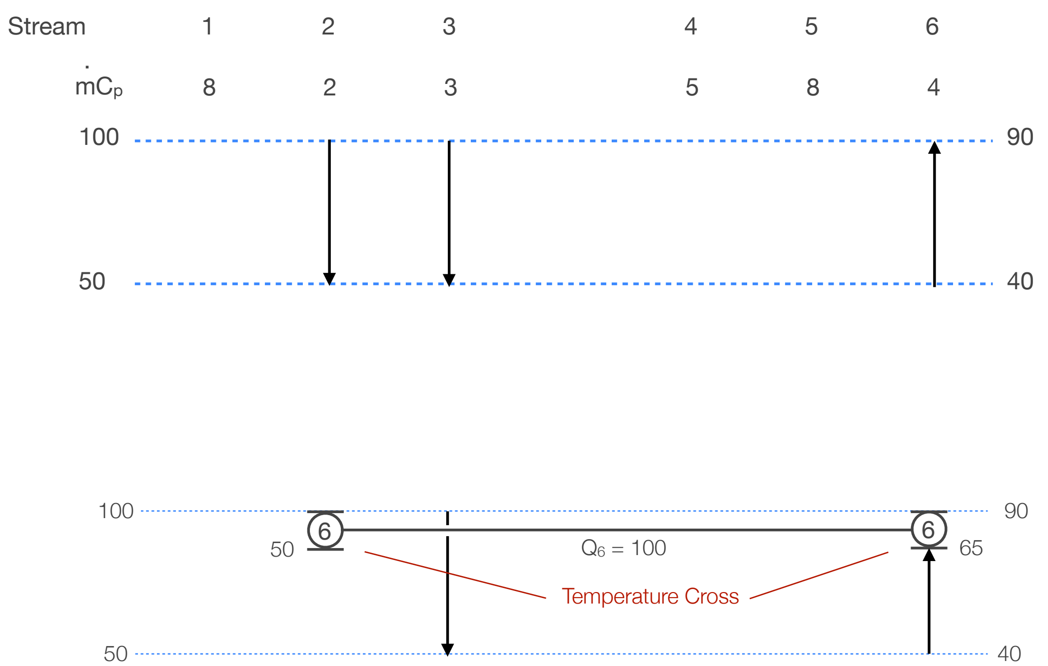


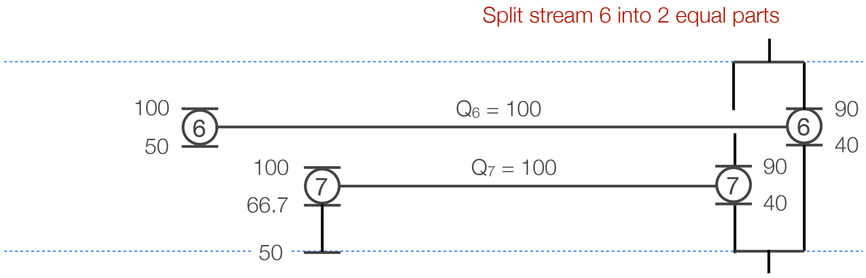


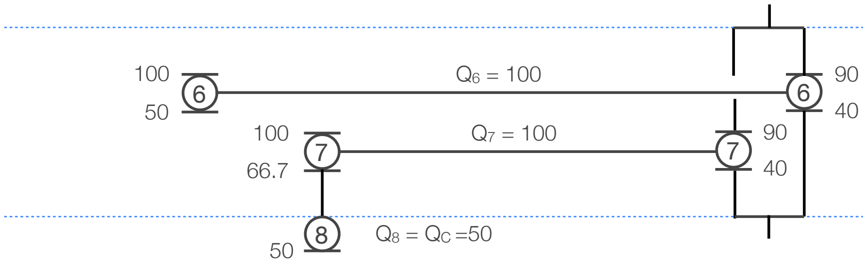
_____ heat exchangers!

Step 5: Design the HEN

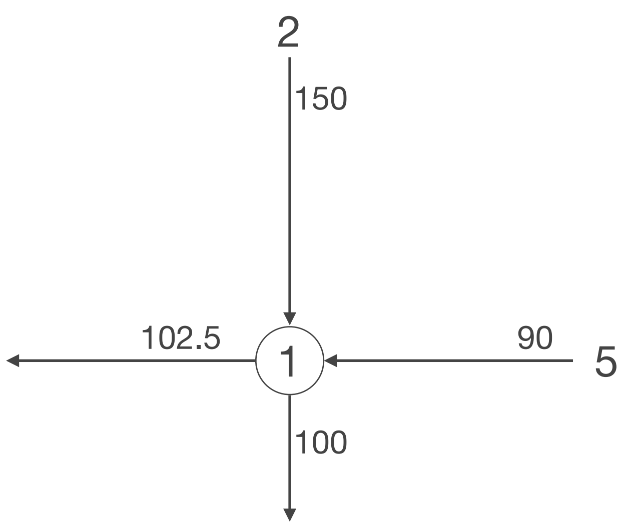
- Below the pinch
  - Draw the temperature interval diagram below the pinch.
  - Start by matching hot and cold streams at the pinch and then move away from the pinch
  - The stream matches will not necessarily be the same as in Step 4, because 2nd law of thermo. and 10°C approach constraint were not considered in Step 4.
- Design at the pinch
  - Match streams such that $\dot{m}C_{p,hot} \geq \dot{m}C_{p,cold}$ to ensure that ΔT_{min} is not violated
  - In the figure of next page, streams 2-6 are matched, but it violates the criterion above. (Physically impossible)
  - Split the stream 6 to have $\dot{m}C_p$ = 2.0 (There are numerous ways)
- Design away from the pinch
  - Remaining hot streams with the remaining cold streams



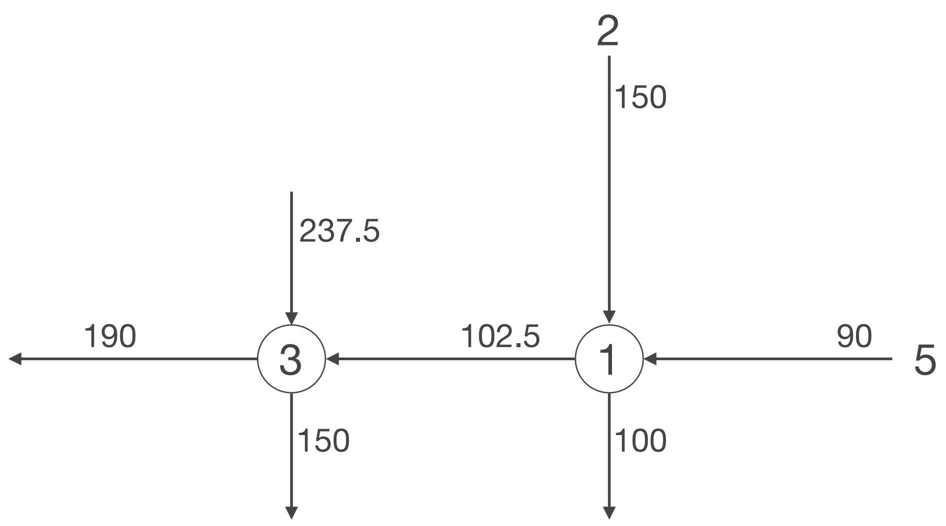




MUMNE Network



MUMNE Network



MUMNE Network