SHIP Egypt

Session 13

System optimisation

Heat transfer, heat exchanger and heat recovery from processes and utilities

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Overview

- **Heat transfer**
  - Basics and influencing parameters
- **Pinch analysis**
  - Basics
  - Example
- **Heat exchangers**
  - Basics
  - Example
- **How to design a heat exchanger network**
- **Heat integration**
  - Test case

Heat transport

- **Conduction**
- **Convection**
- **Radiation**

- **Stationary heat transport**
- **Instationary – transient heat transport**
  - ⇨ Temporal changes: heat transport as a function of time

Conduction

- **Heat transport in solid, fluid or gaseous medium**
- **Driven by temperature difference**
- **Influencing parameters:**
  - Medium
  - Pressure
  - Temperature
  - Phase status
  - Density
- **Calculation using**
  - Thermal conductivity [W/mK]
  - Surface
  - Temperature difference

Convection (1)

- **Based on macroscopic movement in fluid or gaseous medium**
- **Temperature equalization within medium (middle and barrier)**
- **Driven by temperature difference between flowing medium and boundary layer**
- **Influencing parameter:**
  - Turbulence: higher → increased convection
  - Medium properties
- **Calculation using**
  - Heat transfer coefficient [W/m²K]
  - Surface
  - Temperature difference

Radiation

- **In contrast to conduction and convection not linked to material heat carrier**
- **Driven by temperature difference between two objects**
- **Calculation using**
  - Radiation coefficient
  - Surface
  - Temperature difference (fourth power)

Heat transistion

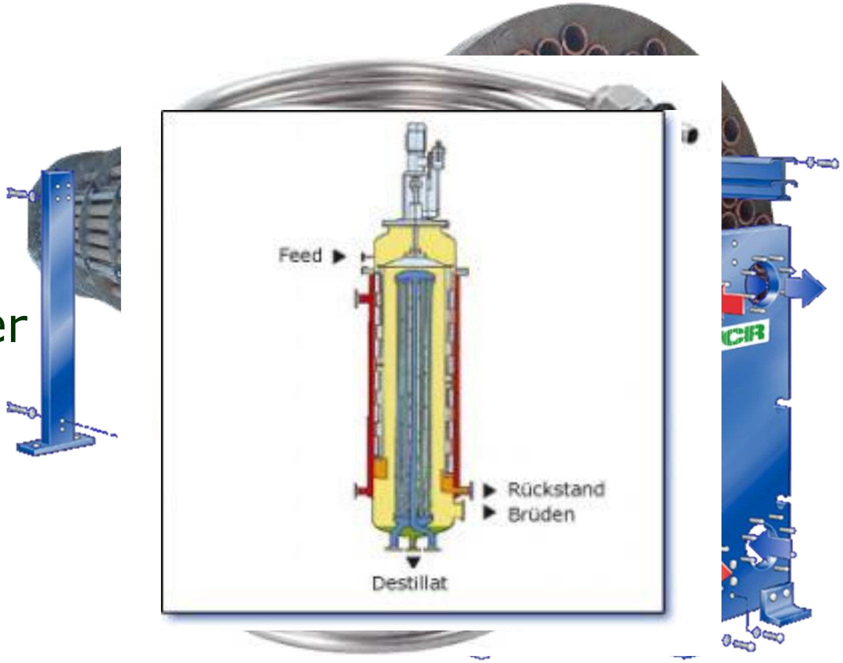
- **Combination of conduction, convection and radiation**
- **Example heating system**
- **Calculation using**
  - Outward heat transfer coefficient
  - Surface
  - Temperature difference

Heat transistion

- **Using logarithmic temperature difference**
- **Dimensionless parameters**
  - Nusselt
    - **Ratio of convective to conductive heat transfer across (normal to) the boundary**
  - Reynolds
    - **Ratio of inertial forces to viscous forces and consequently quantifies the relative importance of these two types of forces for given flow conditions**
  - Prandtl
    - **Ratio of momentum diffusivity (kinematic viscosity) to thermal diffusivity**

Heat exchangers

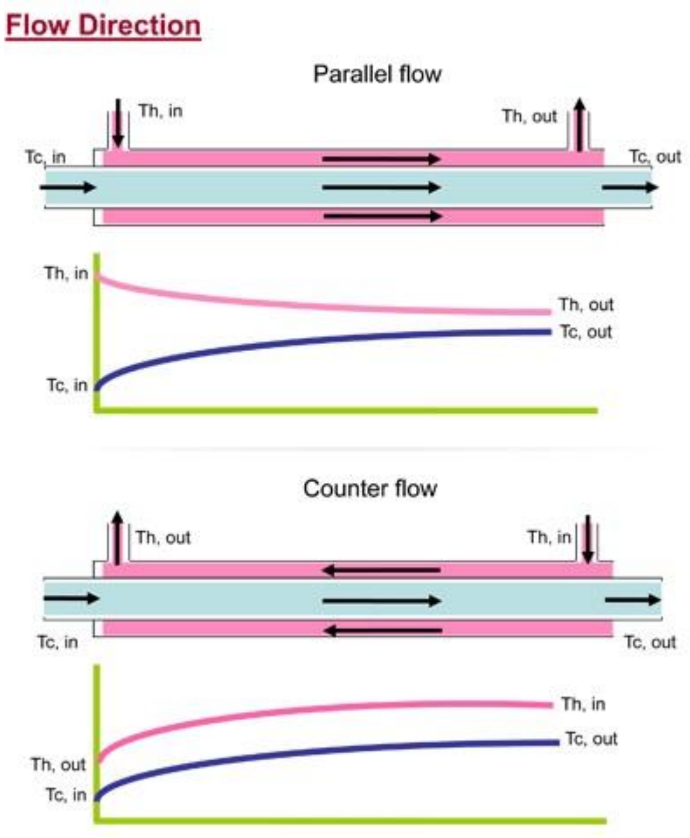
- **Direct heat transfer**
  - Mixing fluid phases with different temperature levels
  - E.g. quenching
- **Indirect heat transfer**
  - Via seperating wall
- **Heat exchanger types**
  - Tube bundle heat exchanger
  - Cooling coils
  - Plate heat exchangers
  - Thin film evaporiser
  - Etc.



Sources: http://www.gireeshcoolingtowers.com, http://www.wcrhx.com, http://www.micromatic.com, http://www.schulzpartner.com

Flows via heat exchangers

- **Cocurrent (parallel flow)**
- **Counter-current**
- **Cross-current**
  - Mix between cocurrent and cross-current
- **dT between two streams (fluid)**
  - Plate-HX: 2K
  - Tube-HX: 5K



Source: http://scopewe.com

Design of heat exchangers

- **Technical parameters**
  - ⇨ Type of heat exchanger
  - ⇨ Flow in heat exchanger
  - ⇨ Control of heat transfer
  - ⇨ Fouling
- **Economic parameters**
  - ⇨ Investment costs (surface)
  - ⇨ Operating costs (pressure loss caused by turbulence)

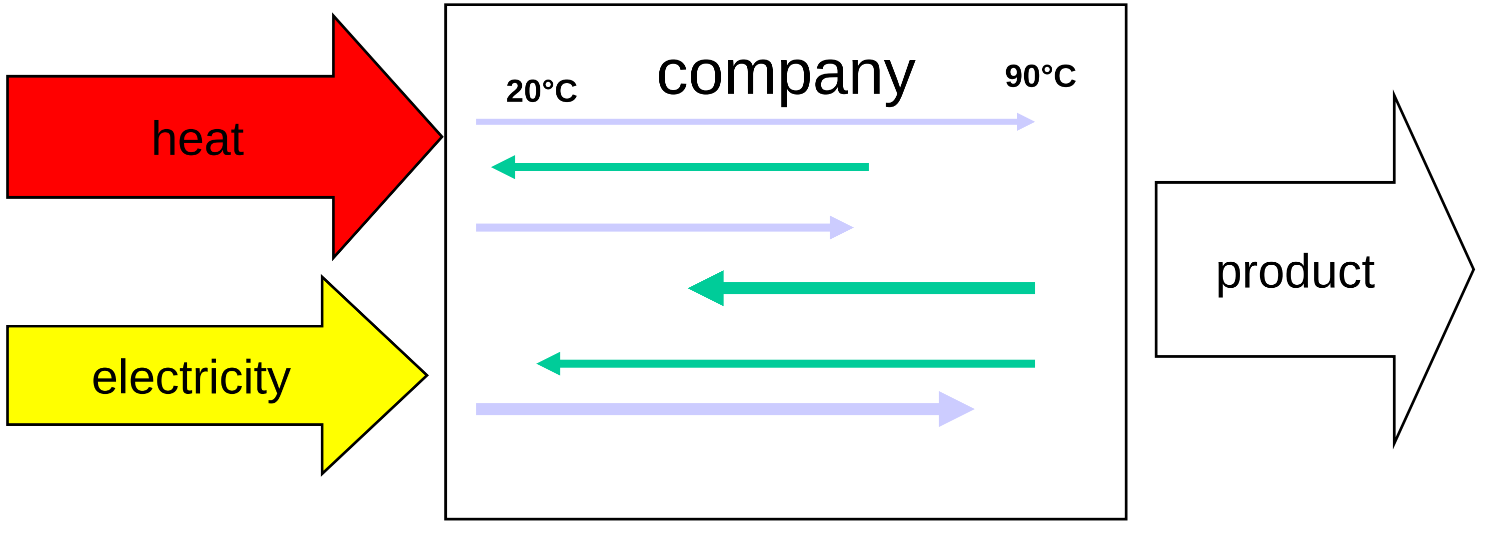
  - ⇨ $Q=k*A*\Delta tm$
    - **Q heat capacity [W]**
    - **k heat transfer coefficient [W/m²K]**
    - **A Surface [m²]**

Pinch analysis: theoretical HR potential

- **Goal**
  - ⇨ Theoretical potential of energy savings by heat recovery (prior to energy supply systems design)
    - **Save fuels and avoid over-dimensioning of supply equipment**
- **Methodology**
  - ⇨ From energy supply and processes to „streams“
  - ⇨ Pinch Analysis
    - **Hot and cold composite curve**
    - **Grand composite curve**
- **Results**
  - ⇨ Theoretical heat recovery potential
  - ⇨ Necessary external heat/cold supply at the different temperature levels

Definition of streams

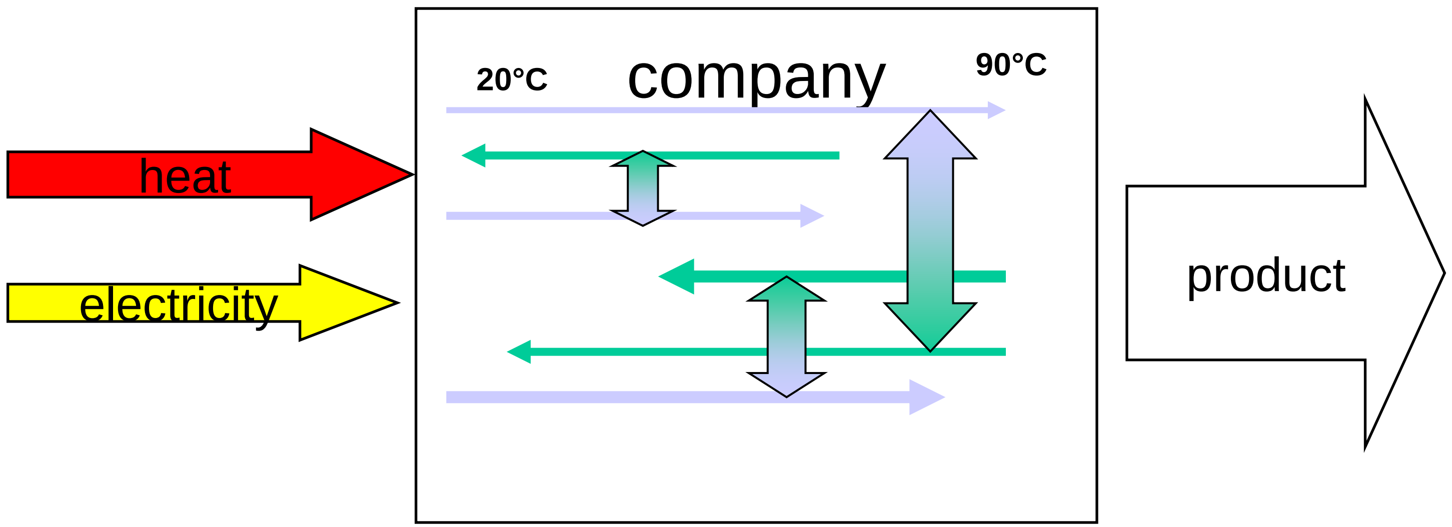
➢ **Heat sources and heat sinks in a company**



Different processes have to heated up or cooled down

Definition of streams

- **Reduction of the primary energy demand by heat exchange**



Aims of Pinch Analysis

- **Visualization of the total cold and heat demand of a system in one diagram**
  - Energy demand of single processes
  - At which temperature level the energy has to be supplied
- **Maximum of heat recovery**
- **Heat exchanger network – combination of the process streams**
- **Be aware of existing piping systems and heat exchangers and the location of the buildings and processes**

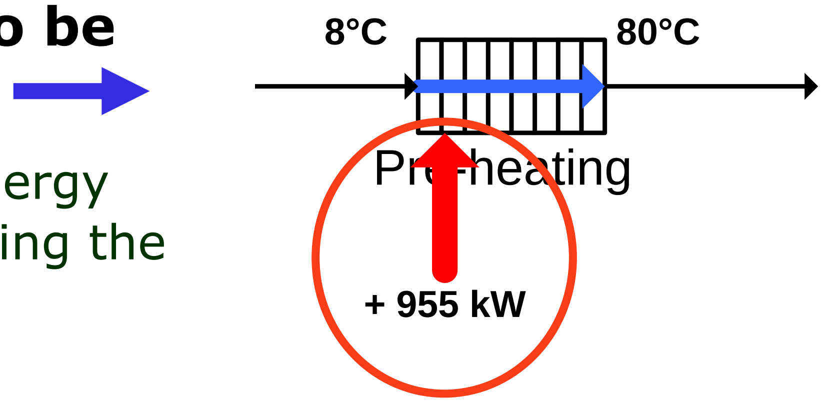
Definition

- **Energy – anergy – exergy**
- **Enthalpy: internal energy and pushing duties**
- **Internal energy depending from T**
  - ⇨ $dH = m * c_p * (T_2 - T_1)$

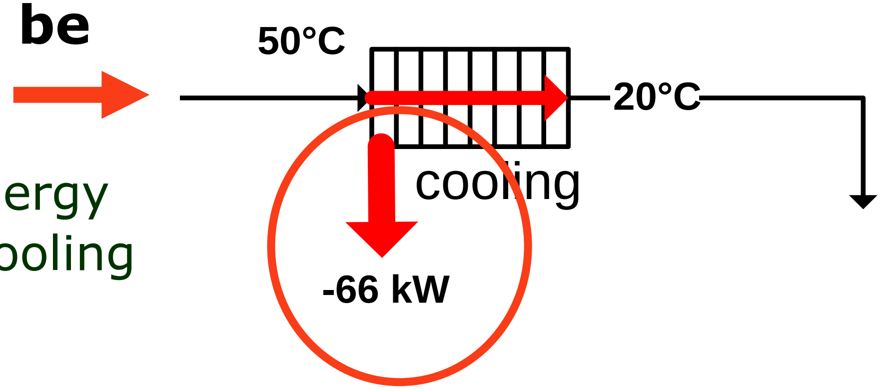
    - **dH** **enthalpy difference [kJ]**
    - **m** **mass [kg]**
    - **cp** **specific heat capacity with constant pressure [kJ/kgK]**
    - **T_2** **higher absolute temperature [K]**
    - **T_1** **lower absolute temperature [K]**

Hot and cold streams

- **„Cold streams“ need to be heated**
  - Any process in which energy input is needed for heating the process flow/stream



- **„Hot streams“ need to be cooled**
  - Any process in which energy input is withdrawn for cooling the process flow/stream



- **No equipment streams !!!**

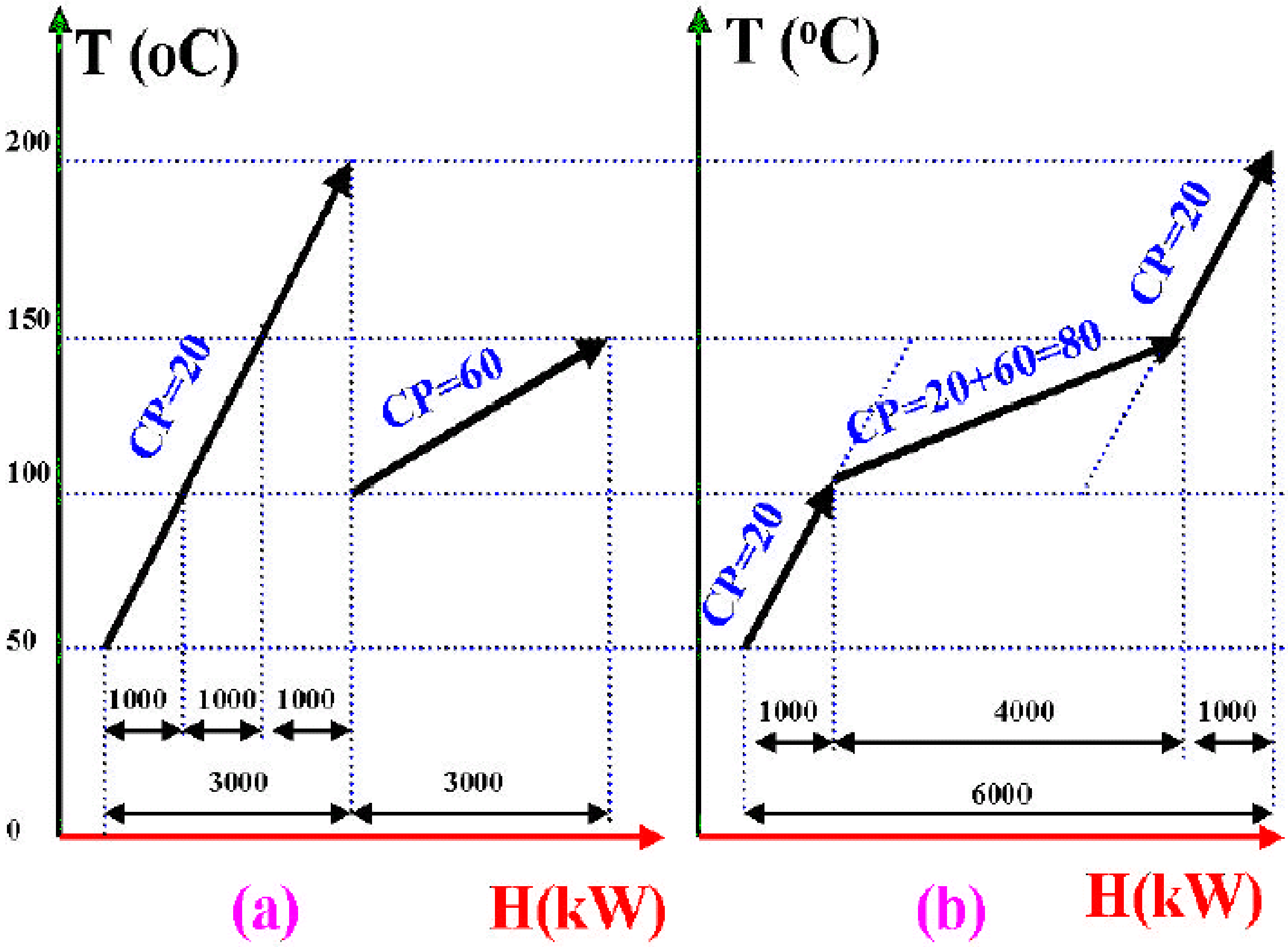
Definition of streams

- **Enthalpy stream (sensible stream)**
  - $\dot{Q} = \dot{m} \cdot c_p \cdot \Delta T$
    - **m** **mass [kg/s]**
    - **c_p** **specific heat capacity [kJ/(kg K)]**
    - **ΔT** **temperature difference [K]**

- **Data for calculation**
  - Yearly operating hours for savings
    - **Q [kW] * h [h/a] = E [kWh/a]**
  - Energy supply [€/kWh] for economical calculation
  - Heat transfer coefficient for heat exchange calculation
  - Material for HX for investment calculation

Stream list

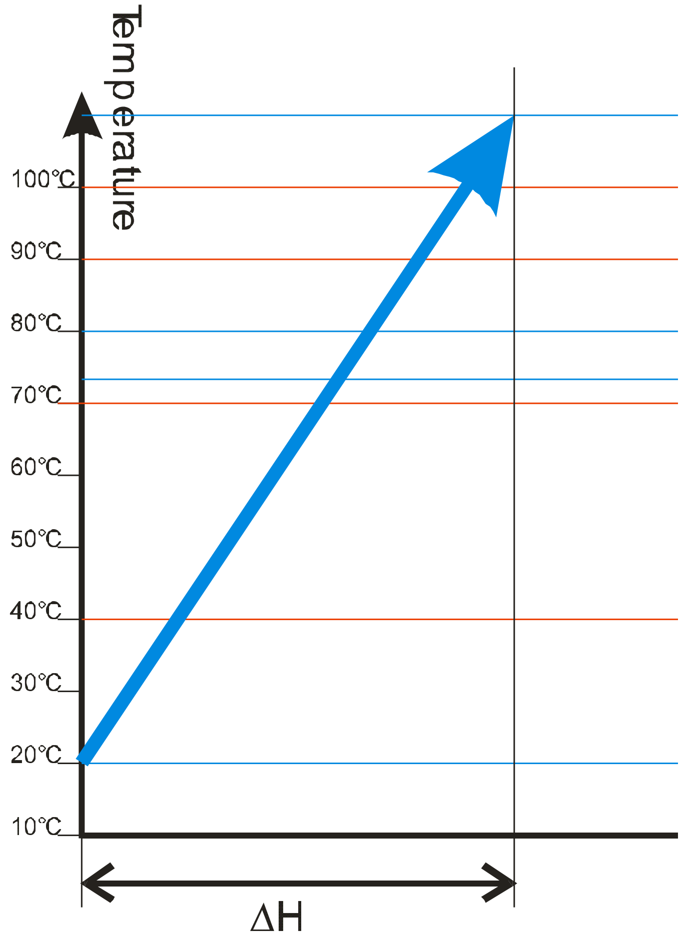
number of pinch streams	Process name	Start Temperature	End Temperature	Hot/Cold	mass flow m	specific heat capacity cp	Enthalpy H	operating hours	Energy
		[°C]	[°C]		[kg/s]	[kJ/kg.K]	[kW]	[h]	kWh/a



T (oC)
200
150
100
50
0
CP=20
CP=60
1000
1000
1000
3000
3000
(a)
H(kW)
T (ºC)
CP=20
CP=20+60=80
CP=20
1000
4000
1000
6000
(b)
H(kW)

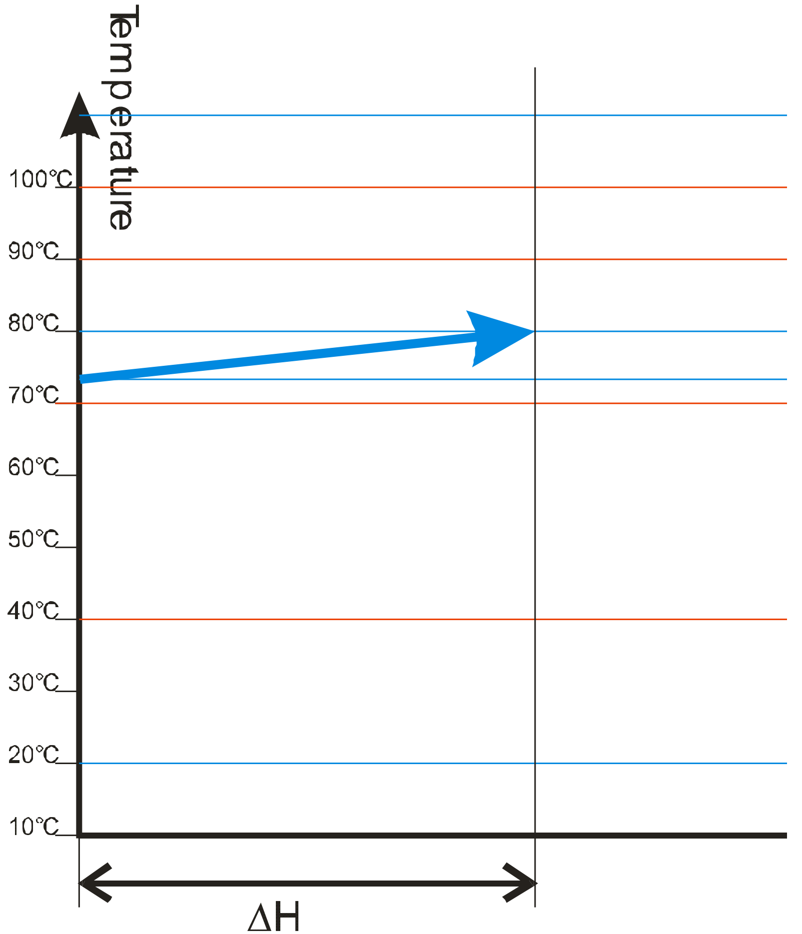
Example 1 - Temperature-enthalpy profile

- Heat up 47,8 kg/h water from 20 to 110°C
- P = ?, dH = ?



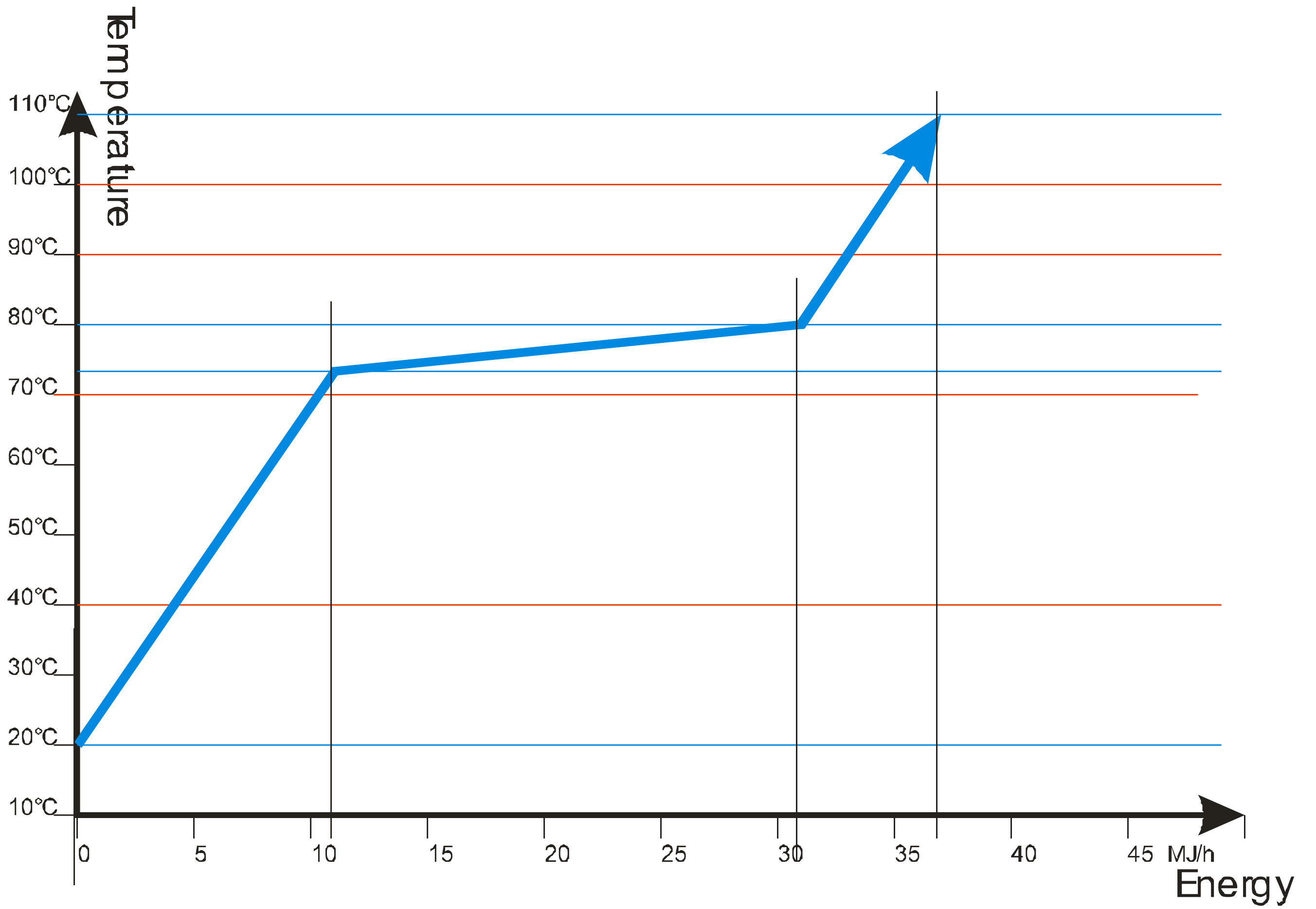
Example 2

- Heat up 636 kg/h water from 73 to 80°C
- P = ?, dH = ?



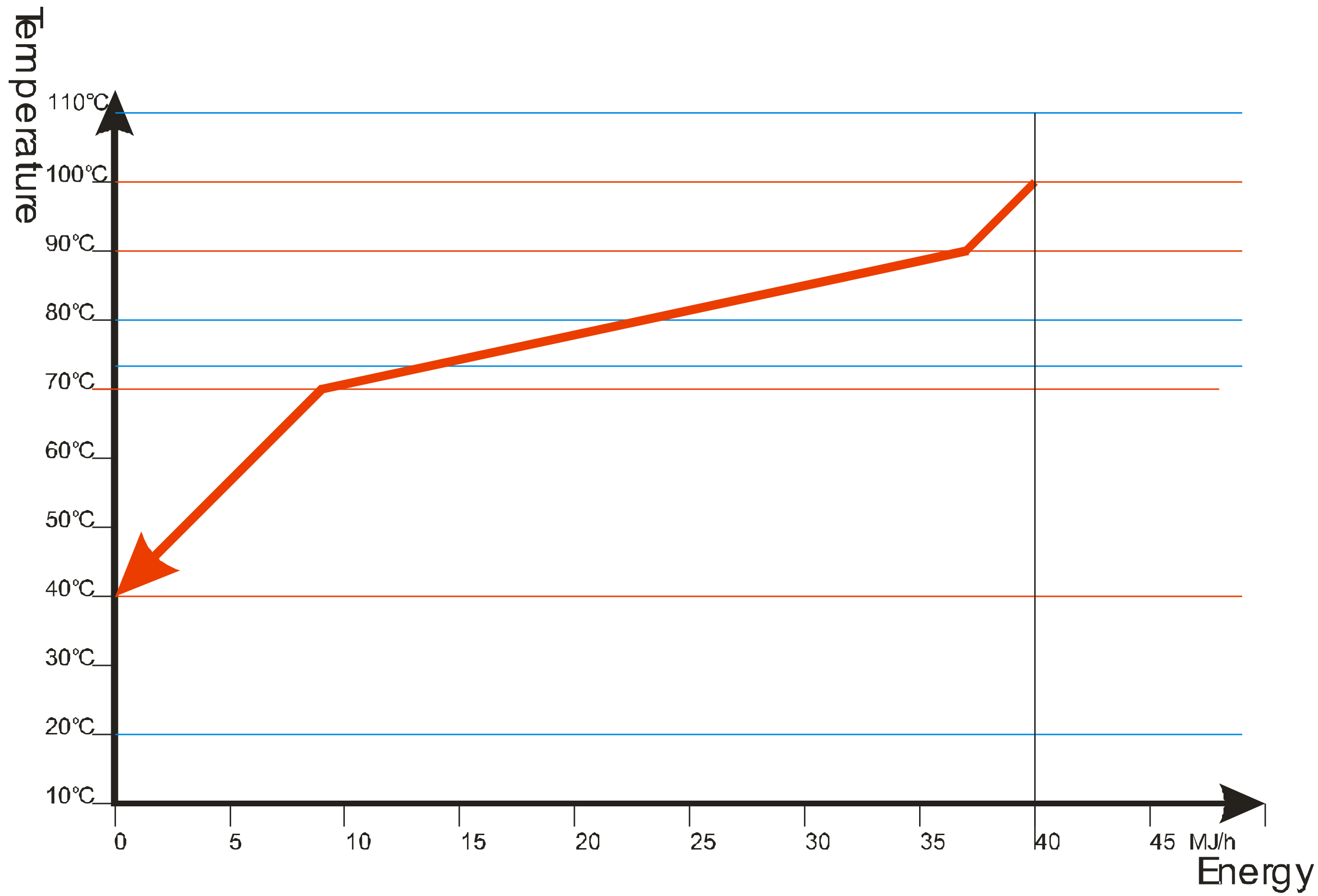
Total heat demand

➢ **Cold composite curve CCC**



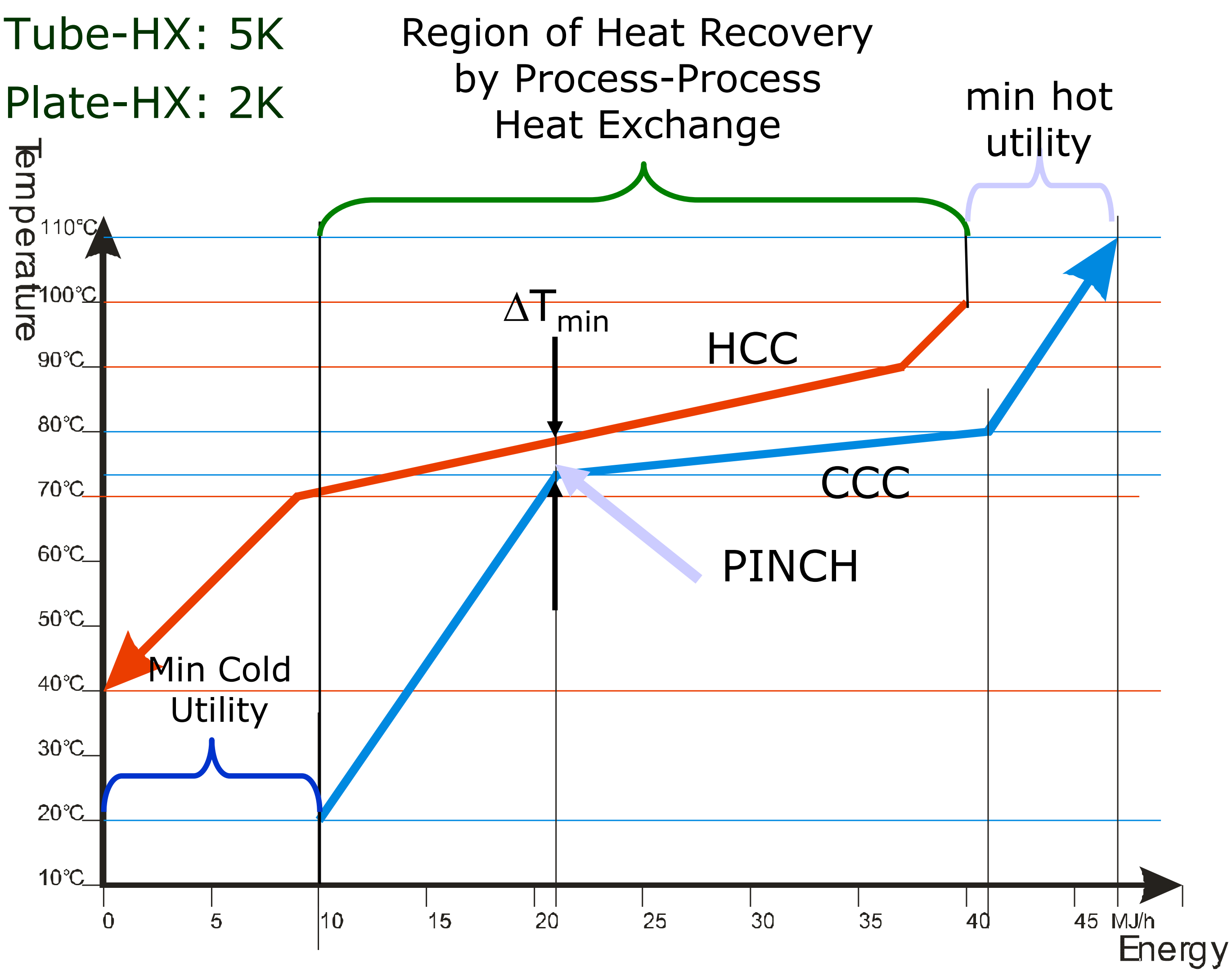
Total cooling demand/availability

- Hot composite curve HCC



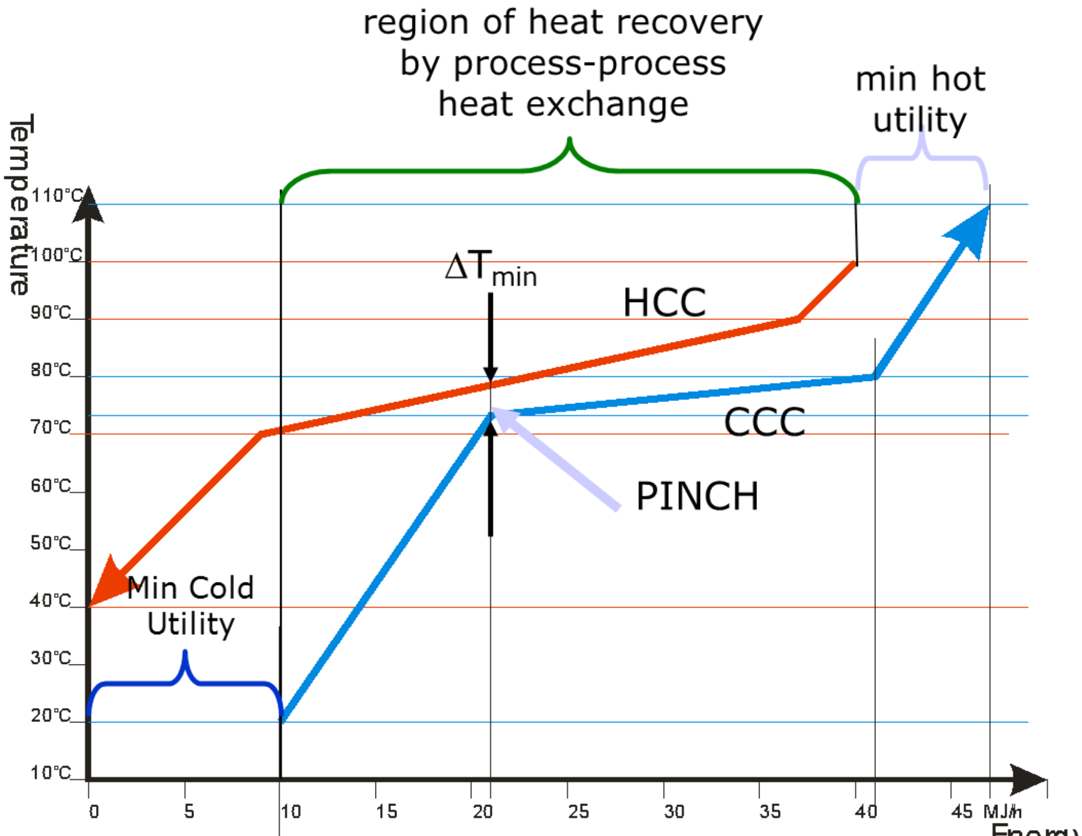
Matching the curves

- **ΔT_{min} defined by type of heat exchanger**
  - Tube-HX: 5K
  - Plate-HX: 2K

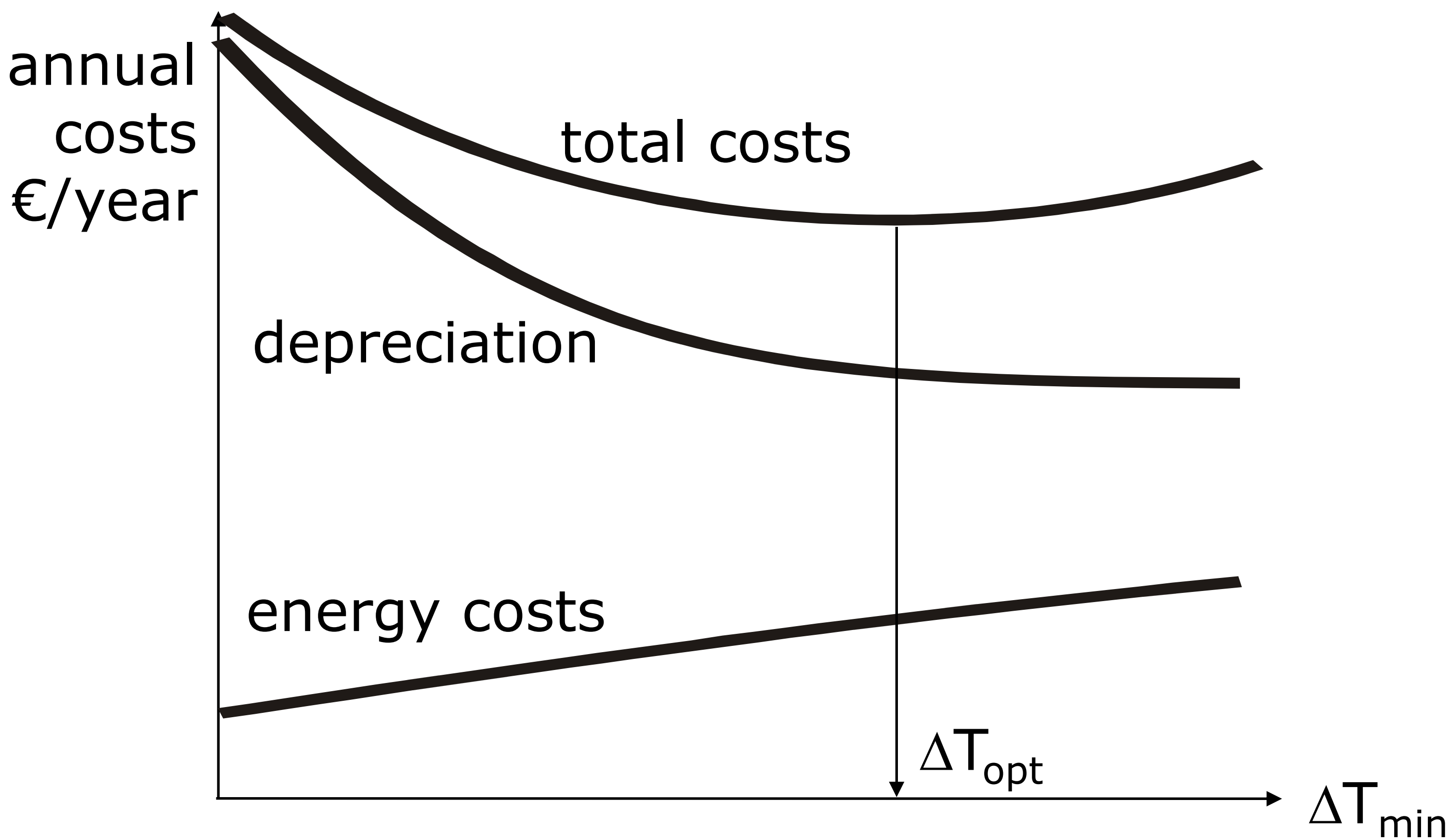


3 pinch rules

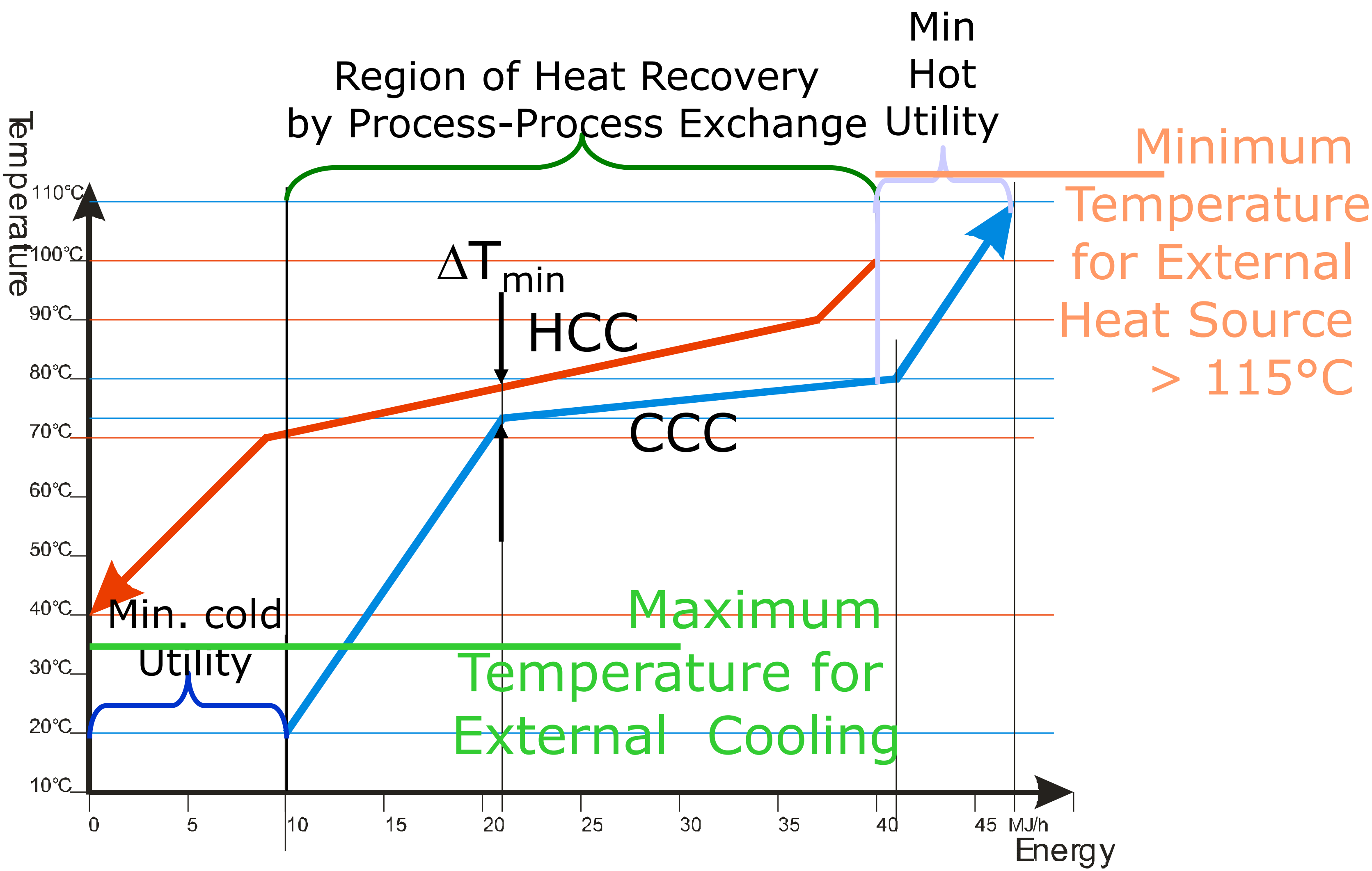
- **3 pinch design rules:**
  - No cold utility must be placed above the pinch
  - No heat transfer must occur across the pinch
  - No hot utility must be placed below the pinch



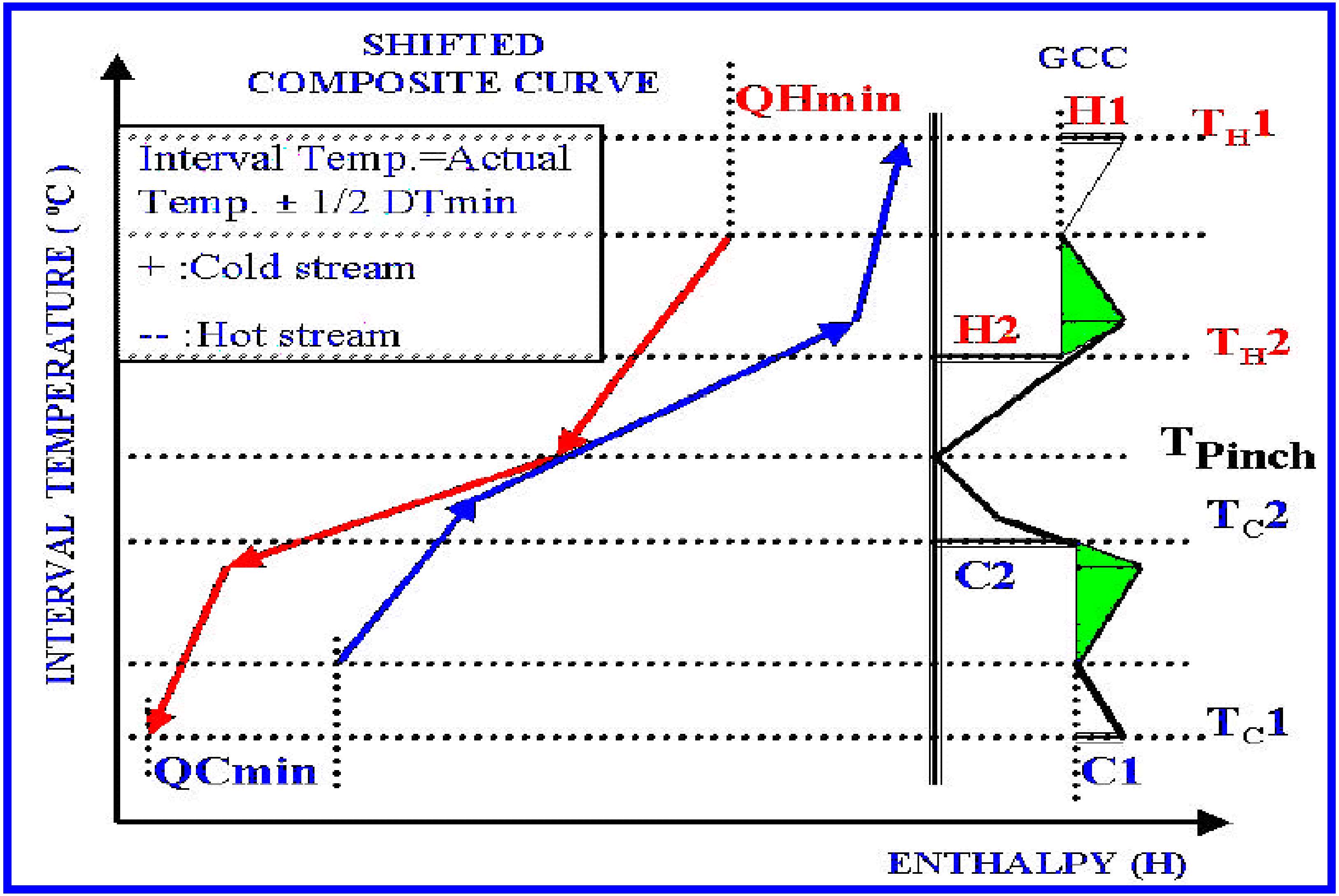
Find optimum ΔT



Temperature level of utilities

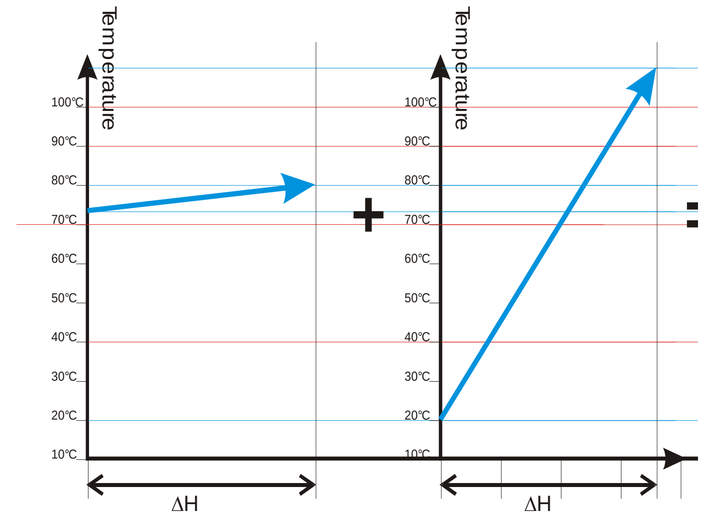


Grand Composite Curve

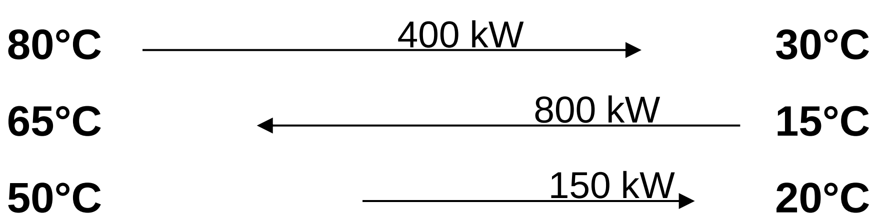


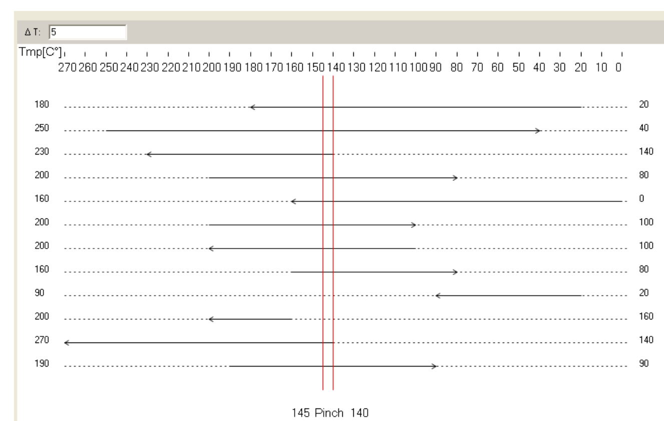
Temperature Grid Diagram

- **For each stream**
  - ⇨ Start temperature - 20°C
  - ⇨ Target temperature - 65°C
  - ⇨ Heat load: m*cp*ΔT = H [kW]



- **Each stream is displayed as a line in the temperature grid diagram:**





Practical work pinch analysis

- **Production with following streams:**
  - Calculation of the enthalpies
  - Draw HCC/CCC
  - Discuss ideas for heat recovery

	m [kg/s]	T_{in}	T_{out}	cp [kJ/kg K]
1	0.08	48	7	4.2
2	0.08	22	70	4.2
3	0.02	82	5	4.2
4	0.023	165	114	1.012
5	0.023	2	90	4.2

Practical work test case pinch analysis

- **Set up stream list for the test case**
  - Temperatures
  - Mass flow
  - Heat capacity
  - Is it a cold or a hot stream?

number	Process name	Start Temperature	End Temperature	Heat Capacity Cp	Hot/Cold	relevant to production (p) or waste heat (np)	mass flow m	specific heat capacity cp	specific enthalpy h	Enthalpy H	heat transfer coefficient of fluid α	current energy source / cooling medium
		[°C]	[°C]	[kJ/K.s]			[kg/s]	[kJ/kg.K]	[kW/kg]	[kW]	[W/m².K]	
1	Milchpasteur Erhitzung	65,00	74,00	41,10	Cold	p	10,90	3,77	33,93	369,87	2500,00	fossil gas

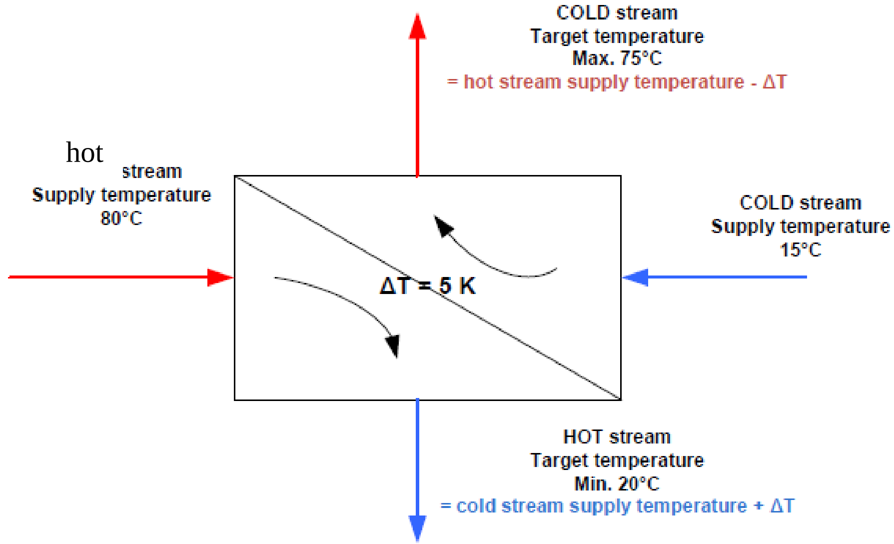
- **Start designing pinch curves for the test case**

Heat exchanger designs

- **Designer rules**
  - ⇨ Right temperature
  - ⇨ Right power
  - ⇨ No heat exchange above the pinch
- **Heat exchanger calculation**
  - ⇨ Definition of temperature
  - ⇨ Definition of enthalpy
- **HEN criteria – cost savings**
  - ⇨ Maximal transfer with a minimum of investment costs
  - ⇨ Optimal thermodynamic use of streams under exergetic considerations

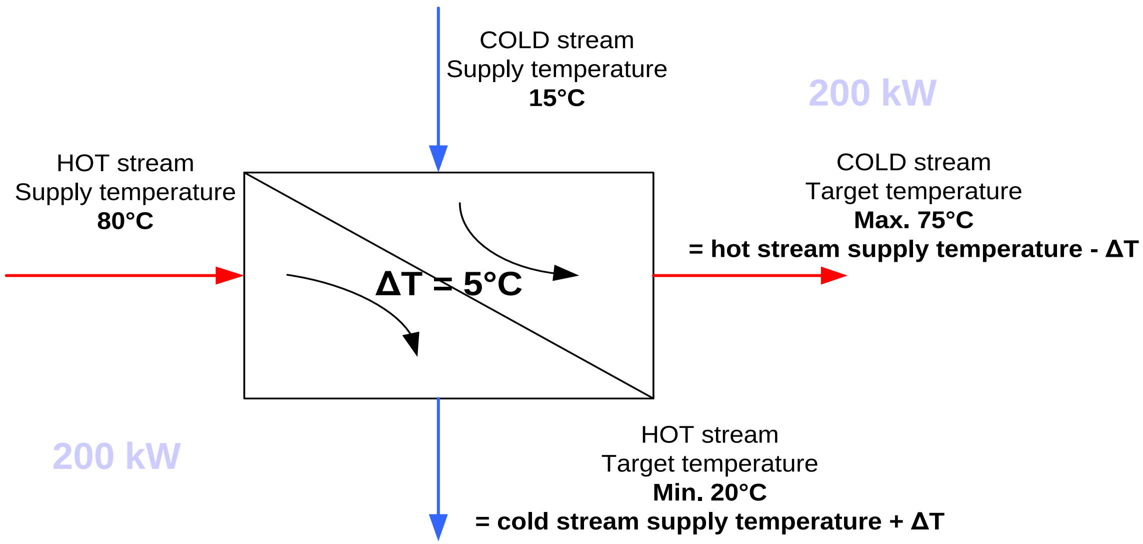
Designer rules (1)

- **Choice of ΔT_{min} for a first concept**
  - ⇨ In a counter current heat exchanger the final temperature of the cold stream can at a maximum reach the start temperature of the hot stream minus ΔT_{min}.
  - ⇨ In a counter current heat exchanger the final temperature of the hot stream can at a minimum reach the start temperature of the cold stream plus ΔT_{min}.



Designer rules (2)

- **Right power**
  - On both sides of the heat exchanger the same power



$$H[kW] = m_{hs} * c_{p\_hs} * \left(T_{supply\_hs} - T_{target\_hs}\right) = m_{cs} * c_{p\_cs} * \left(T_{target\_cs} - T_{supply\_cs}\right)$$

Designer rules examples (1)

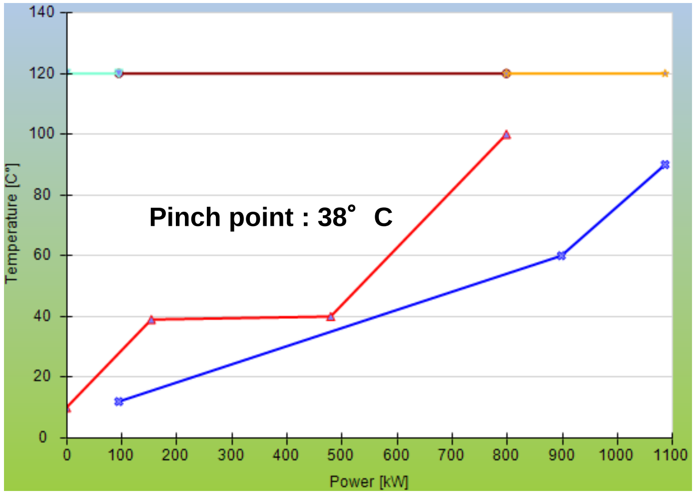
- **Right power**
  - Attention for the limiting temperature of the streams
  - Example cold stream can not be heated up to 90°C otherwise hot stream will be cooled down by -20°C

Status quo streams			Must HX = 780 [kW]		
	Cold stream	**Hot stream**		**Cold stream**	**Hot stream**
T_{start} [°C]	12	100	**T_{start} [°C]**		
T_{end} [°C]	90	15	**T_{end} [°C]**		
$m*cp_m$ [kW/K]	10	6,5	**m*cp [kW/K]**		
Enthalpy [kJ/s]	780	-552.5	**Enthalpy [kJ/s]**		

Designer rules examples (2)

- **No heat exchange above pinch**
  - Pratically it can be usefull to have a HX above the pinch
  - Example
    - **If two streams fit good → no reason to install two HX**

Streams		
	Cold stream	**Hot stream**
T_{start} [°C]	12	100
T_{end} [°C]	90	15
$m*cp_m$ [kW/K]	10	9,5
Enthalpy [kJ/s]	780	-807,5



Designer rules examples (3)

- **Temperature depending**
  - 3 temperatures
  - Example:
    - $H_{cold} = m*cp_{cold} *(T_{end}-T_{start})_{cold}$
    - $H_{hot} = -H_{cold}$
    - $T_{ende,\ hot} = T_{start,\ hot} - H_{hot}/m*cp_{hot}$

Demand - HX - cold stream to 60°C		
	Cold stream	**Hot stream**
T_{start} [°C]	12	100
T_{end} [°C]	60	26.2
m*cp [kW/K]	10	6,5
Enthalpy [kJ/s]	480	-480

Designer rules examples (4)

Power requirement 1

- 2 temperatures and power
- Example
  - $T_{ende,cold} = T_{start,cold} + H_{hot}/(m*cp)_{cold}$
  - $H_{hot} = -H_{cold}$
  - $T_{ende,ho}t = T_{start,hot} - H_{hot}/(m*cp)_{hot}$

HX fixed – 400[kW]		
	Cold stream	**Hot stream**
T_{start} [°C]	12	100
T_{end} [°C]	52.0	38.5
m*cp [kW/K]	10	6,5
Enthalpy [kJ/s]	400	-400

Designer rules examples (5)

- **Power demand 2**
  - Final temperature of cold streams and power for cold stream and on temperature of hot stream
  - Example
    - $\mathbf{H_{cold} = (m*cp)_{cold} *(T_{ende}-T_{start})_{cold}}$
    - $\mathbf{H_{hot} = -H_{cold}}$
    - $\mathbf{T_{ende,hot} = T_{start,hot} - H_{hot}/(m*cp)_{hot}}$

Demand HX heating cold stream to 40°C		
	Cold stream	**Hot stream**
T_{start} [°C]	12	100
T_{end} [°C]	40	56.9
m*cp [kW/K]	10	6.5
Enthalpy [kJ/s]	280	-280

Designer rules examples (6)

- **Power demand 3**
  - Final temperature of hot stream and the power for hot stream (start with starting temp of hot stream) and one temp of cold stream
  - Example:
    - $H_{hot} = (m*cp)_{hot} *(T_{ende}-T_{start})_{hot}$
    - $H_{cold} = -H_{hot}$
    - $T_{start,cold} = T_{ende,cold} - H_{cold}/(m*cp)_{cold}$

Cooling hot stream to 20°C		
	Cold stream	**Hot stream**
T_{start} [°C]	38	100
T_{end} [°C]	90	20
m*cp [kW/K]	10	6.5
Enthalpy [kJ/s]	520	-520

HEN design-criteria

- **Criteria 1: maximum of heat recovery with small investment costs**
  - ⇨ Minimize the number of HX
  - ⇨ Less HX per streams

HEN design-criteria

- **Criteria 2: thermodynamic optimization**
  - Exergy
    - **High temperature level for high temperature demand**
    - **Low temperature level for pre-heating**
  - More complex HEN
    - **Several HX for one stream**
    - **Linked network**

Batch Processes und Pinch Analysis

- **In industry we find very often batch processes**
  - ⇨ Specific batch pinch methodology necessary
- **For analysis of processes/stream not only heat demand between two streams and temperatures is available but also that a stream is available for a defined time (time dependency)**
- **Considering of temperature levels and time intervals**

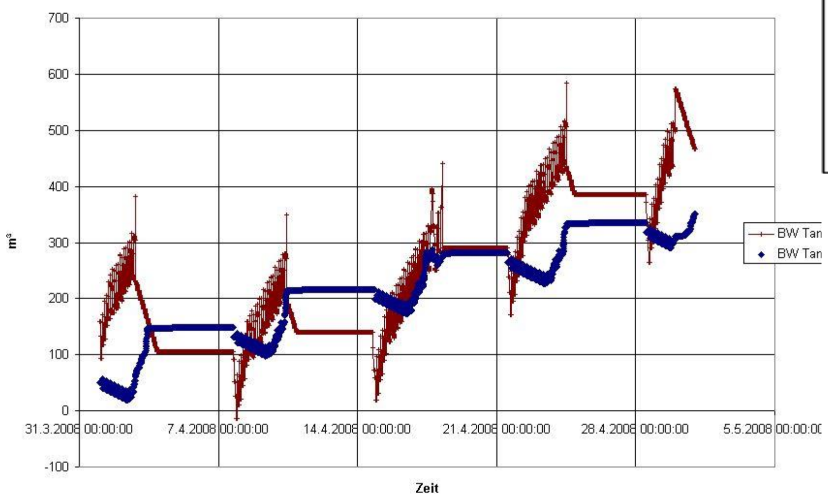
Batch Processes und Pinch Analysis

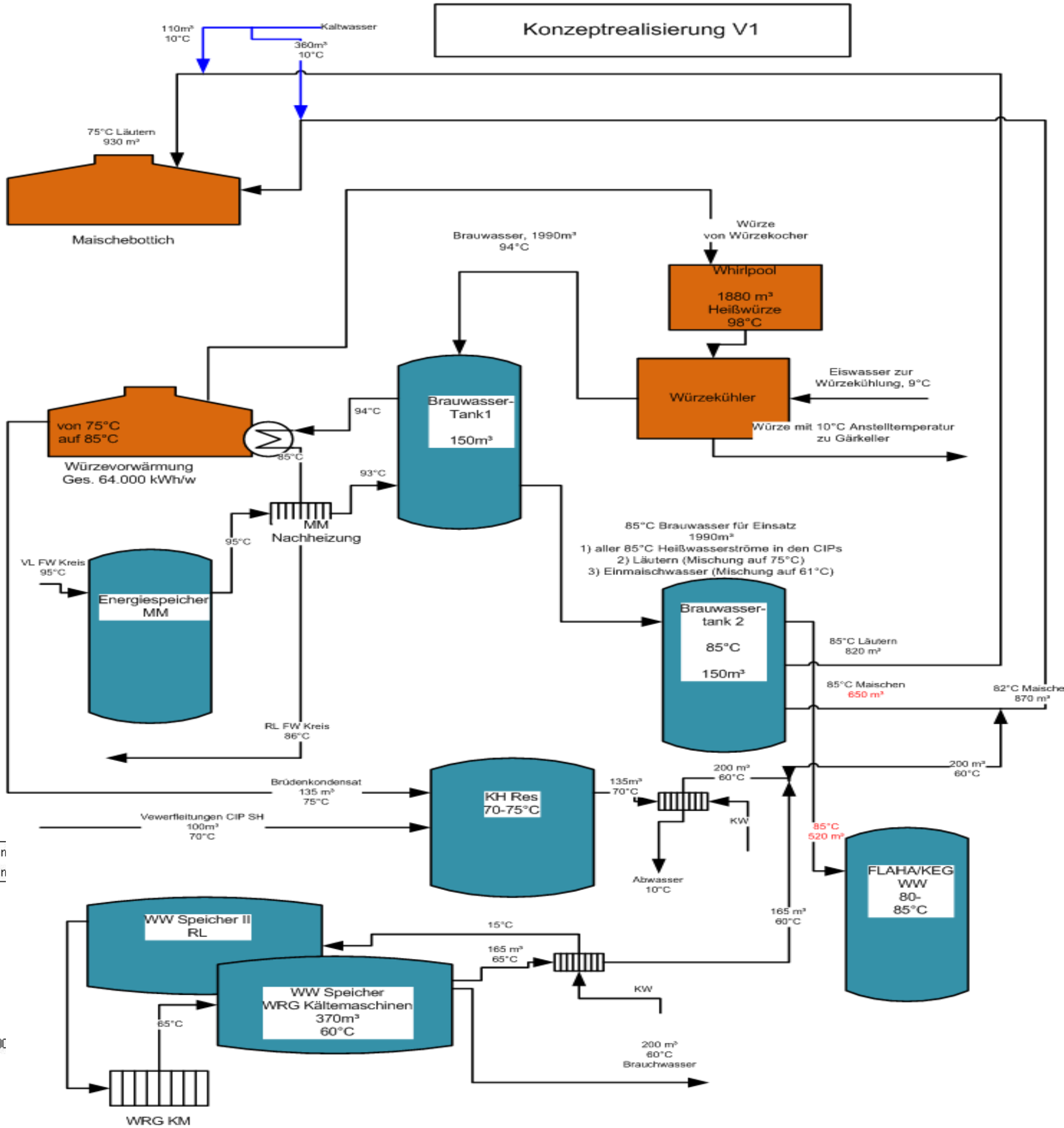
- **Amount of heat Q in [kJ]**

⇨ $$Q = m \cdot c_p \cdot \Delta T \cdot \Delta t$$

- **m mass [kg]**
- **cp specific heat capacity [kJ/(kgK)]**
- **ΔT temperature difference [K]**
- **Δt time difference [s]**

Storage management





Practical work

- **Based on the stream list of the test case discuss in groups**
  - Basic design of pinch curves
  - Which streams can be matched in a heat exchanger network
  - Define these heat exchangers regarding
    - **Type of heat exchanger**
    - **Operating hours**
    - **Control of the heat exchangers**
    - **Influence in following processes**
    - **Energy savings**
    - **Input and output temperatures of the streams**
  - Present your ideas in front of the groups

Heat recovery in industrial processes

- **Internal heat recovery (process optimisation)**
  - Within one process output stream at high temperature level preheats input stream
  - Reduction of energy demand of the process
  - E.g. pasteurisation in a dairy
    - **Milk output stream preheats incoming milk and thereby reduces energy demand of the process**
- **External heat recovery (system optimisation, heat integration)**
  - Output streams of one process is used to preheat input streams of another process
  - Reduction of energy demand of the system
  - E.g. waste heat of a baking oven preheats incoming water used for cleaning (process „heating cleaning water")

Examples for available waste heat streams

- **Dairy**
  - ⇨ Waste water cheese fermentation
- **Meat industry**
  - ⇨ Waste water cooking
- **Bakery**
  - ⇨ Hot air of baking oven
- **Brewery**
  - ⇨ Wort boiling
- **Fruit and vegetables processing**
  - ⇨ Waste water pasteurisation

Waste heat streams from equipment

- **Integration of waste heat streams in HEN**
- **Possible equipment e.g.**
  - Chiller: cooling air
  - Air compressor: cooling air
  - Boiler: flue gas
- **Advantage**
  - Feasible temperature level
  - Centralised
- **Disadvantage**
  - Optimising the system might reduce waste heat potential by reduction of operating hours, availability, etc. of equipment
  - Direct influence on HEN

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