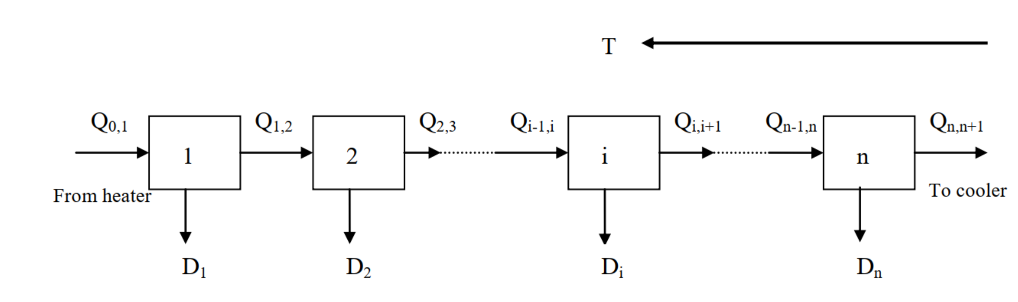
EN 410
Energy Management

Gurubalan Annadurai
guru.a@iitb.ac.in

Problem table approach

5. Estimate the new supplied heat to the each interval, 1710 kW as load input in the interval 1



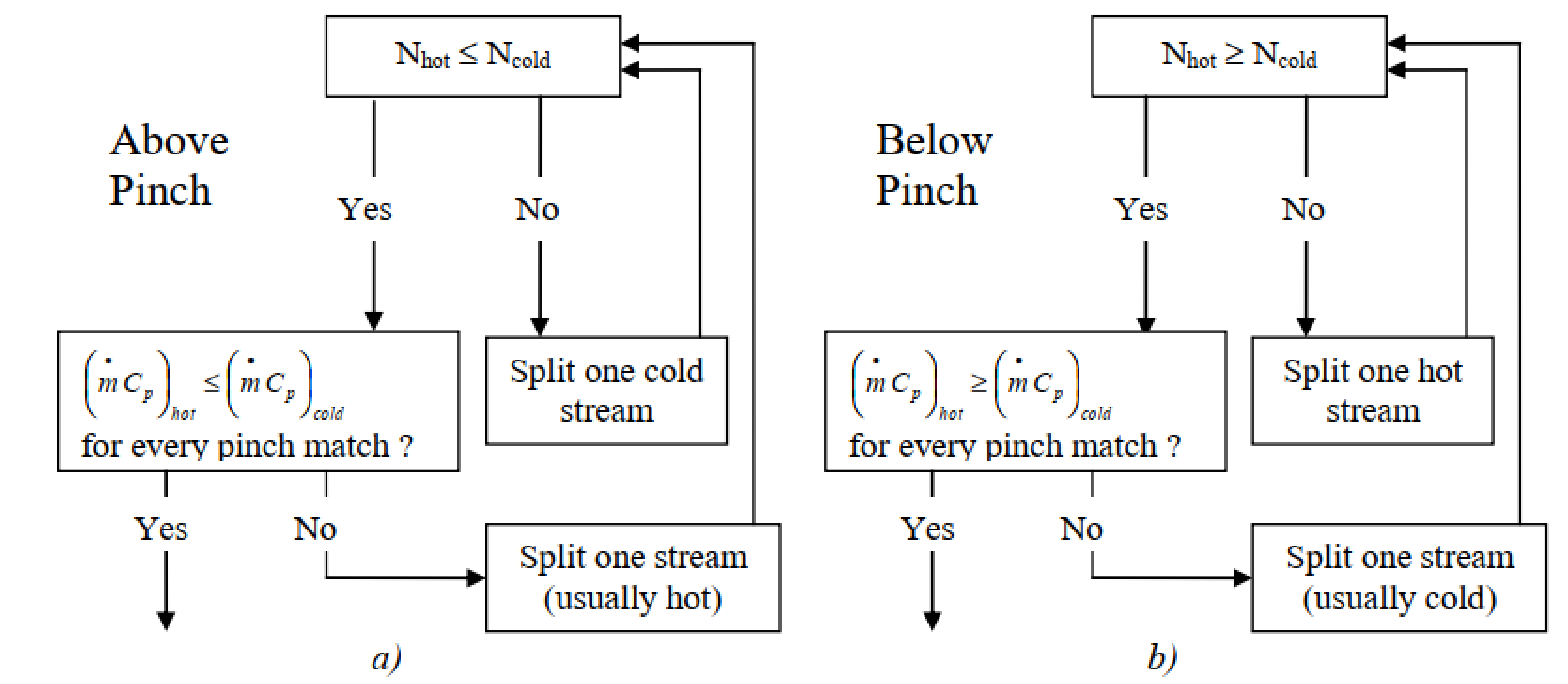
$$\dot{Q}_{i,i+1} = \dot{Q}_{i-1,1} - D_i$$

			Sequential Balance		Max Table	
Interval	Temp. limits	D_i	$\dot{Q}_{i-1,i}$	$\dot{Q}_{i,i+1}$	$\dot{Q}_{i-1,i}$	$\dot{Q}_{i,i+1}$
1	500 – 430	-1680	0	1680	***1710***	3390
2	430 – 420	-510	1680	2190	3390	3900
3	420 – 390	-1230	2190	3420	3900	5130
4	390 – 350	-480	3420	3900	5130	5610
5	350 – 290	1200	3900	2700	5610	4410
6	290 – 200	3960	2700	-1260	4410	450
7	200 – 170	450	-1260	*-1710*	450	***0***
8	170 – 130	-680	-1710	-1030	***0***	680
9	130 – 90	400	-1030	-1430	680	***280***

- Pinch temperature = 170°C (for cold= = 170°C , hot = 180°C)
- Minimum heating utility = 1710 kW
- Minimum cooling utility = 280 kW

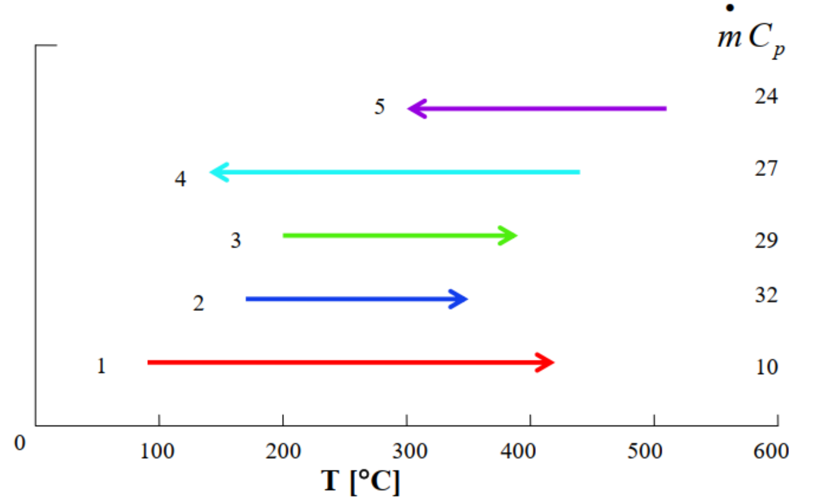
Heat exchanger network

- The network above and below the pinch shall be designed separately (independently)
- Start with placing a heat exchanger close to the pinch point and continue outwards
- Allow the heat exchangers transfer heat as much as possible



Process streams above and below pinch

	Process stream type	Inlet temp	Outlet temp	Heat capacity rate
	-	°C	°C	kW/K
1	Cold	90	420	10
2	Cold	170	350	32
3	Cold	200	390	29
4	Hot	440	140	27
5	Hot	510	300	24



1. Below Pinch

Process stream Nr / Type	Inlet Temp. [°C]	Outlet Temp. [°C]
1. cold	90	170
2. cold	–	–
3. cold	–	–
4. hot	180	140
5. hot	–	–

2. Above Pinch

Process stream Nr / Type	Inlet Temp. [°C]	Outlet Temp. [°C]
1. cold	170	420
2. cold	170	350
3. cold	200	390
4. hot	440	180
5. hot	510	300

3. Estimate ΔH

Process streams above and below pinch

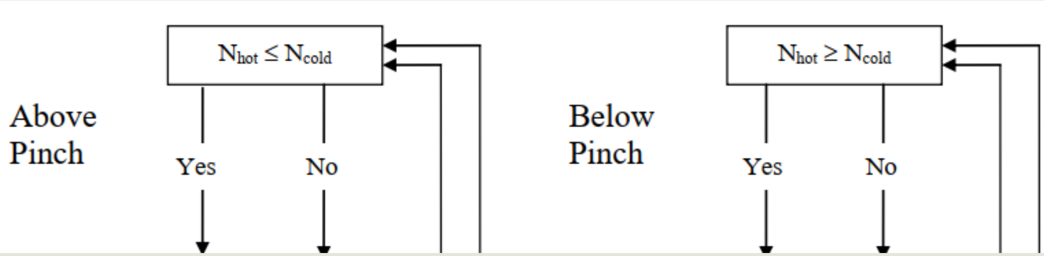
3. Estimate ΔH

Table 7. Process streams above the pinch with ΔT_{min} = 10 ℃ .

Process stream Nr / Type	Inlet Temp. [°C]	Outlet Temp. [°C]	Heat capacity rate [kW/K]	$\dot{Q}$ [kW]
1. cold	170	420	10	2500
2. cold	170	350	32	5760
3. cold	200	390	29	5510
4. hot	440	180	27	7020
5. hot	510	300	24	5040

Table 8. Process streams below the pinch with ΔT_{min} = 10 ℃.

Process stream Nr / Type	Inlet Temp. [°C]	Outlet Temp. [°C]	Heat capacity rate [kW/K]	$\dot{Q}$ [kW]
1. cold	90	170	10	800
2. cold	–	–	–	–
3. cold	–	–	–	–
4. hot	180	140	27	1080
5. hot	–	–	–	–

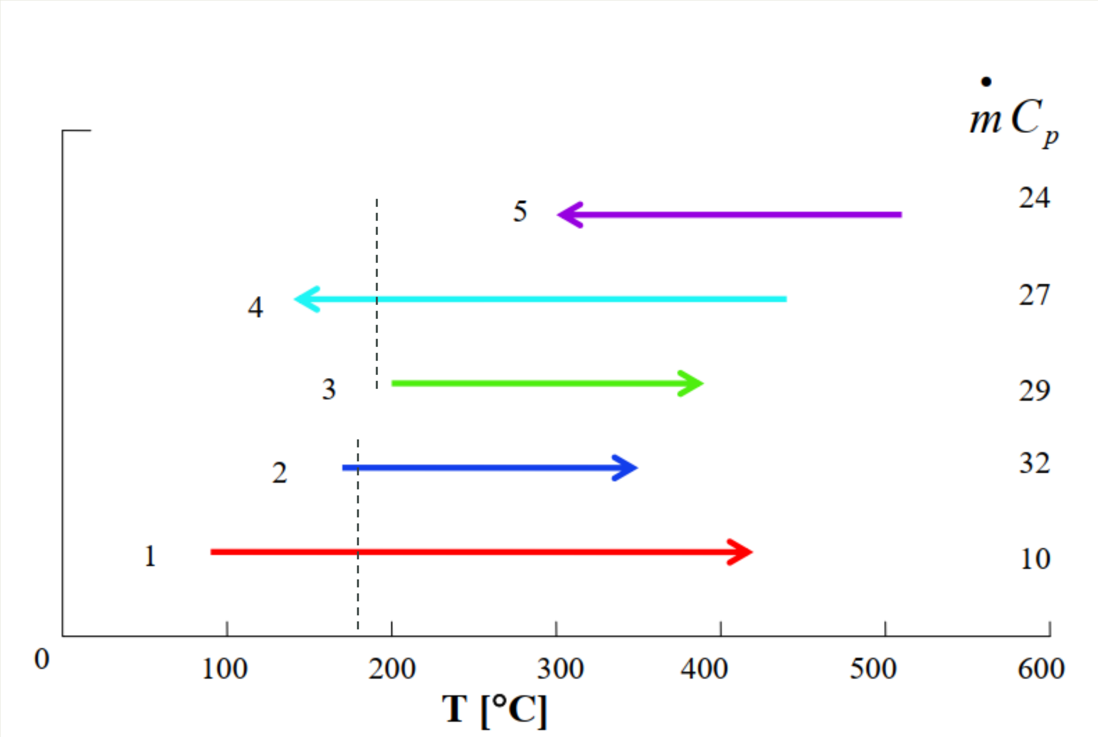


Grid diagram above pinch

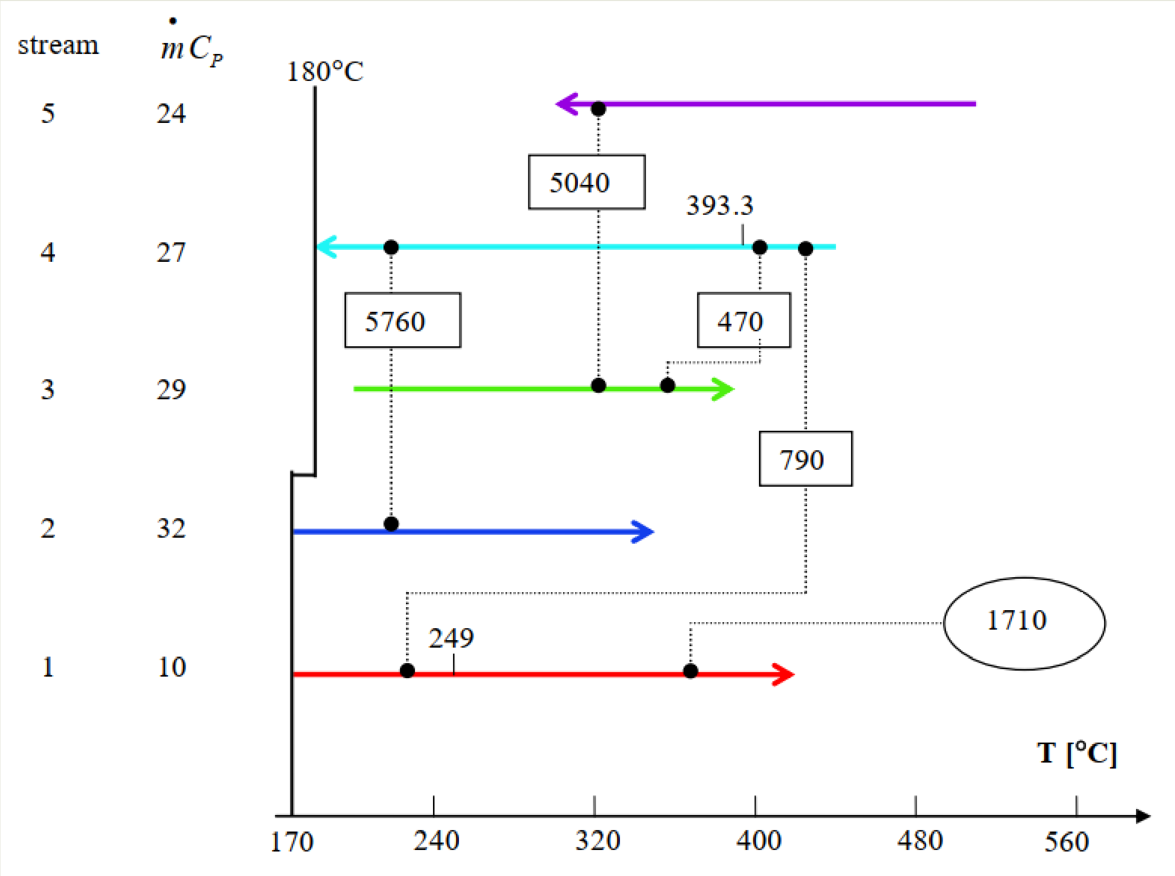
- $\left(\dot{m}\,C_p\right)_{hot} \leq \left(\dot{m}\,C_p\right)_{cold}$ immediate above the pinch point

Table 7. Process streams above the pinch with ΔT_{min} = 10 ℃ .

Process stream Nr / Type	Inlet Temp. [°C]	Outlet Temp. [°C]	Heat capacity rate [kW/K]	$\dot{Q}$ [kW]
1. cold	170	420	10	2500
2. cold	170	350	32	5760
3. cold	200	390	29	5510
4. hot	440	180	27	7020
5. hot	510	300	24	5040



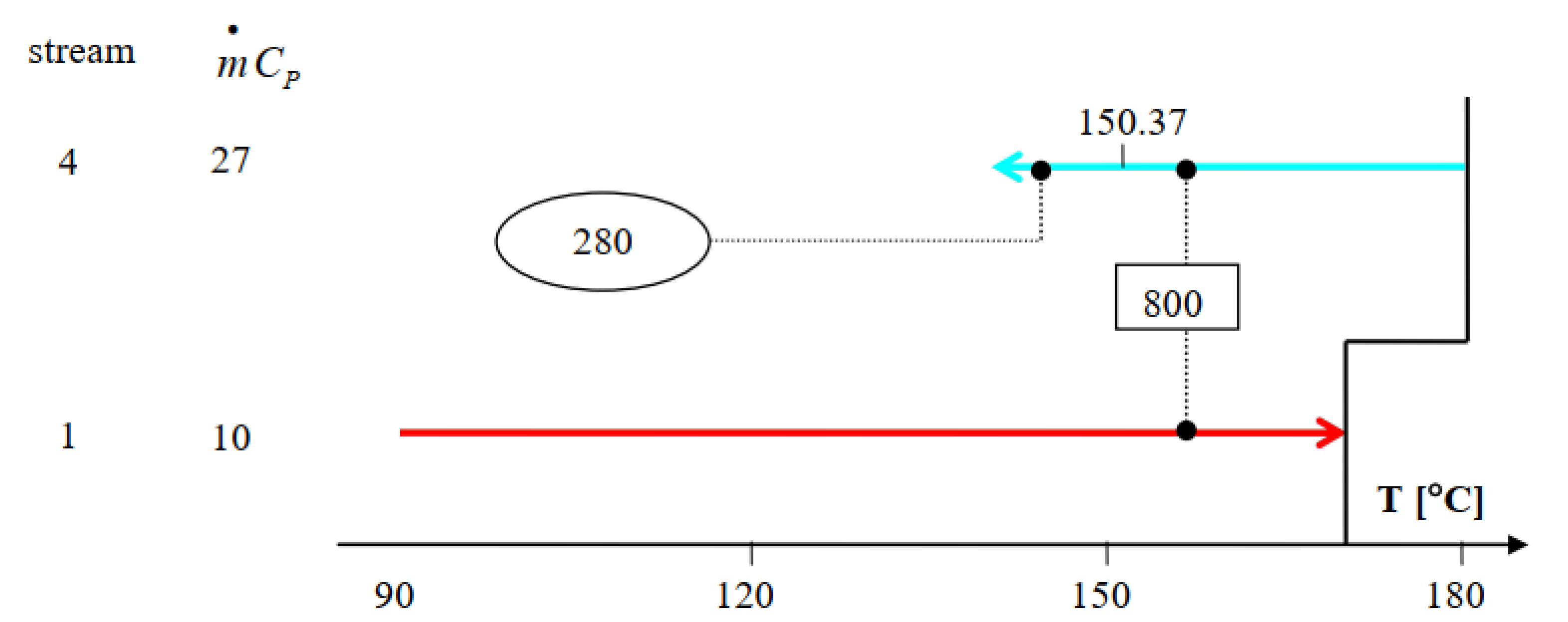
Grid diagram above pinch



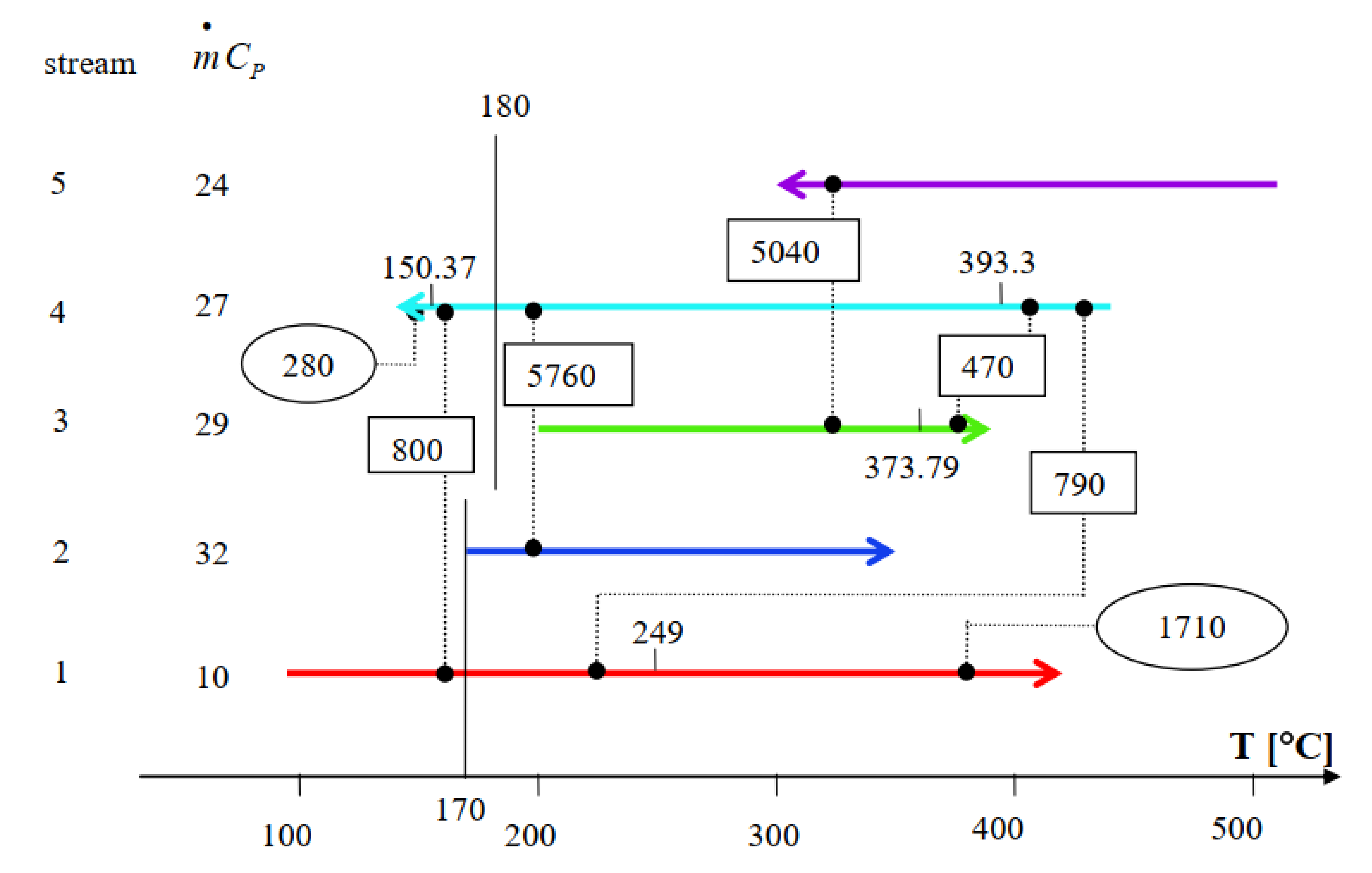
Grid diagram below pinch

Table 8. Process streams below the pinch with ΔT_{min} = 10 °C.

Process stream Nr / Type	Inlet Temp. [°C]	Outlet Temp. [°C]	Heat capacity rate [kW/K]	$\dot{Q}$ [kW]
1. cold	90	170	10	800
2. cold	–	–	–	–
3. cold	–	–	–	–
4. hot	180	140	27	1080
5. hot	–	–	–	–



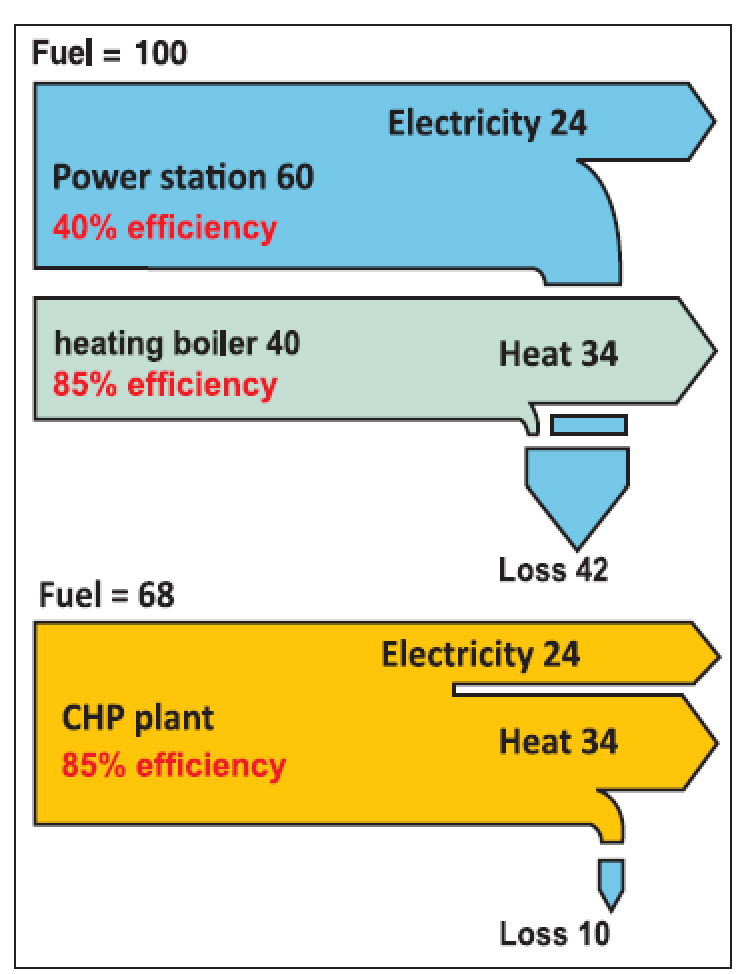
Grid diagram



Cogeneration

- Many industries require energy input in the form of heat, called ***process heat***. Process heat in these industries is usually supplied by steam
- Industries that use large amounts of process heat also consume a large amount of electric power.
- The result is a plant that produces electricity while meeting the process-heat requirements of certain industrial processes (cogeneration plant)
- **Cogeneration:** The production of more than one useful form of energy (such as process heat and electric power) from the same energy source.

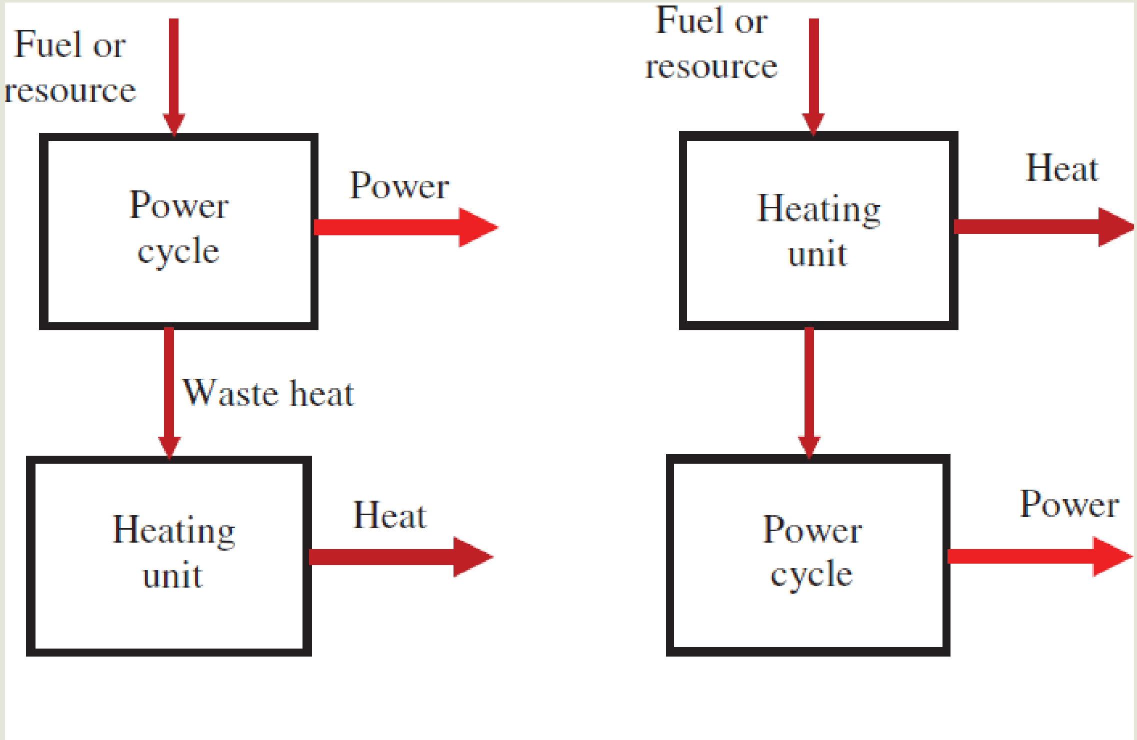
Cogeneration



- Higher efficiency – lesser fuel – lesser loss – lesser pollution
- A combination of power production and heating/cooling can also be used in a cogeneration scheme.
- It is called trigeneration if three useful forms of energy (such as electric power, process heat, and cooling) are produced from the same energy source.

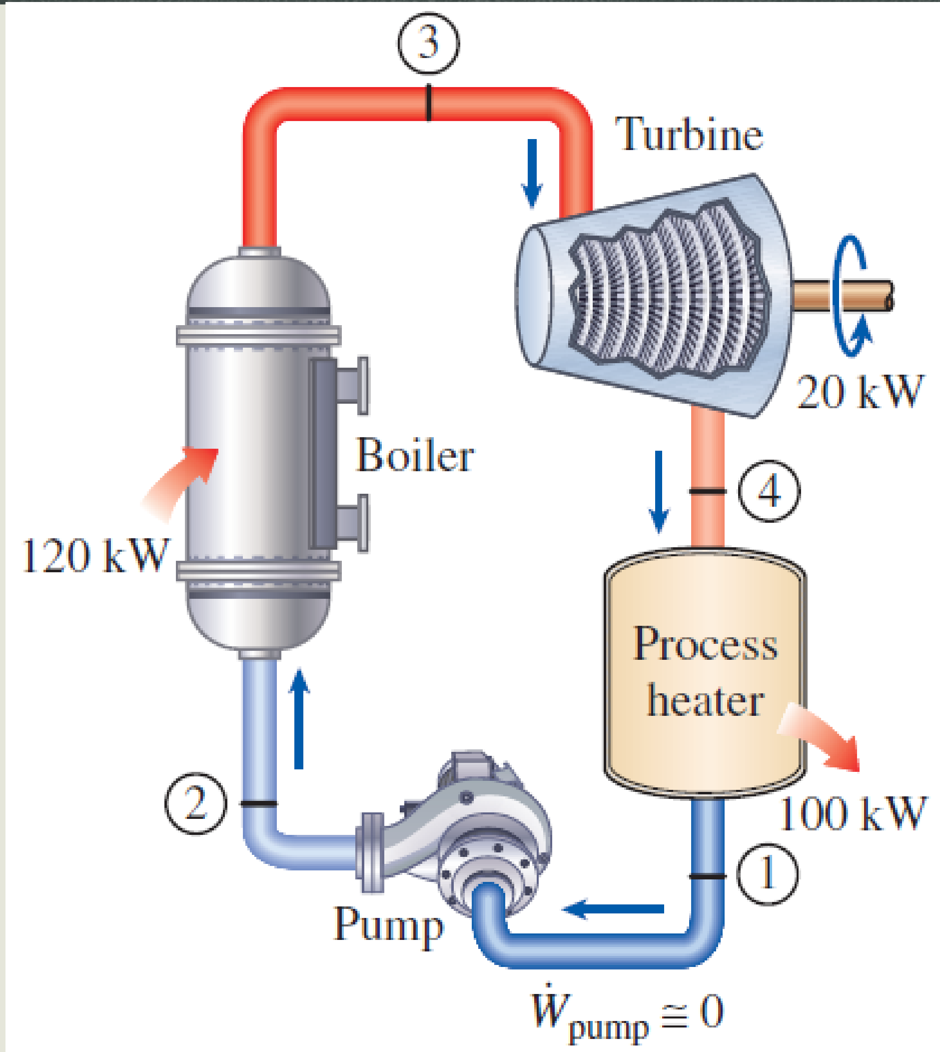
Cogeneration Schemes

- Topping cycle is most commonly used. It is particularly suitable when the electric demand of the facility is greater than the thermal demand, and the process heat temperature requirements are not high.
- Bottoming cyle is particularly suitable when the plant needs process heat at a high temperature. Some examples include steel reheat furnaces, clay and glass kilns and aluminum remelt furnaces.
- The power cycle is also called prime mover.
- Steam-turbine (Rankine) cycle, a gas-turbine (Brayton) cycle, a combined cycle (combination of Rankine and Brayton cycles), an internal combustion engine



(a) Topping cycle (b) Bottoming cycle

Steam-turbıne cogeneratıon



Utilization factor

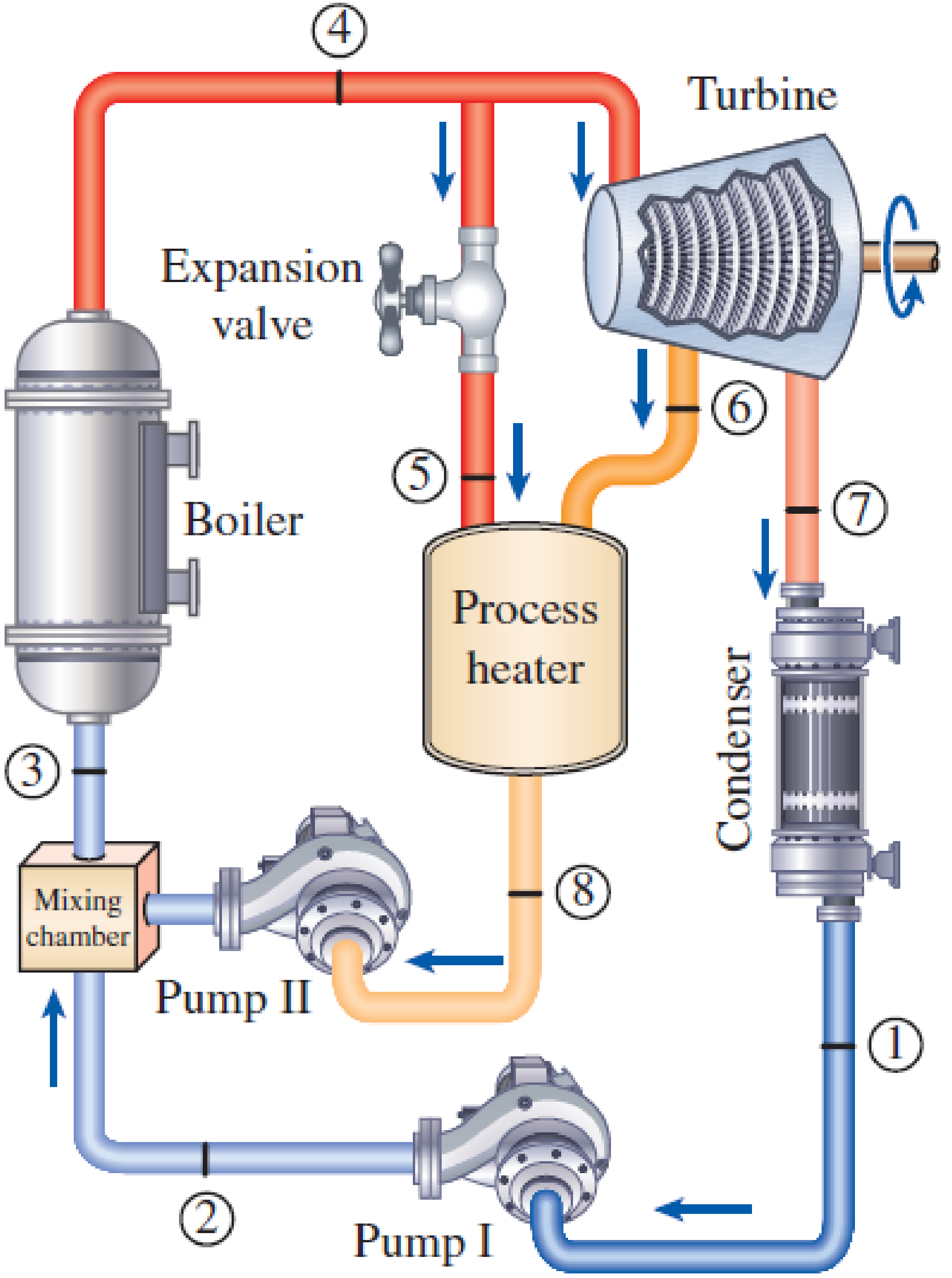
$$\epsilon_u = \frac{\text{Net power output} + \text{Process heat delivered}}{\text{Total heat input}} = \frac{\dot{W}_{\text{net}} + \dot{Q}_p}{\dot{Q}_{\text{in}}}$$

$$\text{Electricity-to-heat ratio} = \frac{\dot{W}_{\text{net}}}{\dot{Q}_{\text{process}}}$$

Ideal since not suitable for load variation

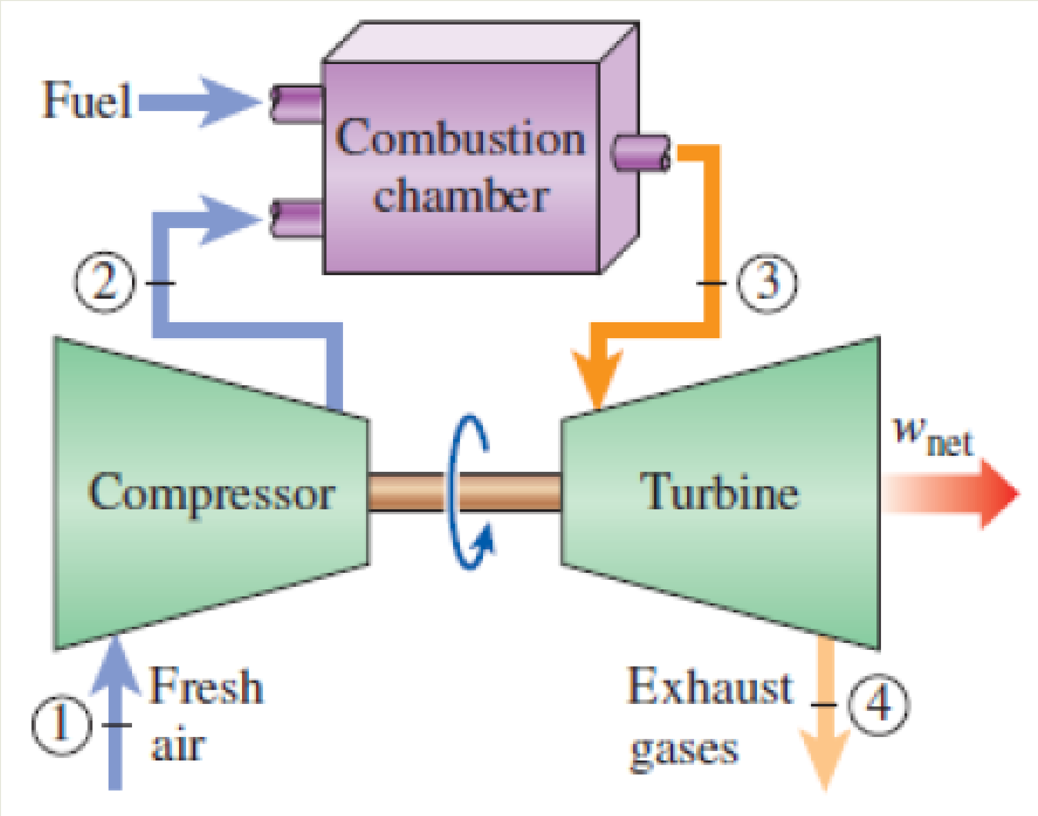
Cogeneration plant with adjustable loads

- At times of high demand for process heat, all the steam is routed to the process-heating units and none to the condenser ($m_7 = 0$). The waste heat is zero in this mode.
- If this is not sufficient, some steam leaving the boiler is throttled by an expansion or pressure-reducing valve and directed to the process-heating unit.
- Maximum process heating is realized when all the steam leaving the boiler passes through the valve ($m_5 = m_4$). No power is produced in this mode.
- When there is no demand for process heat, all the steam passes through the turbine and the condenser ($m_5 = m_6 = 0$), and the cogeneration plant operates as an ordinary steam power plant.



Gas-turbıne cogeneratıon

- Heat is rejected to the atmosphere at a high temperature (300 to 400°C) which makes this plant very suitable for cogeneration applications.
- Steam is usually taken at an intermediate stage in the turbine or from the outlet of the boiler so that the temperature is sufficiently high for process heating.
- Multiple process heating at high temperature
- Advantages : Simpler, easier and quicker to install and operate, and cheaper compared to steam power based cogeneration.



Selection of prime movers

	Reciprocating engine	*Gas turbine*	*Steam turbine*
Application	Small and medium size plants	Small, medium, and large plants	Large plants, residential and commercial districts
Capacity	50 – 3000 kW	500 – 30,000 kW	> 1000 kW
Fuel	Diesel, fuel-oil, natural gas, propane	Natural gas, diesel	Coal, natural gas, Diesel, fuel-oil, propane, biofuel, pellet
Thermal efficiency	Approaching 50%	Around 30%	30 – 45% Combined cycle: 50 – 60%
Maintenance requirements	High	Low	Low

Load Factor

Electricity and heat use: A preliminary investigation of a proposed cogeneration application should start with the analysis of plant's energy use profile. The upper and lower limits of electricity and heat use of the facility should be analyzed.

$$\text{Average electric demand (kW)} = \frac{\text{Total electricity consumption (kWh)}}{\text{Annual operating hours (h)}}$$

$$\text{Electric load factor} = \frac{\text{Average electric demand (kW)}}{\text{Peak electric demand (kW)}}$$

$$\text{Average thermal demand (kJ/h)} = \frac{\eta_{\text{boiler}} \times \text{Total fuel consumption (kg)} \times \text{HHV (kJ/kg)}}{\text{Annual operating hours (h)}}$$

$$\text{Thermal load factor} = \frac{\text{Average thermal demand (kJ/h)}}{\text{Peak thermal demand (kJ/h)}}$$

Thermal/electric load ratio

$$\text{Thermal/electric load ratio} = \frac{\text{Thermal demand (kW)}}{\text{Electric demand (kW)}}$$

1 mbh = 1000 Btu/h

$$\text{Thermal/electric load ratio} = 0.2931 \times \text{Thermal/electric load ratio (mbh/kW)}$$

A high value of thermal/electric load ratio corresponds to a higher utilization factor for a given cogeneration system.

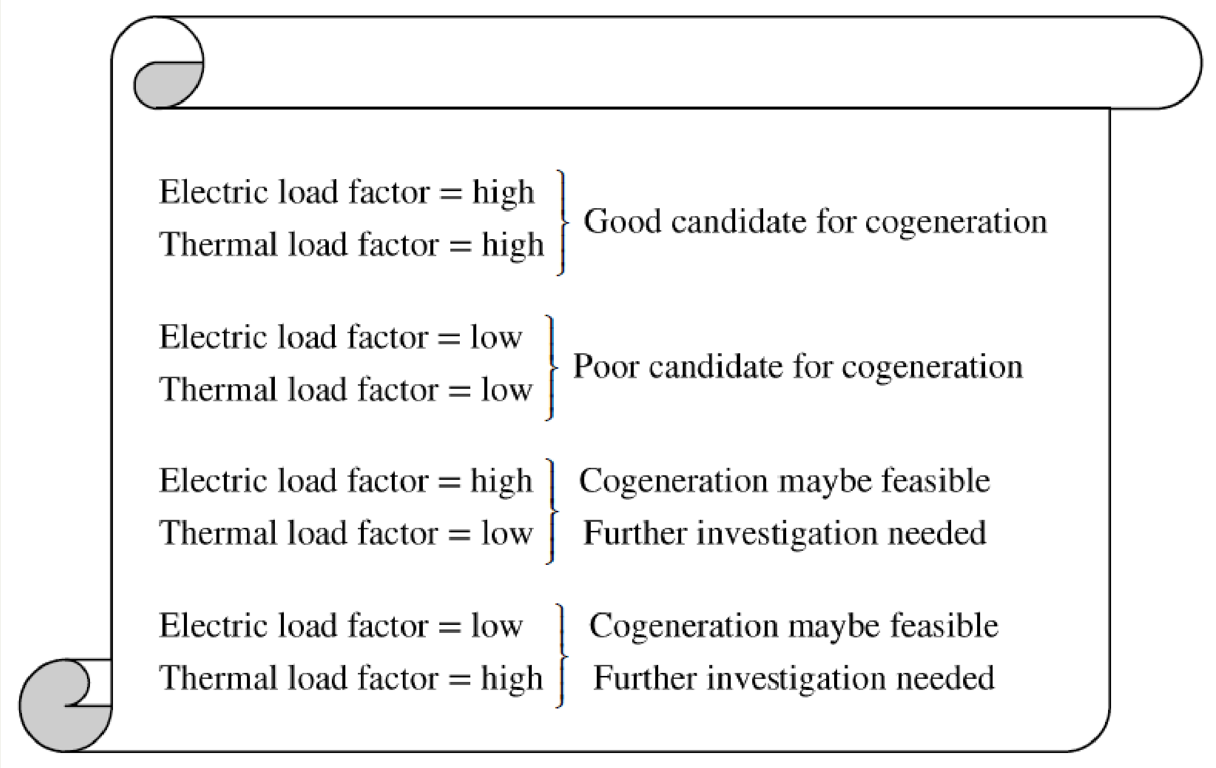
$$\left.\begin{array}{l} \text{Thermal/electric load ratio} > 10 \text{ mbh/kW} \\ \text{Thermal/electric load ratio} > 3 \end{array}\right\} \begin{array}{c} \text{Excellent candidate} \\ \text{for cogeneration} \end{array}$$

$$\left.\begin{array}{l} \text{Thermal/electric load ratio} > 5 \text{ mbh/kW} \\ \text{Thermal/electric load ratio} > 1.5 \end{array}\right\} \begin{array}{c} \text{Good candidate} \\ \text{for cogeneration} \end{array}$$

$$\left.\begin{array}{l} \text{Thermal/electric load ratio} < 2 \text{ mbh/kW} \\ \text{Thermal/electric load ratio} < 0.6 \end{array}\right\} \begin{array}{c} \text{Poor candidate} \\ \text{for cogeneration} \end{array}$$

Load Factor

- A high load factor is preferred for cogeneration applications as it represents the greater use of installed capacity.
- A low load factor (e.g. 40%) means that if the cogeneration electricity capacity is selected based on the peak demand, the system will supply on average 40% of the installed capacity most of the time and close to full capacity for only a short period of time over a year.



Load Factor

- If the electric load factor is high and the thermal load factor is low:
- A cogeneration application can still be feasible provided that additional heat demand can be supplied from a backup boiler.
- A plant may have a low thermal load factor when the boiler shuts down during a certain season (summer, no space heating)
- If the electric load factor is low and the thermal load factor is high:
- A cogeneration application can still be feasible provided that additional electric demand can be purchased from the utility at a reasonable price.
- In this case, the voltage transformation and associated equipment cost may have to be taken care of by the plant.

Refences

- Introduction to Pinch Technology, Rokni, Masoud, DTU
- https://www.youtube.com/watch?v=MQejghnZj_w&list=PL_UhBh-E8IOLmkctKJng1EmQru3RDZyV7&index=8