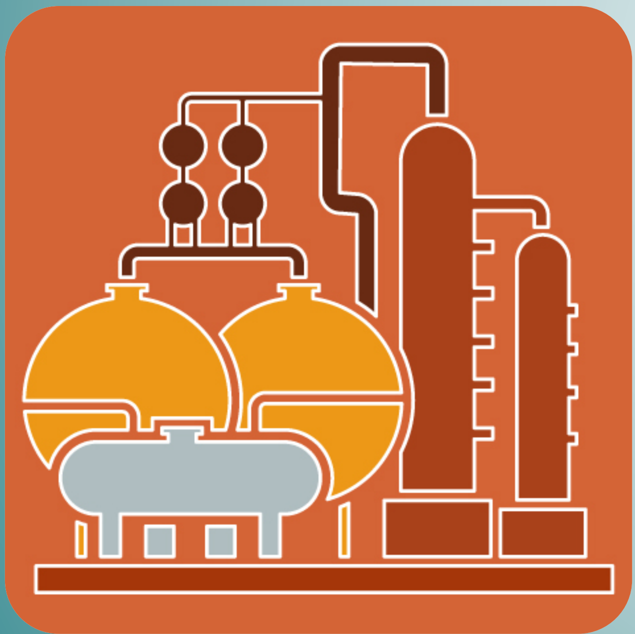
Chemical Process Design / Diseño de Procesos Químicos

Topic 5.3. Heat transfer equipment



Javier R. Viguri Fuente
Eva Cifrian Bemposta

Department of Chemistry and Process & Resource Engineering
GER Green Engineering and Resources Research Group

Heat Transfer Equipment Sizing

Heat exchanger types used in chemical processes:

- **By function:**
  - Refrigerants (air or water).
  - Reboilers, vaporizers (l → v).
  - Condensers (v, v + l → l).
  - Exchangers in general.

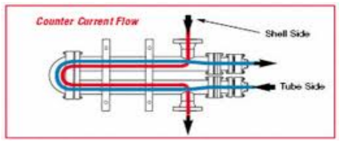
- **By constructive shape:**
  - Double pipe exchanger: the simplest one.
  - Shell and tube exchangers: used for all applications.
  - Plate and frame exchangers.
  - Air cooled: used for coolers and condensers.
  - Direct contact: used for cooling and quenching (enfriamiento brusco).
  - Jacketed vessels, agitated vessels and internal coils (serpentines).
  - Fired heaters: furnaces and boilers.

Heat Transfer Equipment Sizing

Heat exchanger types used in chemical processes:

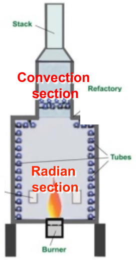
- **By constructive shape:**

Double pipe exchanger:
the simplest one



- Koch Heat Transfer Company:
http://kochheattransfer.com/

Fired heaters:
furnaces and boilers



- Thermax, Ltd. - Lenox Instrument Co.

Jacketed vessels, agitated vessels
and internal coils.

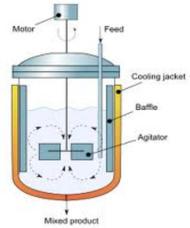
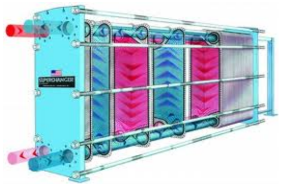


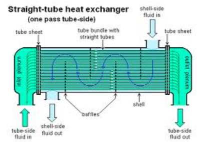
Plate and frame exchangers

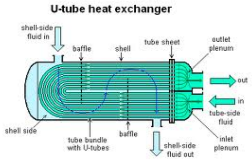


- Tranter - The Heat Transfer People:
https://www.tranter.com/about-us

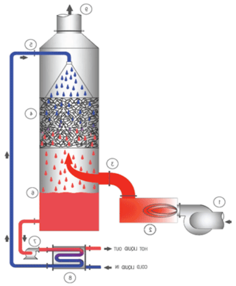
Shell and tube exchangers:
used for all applications

- APL Apparatebau GMBH.

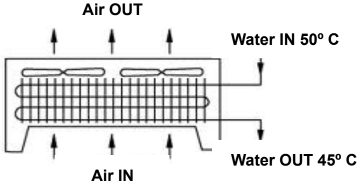




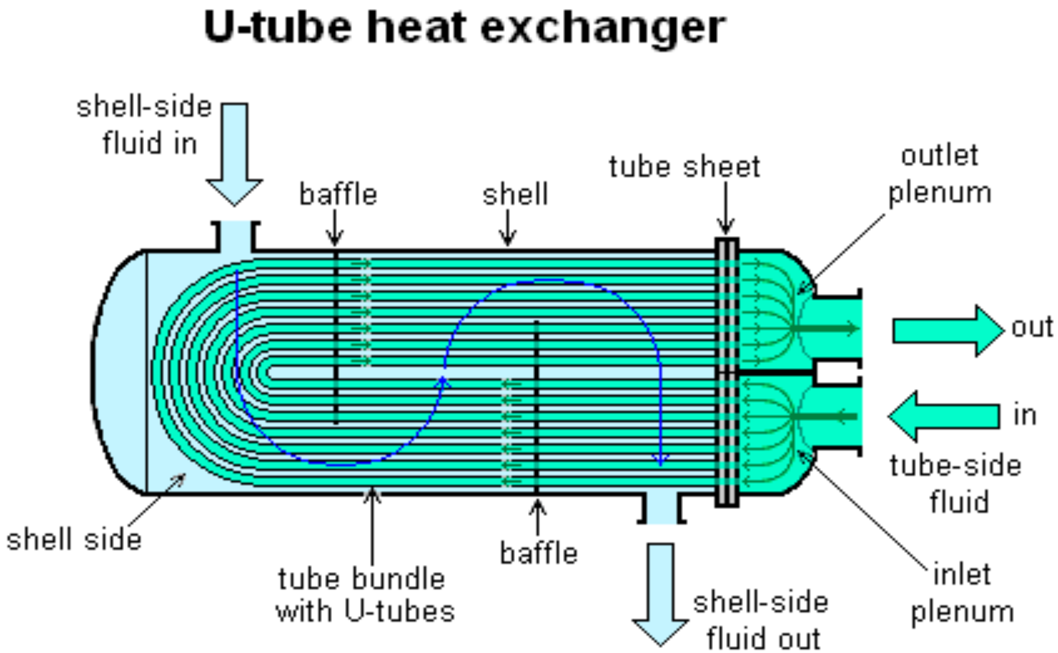
Direct contact:
used for cooling and quenching



Air cooled:
used for coolers and condensers



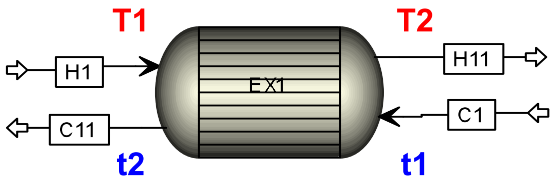
HEAT EXCHANGERS



HEAT EXCHANGERS

Heat Transfer Equipment Sizing

Shell and tube countercurrent exchanger, steady state:



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

Q: from the energy balance.

U: estimation of heat transfer coefficient. Depending on configuration and media used in the Shell and Tube side: L-L, Condensing vapor-L, Gas-L, Vaporizers). (Perry's Handbook (2008): www.tema.org.

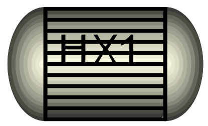
A: area.

ΔT_{lm}: logarithmic Mean DT = (T1 – t2) – (T2 – t1) / ln (T1 – t2 / T2 – t1).

- If phase changes → Approximation of 2 heat exchangers (A = A1 + A2).
- Maximum area A → 1000 m^2, else → Parallel HX.

$$MPF = Fm\ (F_p + F_d)$$

Heat exchanger: Countercurrent, steady state



Guthrie Material and pressure factors for Heat Exchangers: $MPF = F_m (F_p + F_d)$

Design Type,	F_d
Kettle Reboiler	1.35
Floating Head	1.00
U Tube	0.85
Fixed tube sheet	0.80

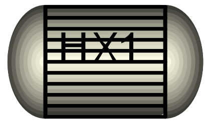
Vessel Pressure (psig)

Up to	150	300	400	800	1000
F_p	0.00	0.10	0.25	0.52	0.55

Shell/Tube Materials, F_m

Surface Area (ft^2)	CS/ CS	CS/ Brass	CS/ SS	SS/ SS	CS/ Monel	Monel Monel	CS/ Ti	Ti/ Ti
Up to 100	1.00	1.05	1.54	2.50	2.00	3.20	4.10	10.28
100 to 500	1.00	1.10	1.78	3.10	2.30	3.50	5.20	10.60
500 to 1000	1.00	1.15	2.25	3.26	2.50	3.65	6.15	10.75
1000 to 5000	1.00	1.30	2.81	3.75	3.10	4.25	8.95	13.05

Heat exchanger: Countercurrent, steady state



Equipment Type	C_0 (\$$10^3$)	S_0	Range (S)	a	MF2 / MF4 / MF6 / MF8 / MF10
Heat exchanger *Shell and tube, S = Area (ft²)*	5	400	**100 - 10^4**	0.6	3.29 / 3.18 / 3.14 / 3.12 / 3.09
Heat exchanger *Shell and tube, S = Area (ft²)*	0.3	5.5	**2 - 100**	0.024	1.83 / 1.83 / 1.83 / 1.83 / 1.83
Air Coolers *S = [calculated area (ft²) / 15.5]*	3	200	**100 - 10^4**	0.82	2.31 / 2.21 / 2.18 / 2.16 / 2.15

S ≡ Area from sizing calculations

$$C = BC = C_0 (S / S_0)^a$$

MF (Module Factor)

- **MF 2: If C < 200.000 \$**
- **MF 4: If C = 200.000 - 400.000 \$**
- **MF 6: If C = 400.000 - 600.000 \$**
- **MF 8: If C = 600.000 - 800.000 \$**
- **MF 10: If C = 800.000 - 1.000.000 \$**

Materials and Pressure correction Factor: $MPF = F_m (F_p + F_d)$

Update Factor UF = Present Cost Index (CI_{actual}) / Base Cost Index (CI_{base})

Updated bare (simple) module cost: BMC = UF(BC) (MPF + MF – 1)

Furnaces and Direct Fired Heaters

Boilers, reboilers, pyrolysis, reformers:

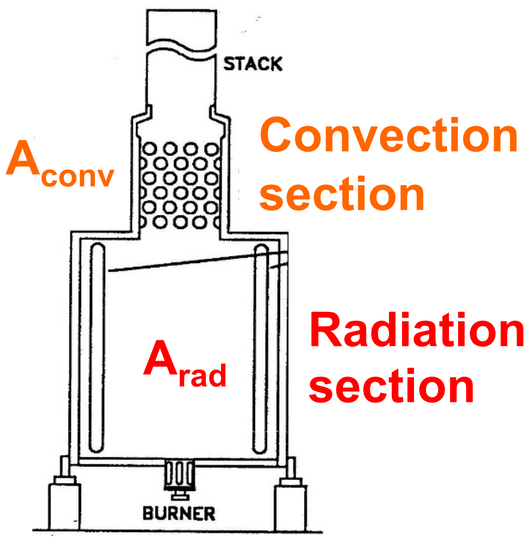
Q = Absorbed duty from heat balance

Radiant section (q_{rad} = 37.6 kW/m^2 heat flux) **+**

+ Convection section (q_{conv} = 12.5 kW/m^2 heat flux).

Equal heat transmission (kW) →

A_{rad} = 0.5 · **Q** kW/q_{rad} ; A_{conv} = 0.5 · **Q** kW/q_{conv}



Sectional view of a heater.

- Basic configuration for furnaces is given by a process heater with a box or A-frame construction, carbon steel tubes, and a 500 psig design Pressure. This includes complete field erection.

- Direct fired heaters is given by a process heater with cylindrical construction, carbon steel tubes, and a 500 psig design pressure.

Furnaces and Direct Fired Heaters

Boilers, reboilers, pyrolysis, reformers:

Guthrie MPF for Furnaces

$$MPF = F_m + F_p + F_d$$

Design Type,	F_d
Process Heater	1.00
Pyrolysis	1.10
Reformer	1.35

Vessel Pressure (psig)

Up to	500	1000	1500	2000	2500	3000
Fp	0.00	0.10	0.15	0.25	0.40	0.60

Radiant Tube Material,	F_m
Carbon Steel	0.00
Chrome/Moly	0.35
Stainless Steel	0.75

Guthrie MPF for Direct Fired Heaters

$$MPF = F_m + F_p + F_d$$

Design Type,	F_d
Cylindrical	1.00
Dowtherm	1.33

Vessel Pressure (psig)

Up to	500	1000	1500
Fp	0.00	0.15	0.20

Radiant Tube Material,	F_m
Carbon Steel	0.00
Chrome/Moly	0.45
Stainless Steel	0.50

Furnaces and Direct Fired Heaters

Boilers, reboilers, pyrolysis, reformers:

Equipment Type	C_0 (\$$10^3$)	S_0	Range (S)	a	MF2 / MF4 / MF6 / MF8 / MF10
Process furnaces *S = Absorbed duty (10^6 Btu/h)*	100	30	**100 - 300**	0.83	2.27 / 2.19 / 2.16 / 2.15 / 2.13
Direct fired heaters *S = Absorbed duty (10^6 Btu/h)*	20	5	**1 - 40**	0.77	2.23 / 2.15 / 2.13 / 2.12 / 2.10

S ≡ Absorbed duty, Q

$C = BC = C_0 (S / S_0)^a$

MF (Module Factor)

- MF 2: If C < 200.000 \$
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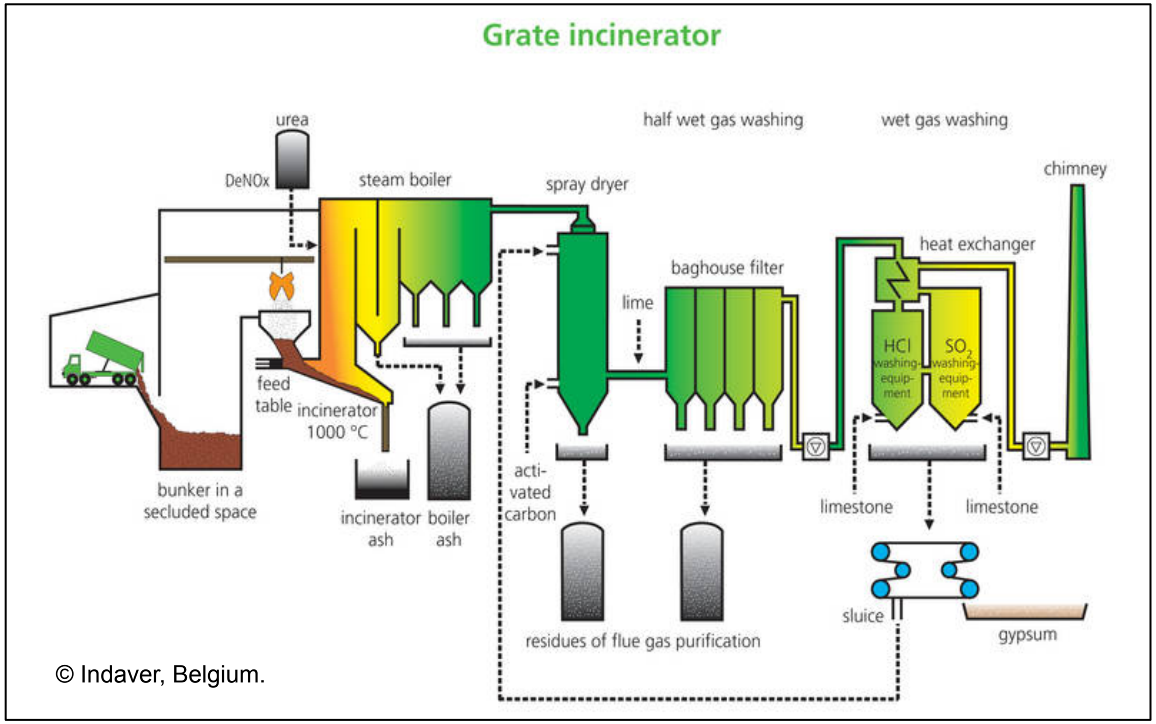
Materials and Pressure correction Factor: $MPF = F_m (F_p + F_d)$

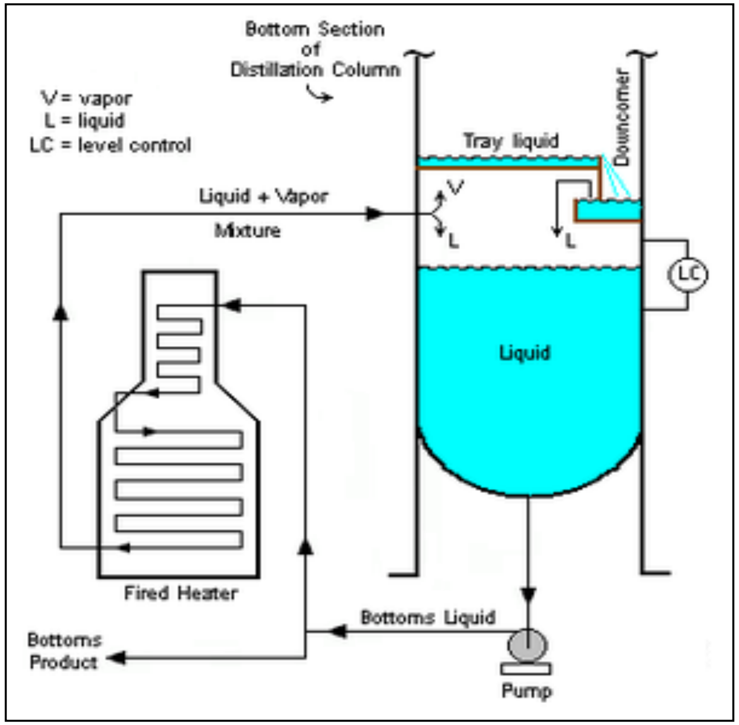
Update Factor UF = Present Cost Index (CI_{actual}) / Base Cost Index (CI_{base})

Updated bare (simple) module cost: BMC = UF(BC) (MPF + MF – 1)

Furnaces and Direct Fired Heaters

Boilers, reboilers, pyrolysis, reformers:





Fired Reboiler (CC BY-SA 3.0).