Investment Estimation in energy systems

Prof François Marechal

IPESE
Industrial Process
and Energy Systems
Engineering

Sizing units

- Sizing function may be complex and heuristics
  - Describe the transfer phenomena
  - Residence time => sizes

$$Size_u(x, \pi_u^*)$$

$$where \qquad x \in \{x_u^+, x_u^-, \pi_u\} \qquad : \text{problem state variable}$$

x_u^+ Streams entering the unit u

x_u^- Streams leaving the unit u

π_u Parameters of the unit u

π_u^* sizing model parameters the unit u

Ulrich, K.T., and S.D. Eppinger, others. *Product design and development*. Vol. 384. McGraw-Hill New York, 1995.

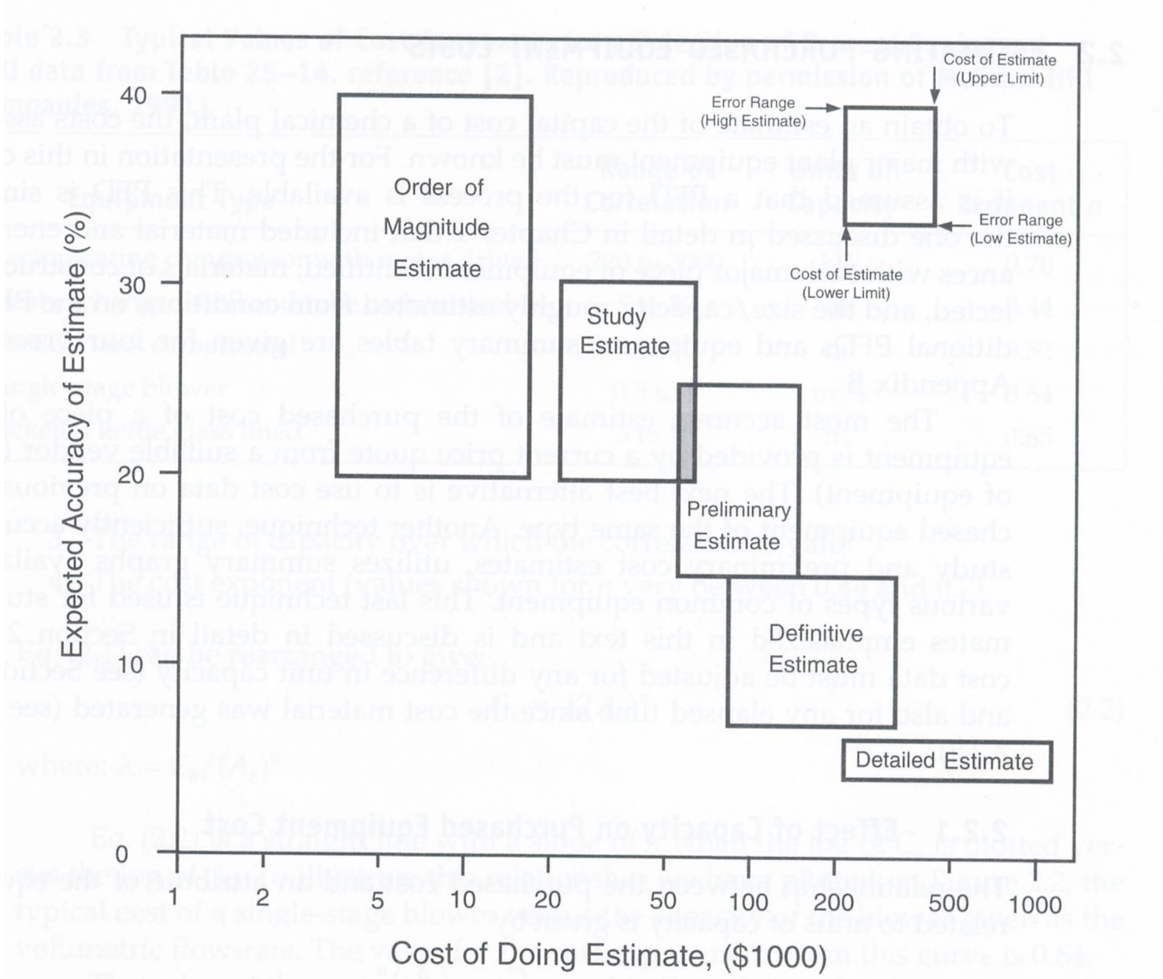
see also : http://www.mech.utah.edu/senior_design/07/uploads/Main/Lect12-ConceptSelection.pdf.

Estimating the investment from the size

- Cost of doing a investment estimation

Offer call

Detailed design



From Turton, 2008

Estimating purchased cost based on reference data

- Purchased cost of unit u

$$C_{p,u} = C_{p_{ref},u} \cdot \left(\frac{S_u}{S_{u,ref}}\right)^{\gamma_u} \cdot \frac{Id_{year_{project}}}{Id_{year_{ref}}}$$

  - $C_{p_{ref},u}$: purchased cost of a unit u for a reference size
  - S_u Equipment sizing attribute of unit u
  - $S_{u_{ref}}$ Equipment sizing attribute of the reference unit u
  - γ_u capacity exponent for unit u typical values are between 0.6 and 0.8
  - $Id_{year_{ref}}$ cost index for the reference year where $C_{p_{ref},u}$ is given
  - $Id_{year_{project}}$ cost index for the project year

=> Size

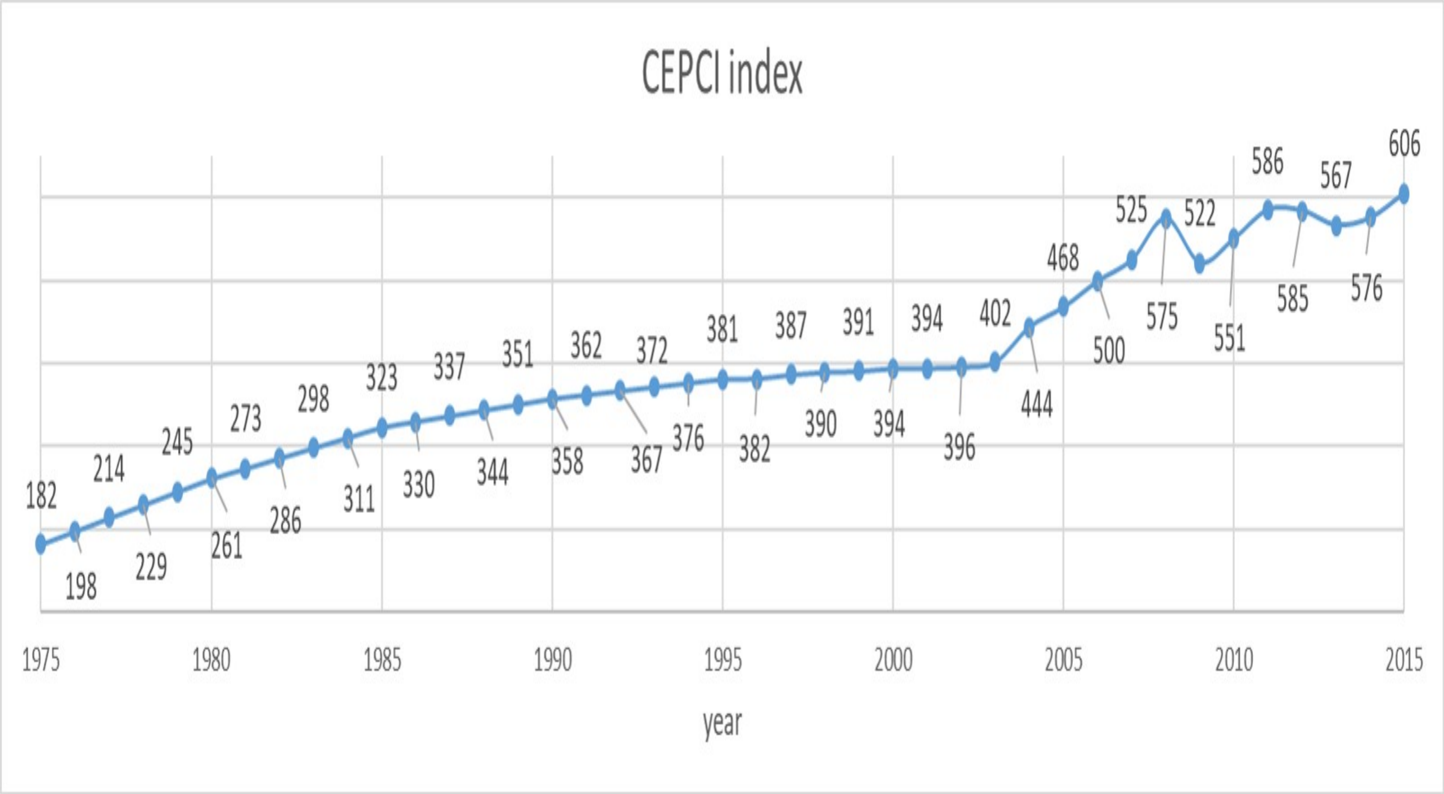
=> is a function of equipment type

=> year adaptation

- Ranges => Min and Max bounds (comparable equipment)
- Cost index :
  - Marshall & Swift Equipment Cost Index
  - CEPCI : Chemical Engineering Plant Cost Index
    - Chemical Engineering Journal

Equipment index

- Adapting the cost estimate from one year to another



$$C_{p,u} = C_{p_{ref},u} \cdot \left(\frac{S_u}{S_{u,ref}}\right)^{\gamma_u} \cdot \frac{I_{year_{project}}}{I_{year_{ref}}}$$

year of the evaluation

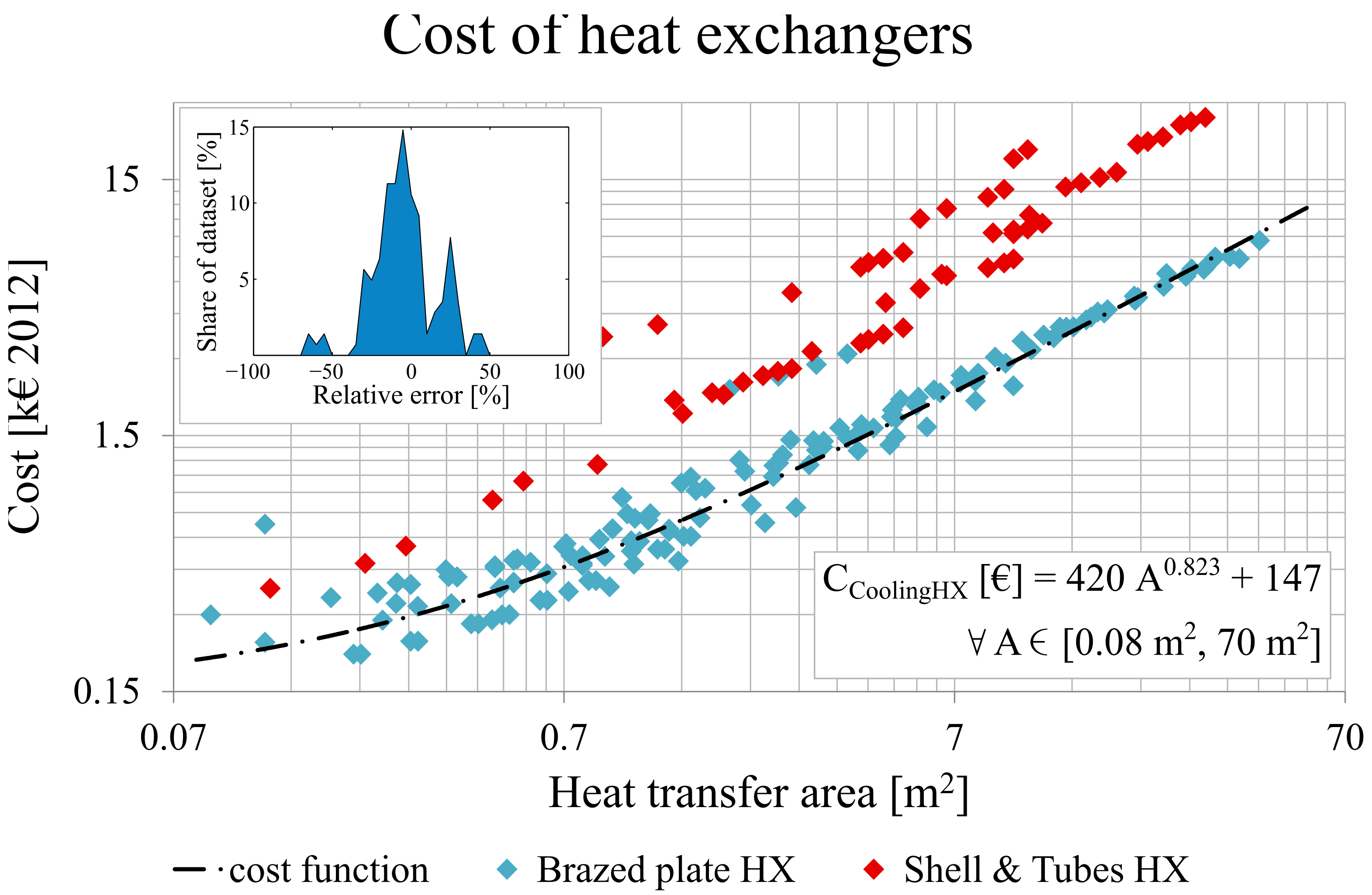
year of the reference
where the cost is known for a reference size

Example of data [US$, 1998]

Equipment description	Capacity exponent γ	Relative base cost $C_{p,ref}$ (values from 1998)
Blowers and fans	0.68	9.5
Boilers, packaged unit	0.7	60
Boiler (industrial), 15psig	0.5	92
Boiler (industrial), 150psig	0.5	101.2
Boiler (industrial), 300psig	0.5	115
Boiler (industrial), 600psig	0.5	138
Column with trays	0.73	33.5
Column with packing	0.65	35.2
Compressor, air, 125psig	0.28	36.5
Compressor, process gas, 1000psig	0.82	85
Cooling tower facilities	0.6	9.9
Crushers, cone	0.85	12
Crushers, gyratory	1.2	3
Crushers, jaw	1.2	4.7
Crushers, pulverisers	0.35	23.4
Crystallisers, growth	0.65	385
Crystallisers, forced circulation	0.55	276.5
Crystallisers, batch	0.7	32.5
Dryers, drum	0.45	30
Dryers, pan	0.38	12.5
Dryers, rotary vacuum	0.45	43.4
Evaporators, forced circulation	0.7	270
Evaporators, vertical tube	0.53	37.2
Evaporators, horizontal tube	0.53	30.4
Evaporators, jacketted vessel	0.6	32
Filters, plate and frame	0.58	4.3
Filters, pressure leaf (wet)	0.58	5.3
Filters, pressure leaf (dry)	0.53	15.1
Filters, rotary drum	0.63	17.5
Filters, rotary disc	0.78	31
Furnace, process	0.85	135
Heat exchangers, cooler	0.66	6.8
Heat exchangers, kettle reboiler	0.65	8.8
Heat exchangers, shell and tube	0.65	6.5
Heat exchangers, U-tube	0.65	5.5
Heater, direct fired	0.85	103,5

Importance of
- Size range
- Type of materials
- Application area
  - Domestic
  - Industry
  - Production
  - Custom made

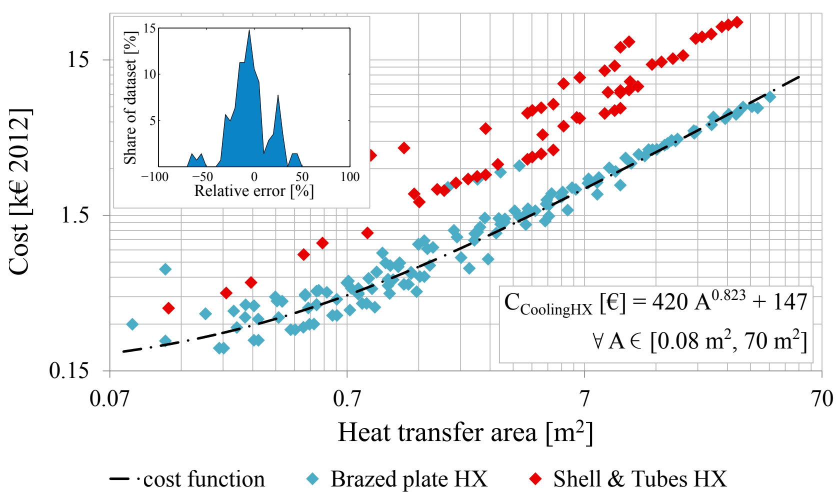
Observing the market : note the log scale !!!



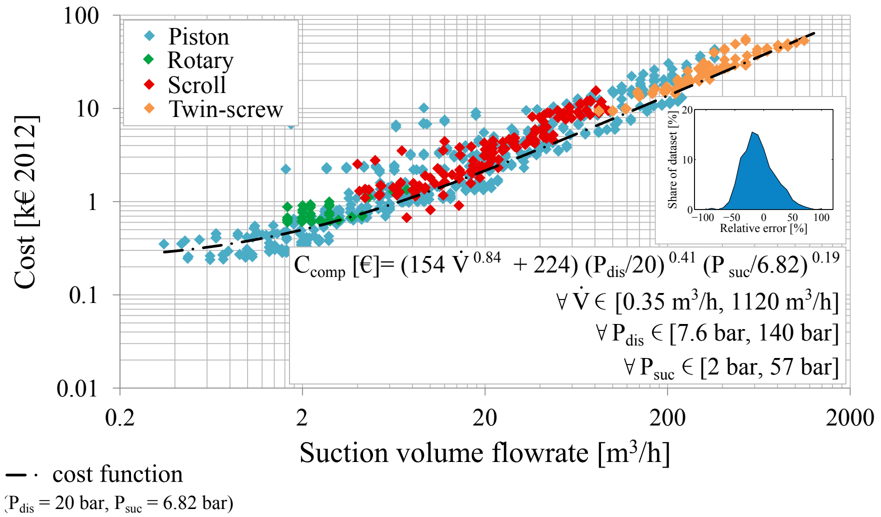
Thesis Henchoz, 2015, Heat exchanger cost for CO2 network

Validity for the different types of technologies

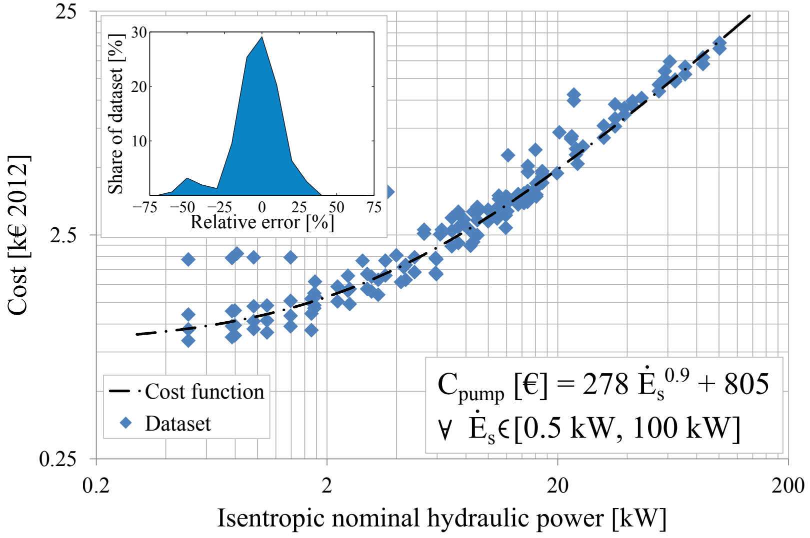
Cost of heat exchangers



Cost of compressors



Cost of centrifugal water pumps



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Thesis Henchoz, 2015, Heat exchanger cost for CO2 network

Estimating purchased cost based on correlations

- Purchased costs of an equipment : statistical analysis (log/log) of the equipment market

$$C_{p,u} = \frac{Id_{year_{project}}}{Id_{year_{ref}}} \cdot 10^{(k_{1,u}+k_{2,u}log(S_u)+k_{3,u}(log(S_u))^2)}$$

  - k_i empirical constants derived from the cost database
    - Note that : if $k_{3,u} = 0$ $\quad C_{p,u} = \frac{I_{year_{project}}}{I_{year_{ref}}} \cdot 10^{k_{1,u}} \cdot (S_u)^{k_{2,u}}$

Reference year = year of the data publication :
e.g. Turton, R., Whiting, W., and Shaeiwitz, J. (1998).
Analysis, Synthesis and Design of chemical processes, ,
(ISBN:130647926),

Installed cost

Installed cost proportional to purchased cost

Accounts for

- Pipings, contingencies, control, etc…
- Materials
- Pressure

$$C_{BM,u} \quad [CHF_{installed}] = F_{BM,u} \cdot C_{p,u}$$

$F_{BM,u}$: Order of magnitude

Fluids : 4.74

Solids : 3.1

Solids- fluids : 3.63

$$i_{u_{\dot{Q}_{u,max}}} \quad [CHF/kW] = \frac{C_{BM,u}}{\dot{Q}_{u,max}}$$

Effect of pressure and materials

Update the statistics by further statistics

$$F_{BM} = B_1 + B_2 \cdot F_m \cdot F_p$$

B_i constants computed on the base of existing equipment cost databases

F_m material factor, describes the effect of material change on the bare-module cost. If there is no material change $F_m = 1$

F_p pressure factor, describes the effect of operating pressure change on the bare-module cost.

$$F_p = 10^{c_1 + c_2 \cdot log\tilde{P} + c_3 \cdot (log\tilde{P})^2}$$

c_i empirical constant derived from the existing plant cost database

$\tilde{P}$ pressure difference from atmospheric pressure e.g. pressure expressed in bar gauge (barg)

Data in : Turton, R., Whiting, W., and Shaeiwitz, J. (1998).
Analysis, Synthesis and Design of chemical processes, , (ISBN:130647926),

Heat exchangers correlations

Ranges

Types of equipment

Table A.1 Correlation Coefficients for Heat Exchangers

Exchanger Type	K_1	K_2	K_3	C_1	C_2	C_3	B_1	B_2	A_{min} (m^2)	A_{max} (m^2)	P_{max} (barg)
Double Pipe	3.0238	0.0603	0	6.4945[1]	–6.6786	1.7442	0.74	1.21	0.2	10	300
Multiple Pipe	2.1138	0.9658	0	6.4945[1]	–6.6786	1.7442	0.74	1.21	10	75	300
Fixed Tube Sheet or U-Tube	3.2138	0.2688	0.07961	–0.06499[2]	0.05025	0.01474	1.80	1.50	4	900	140
Floating Head	3.4338	0.1445	0.10790	–0.06499[2]	0.05025	0.01474	1.80	1.50	10	900	140
Bayonet	3.5238	0.1916	0.09474	–0.06499[2]	0.05025	0.01474	1.80	1.50	10	900	140
Kettle Reboiler	3.5638	0.1906	0.11070	–0.06499[2]	0.05025	0.01474	1.80	1.50	10	100	140
Scraped Wall	3.7438	0.9270	0	6.4945[1]	–6.6786	1.7442	0.74	1.21	2	20	300
Teflon Tube	3.5738	0.4548	0	0	0	0	1.80	1.50	7	75	15
Air Cooler	3.6418	0.4053	0	–0.06154	0.0473	0	1.53	1.27	3.5	20,000	250
Spiral Tube	3.4088	0.6000	0.09944	–0.4045[3]	0.1859	0	0.74	1.21	.1	45	400
Spiral Plate	3.6788	0.4412	0	0	0	0	1.53	1.27	2	200	19
Flat Plate	3.8528	0.4242	0	0	0	0	1.53	1.27	15	1,500	19

[1] Pressure factors given are for $100 < P < 300$ barg, for $40 < P < 100$ use $C_1 = 0.6209$, $C_2 = -0.9274$, $C_3 = 0.3369$, for $P < 40$ $C_1 = C_2 = C_3 = 0$

[2] Pressure factors given are for when shell or both shell and tube are > 10 barg, when tubes only >10 barg use $C_1 = -0.04139$, $C_2 = 0.04139$, $C_3 = 0$

[3] Pressure factors given are for when shell or both shell and tube are > 10 barg, when tubes only >10 barg use $C_1 = -0.21150$, $C_2 = 0.09717$, $C_3 = 0$

CEPCI : 382, Turton, R., Whiting, W., and Shaeiwitz, J. (1998). Analysis, Synthesis and Design of chemical processes, , (ISBN:130647926),

Material Factors

Table A.2 Material Factors for Heat Exchangers

Exchanger Type	Material Factor, F_M: Shell—CS Tube—CS	CS Cu	Cu Cu	CS SS	SS SS	CS Ni	Ni Ni	CS Ti	Ti Ti
Double Pipe	1.00	1.25	1.60	1.70	3.00	2.80	3.80	7.20	12.00
Multiple Pipe	1.00	1.25	1.60	1.70	3.00	2.80	3.80	7.20	12.00
Fixed Tube Sheet or U-Tube	1.00	1.25	1.60	1.70	3.00	2.80	3.80	7.20	12.00
Floating Head	1.00	1.25	1.60	1.70	3.00	2.80	3.80	7.20	12.00
Bayonet	1.00	1.25	1.60	1.70	3.00	2.80	3.80	7.20	12.00
Kettle Reboiler	1.00	1.25	1.60	1.70	3.00	2.80	3.80	7.20	12.00
Scraped Wall	1.00	1.25	1.60	1.70	3.00	2.80	3.80	7.20	12.00
Spiral Tube	1.00	1.25	1.60	2.30	3.00	2.80	3.80	7.20	12.00

Teflon Tube Exchanger: Shell Material	F_M	Flat and Spiral Plate: Material in Contact with Process Fluid	F_M	Air Cooler: Tube Material	F_M
CS	1.00	CS	1.00	CS	1.00
Cu	1.20	Cu	1.20	Al	1.50
SS	1.30	SS	2.30	SS	3.00
Ni	1.40	Ni	2.80	—	—
Ti	3.30	Ti	7.20	—	—

CEPCI : 382, Turton, R., Whiting, W., and Shaeiwitz, J. (1998).
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Summary calculating $i_{u_{\dot{Q}_{u,max}}} \quad [CHF/kW]$

- Estimation of an investment when equipment **type** and **size [kW or m2]** is known

$$i_{u_{\dot{Q}_{u,ref}}} \quad [CHF/kW] = \frac{\sum_{e_u=1}^{n_{e,u}} C_{BM,e_u}}{\dot{Q}_{u,ref}}$$

  - e_u : equipment e of the $N_{e,u}$ equipment needed to construct the unit u
  - 20% precision
  - Similar equipment or correlations
    - Check validity range
    - Note the year of the data and use index update $\frac{Id_{year_{project}}}{Id_{year_{ref}}}$
    - Scaling factor (default =0.8)
  - Installed cost = (3 to 4) * Purchased cost
  - Factors for Materials + Pressure

Summary

- Cost estimation
  - Comparing sizes => scaling factor
  - Statistical values from data base (log/log) => precision ???
  - Index for the year of the reference data update
  - Heuristics
  - Installation Factor
  - Materials/Pressure Factor