Cost Estimation using NoDoC Models

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- Distillation columns
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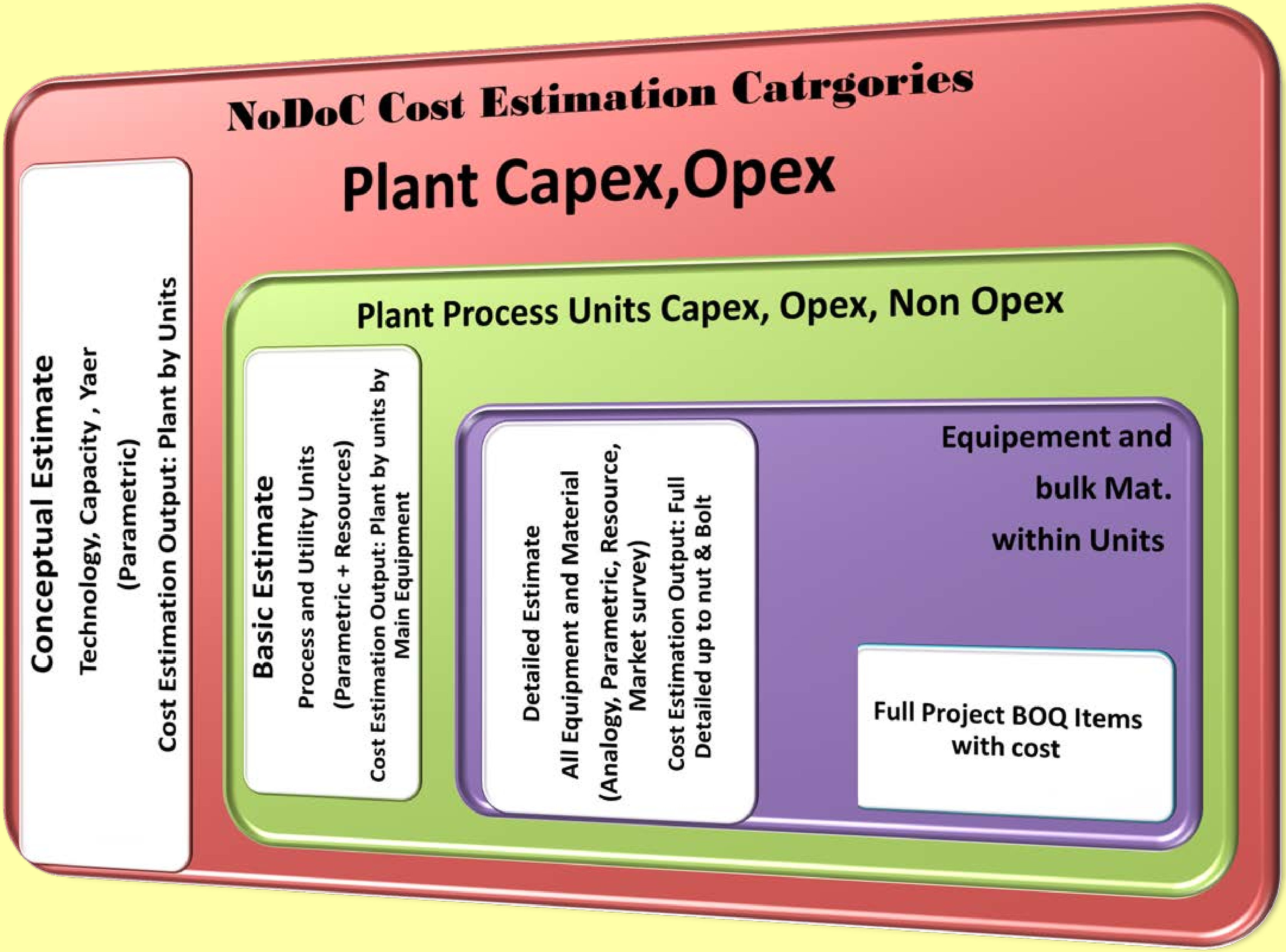
- Compressors (or turbines)
- Pumps
- Refrigeration

3.- Cost estimation of equipment

- Base costs for equipment units
- ´ modular method

The categories of NoDoC Cost Models For Oil & Gas Projects Within CostOs



1.- INTRODUCTION

Process Alternatives Synthesis (candidate flowsheet)
Analysis (Preliminary mass and energy balances)
SIZING (Sizes and capacities)
COST ESTIMATION (Capital and operation)
Economic Analysis (economic criteria)

SIZING

Calculation of all physical attributes that allow a unique costing of this unit

- Capacity, Height
- Cross sectional area
- Pressure rating
– Materials of construction

Short-cut, approximate calculations (correlations) → Quick obtaining of sizing parameters → Order of magnitude estimated parameters

COST

Total Capital Investment or Capital Cost: **Function of the process equipment → The sized equipment will be costed**

*** Approximate methods to estimate costs**

Manufacturing Cost: **Function of process equipment and utility charges**

Categories of total capital cost estimates

based on accuracy of the estimate

NoDoC Model

Level of Estimation	Based on	Error %	Cost Etimation Duration	Use To	Model Output	Example
Conceptual	- Technology - Capacity - Plant's Unites Factored	30-40	Couple of Hours	- Review Project Execution Alternatives - Create scenarios - Technical assessment - Selection of the execution method - Financial and economic Analysis	Opex and Capex by the Factory Production and Process Units and by Project Phase (E,P,C)	what is the capex for a 100,000 bbpd oil refinery?
Basic	- Basic Design Documents - main Equipment Factored	15-30	Couple of Days	- Find Source of Finance - Investment Analysis - As a basis for Evaluation of EPC Contractor's Commercial Proposal - Prepare tender Documents - prepare vendor list	Opex, Non Opex and Capex by the Factory Production and Process Units and Main Equipment within the Units and by Long Lead Items* and by Project Phase (E,P,C)	what is the capex for process and utility units of a Refinary with 100,000 bbpd capacity? What is the main equipment cost within the Units?
Detailed	- Detailed Design Documents - Full MTO Factored	5-15	Couple of Weeks	- Construction Control - Cost Control - Sub-Contractors Selection and Control	Opex, Non Opex and Capex by the Factory Production and Process Units and Main Equipment within the Units and by Long Lead Items* and by Project Phase (E,P,C) and by bulk materials, by discipline, …	More Detailed Estimate of an oil refinary such as the equipment and material cost and what are & how much reaources the project needs, and what is the cost for E,P,C,I,H,Co,Com

*** A "Long Lead item" is any piece that is required to be engaged in the project with a procurement cost and time that is likely to affect the project completion Cost and date.**

Cost Estimation Method

• **Equipment purchase cost: equations / Manufacturing Cost**

Based on a power law expression: Williams Law $C = BC = Co\ (S/So)^{\alpha}$ →

→ **Economy of Scale (incremental cost C, decrease with larger capacities S)**

Based on a polynomial expression $BC = \exp\{A_0 + A_1 [\ln(S)] + A_2 [\ln(S)]^2 + \ldots\}$

• **Installation: Module Factor, MF, affected by BC, taking into account labor, piping ,instruments, accessories, etc.**

Typical Value of MF=2.95 → equipment cost is almost 3 times the BC.
Installation = (BC)(MF)-BC = BC(MF-1)

• **For special materials, high pressures and special designs abroad base capacities and costs (Co, So), the Materials and Pressure correction Factors, MPF, are defined.**

Uninstalled Cost = (BC)(MPF) **Total Installed Cost = BC (MPF+MF-1)**

• **To update cost from mid-1968, an Update Factor, UF to account for inflation is apply.**

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

Materials and Pressure correction Factors: MPF

Empirical factors that modified BC and evaluate particular instances of equipment beyond a basic configuration: Uninstalled Cost = (BC x MPF)

MPF = Φ (Fd, Fm, Fp, Fo, Ft)

Fd: Design variation
Fm: Construction material variation
Fp: Pressure variation
Fo: Operating Limits (Φ of T, P)
Ft: Mechanical refrigeration factor Φ (T evaporator)

EQUIPMENT	MPF
Pressure Vessels	Fm . Fp
Heat Exchangers	Fm (Fp + Fd)
Furnaces, direct fired heaters, Tray stacks	Fm + Fp + Fd
Centrifugal pumps	Fm . Fo
Compressors	Fd

Equipment Sizing Procedures

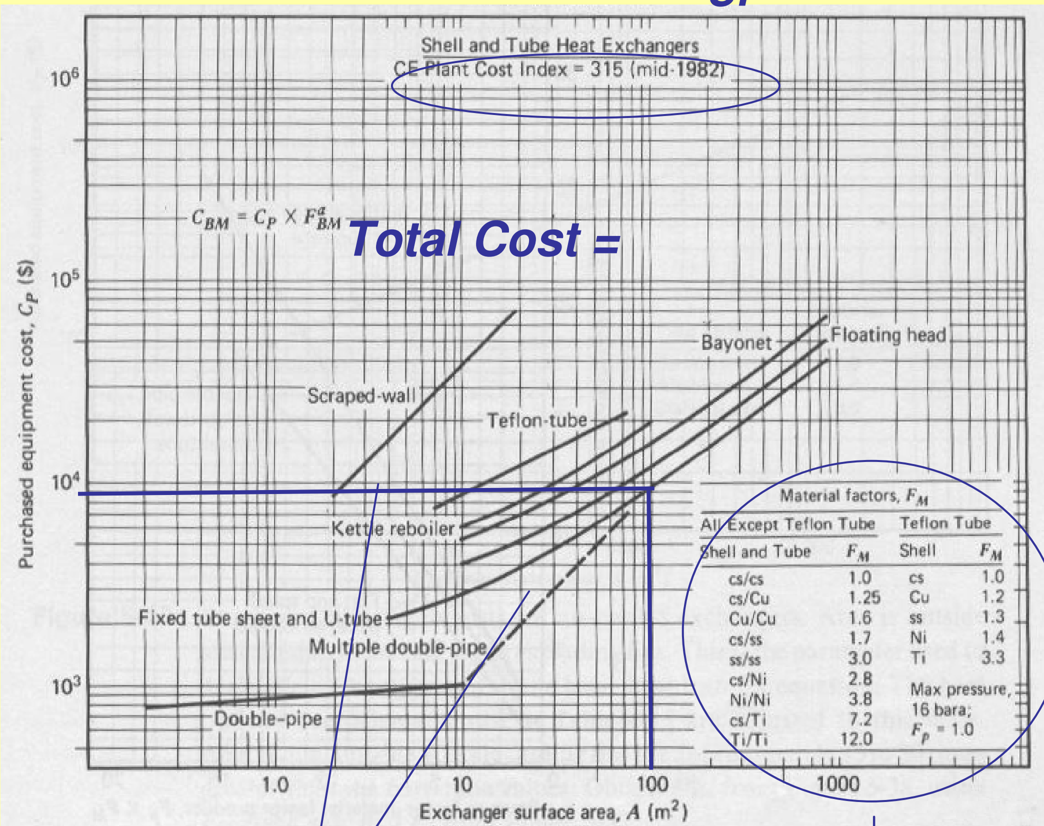
Need C and MPF → required the flowsheet mass and energy balance (Flow, T, P, Q)

An example of Cost Estimation

Equipment purchase price

Cp

UF



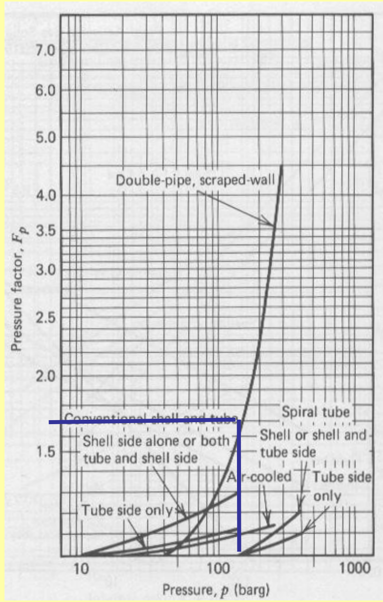
Total Cost =

Design Factor

Fd

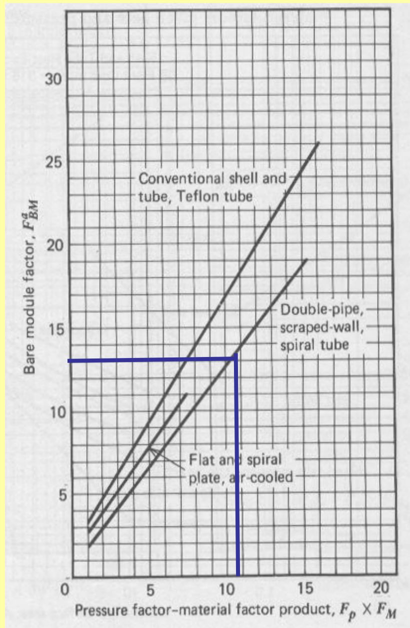
Material Factor

Fm



Pressure Factor

Fp

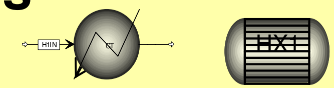
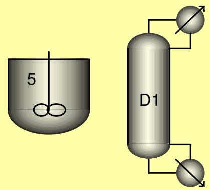
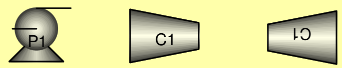


Factor Base Modular

Fbm

2.- EQUIPMENT SIZING PROCEDURES

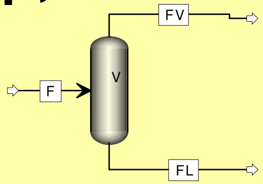
Short-cut calculations for the main equipment sizing

Q, P maintenance	**Vessels**	
Δ Heat contents	**Heat transfer equipment: Heat exchangers** **Furnaces and Direct Fired Heaters** **Refrigeration**	
Δ Composition	**Reactors** **Columns, distillation and Absorption**	
Q, P streams setting	**Pumps, Compressors and Turbines**	

SHORTCUTS for VESSEL SIZING (Flash drums, storage tanks, decanters and some reactors)

1) Select the V for liquid holdup; τ= 5 min + equal vapor volume

$$V=(F_L/\rho_L * \tau)*2$$



2) Select L=4D

$V=\pi D^2/4*L \rightarrow$ $D=(V/\pi)^{1/3}$; If D $\leq$1.2 m Vertical, else Horizontal

•Materials of Construction appropriate to use with the Guthrie´s factors and pressure (P_{rated} =1.5 P_{actual})

• Basic Configuration for pressure vessels

- Carbon steel vessel with 50 psig design P and average nozzles and manways
- Vertical construction includes shell and two heads, the skirt, base rings and lugs, and possible tray supports.
- Horizontal construction includes shell, two heads and two saddles

MPF = Fm . Fp; Fm depending shell material configuration (clad or solid)

Materials of Construction for Pressure Vessels

High Temperature Service

Tmax (°F)	Steel
950	Carbon steel (CS)
1150	502 stainless steels (SS)
1300	410 SS; 330 SS
1500	304,321,347,316 SS. Hastelloy C, X Inconel
2000	446 SS, Cast stainless, HC

Low Temperature Service

Tmin (°F)	Steel
-50	Carbon steel (CS)
-75	Nickel steel (A203)
-320	Nickel steel (A353)
-425	302,304,310,347 (SS)

NoDoC Material and pressure factors for pressure vessels: MPF = Fm Fp

Shell Material	Clad, Fm	Solid, Fm
Carbon Steel (CS)	1.00	1.00
Stainless 316 (SS)	2.35	3.87
Monel (Ni:Cr/2:1 alloy)	3.99	6.48
Titanium	4.43	8.04

Vessel Pressure (psig)

Up to	50	100	200	300	400	500	900	1000
Fp	1.00	1.08	1.25	1.29	1.39	1.49	2.49	2.70

SHORT CUT for REACTORS SIZING

First step of the preliminary design → Not kinetic model available.

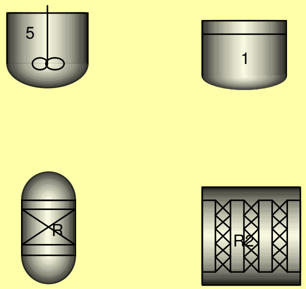
Mass Balance based on Product distribution → High influence in final cost

Assumptions: Reactor equivalent to laboratory reactor, adiabatic reactors are isotherm at average T.

Assume space velocity (S in h^{-1})

$$S = (1/\tau) = \mu / \rho V_{cat} \ ; \quad V = V_{cat} / 1 - \varepsilon$$

μ = Flow rate; ρ= molar density; V_{cat}= Volume of catalyst; ε= Void fraction of catalyst (e.g. ε=0.5)



HEAT TRANSFER EQUIPMENT SIZING

Heat exchanger types used in chemical process

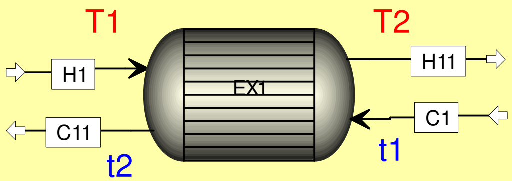
By function

- Refrigerants (air or water)   - Condensers (v, v+l → l)   - Reboilers, vaporizers (l→v)   - Exchangers in general

By constructive shape

- Double pipe exchanger: the simplest one
- Plate and frame exchangers
- Direct contact: used for cooling and quenching
- Fired heaters: Furnaces and boilers
- Shell and tube exchangers: used for all applications
- Air cooled: used for coolers and condensers
- Jacketed vessels, agitated vessels and internal coils

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 ΔT = (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 (Fp + Fd)

Heat exchanger: Countercurrent, steady state 

Material and pressure factors for Heat Exchangers: MPF: Fm (Fp + Fd)

Design Type	Fd
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
Fp	0.00	0.10	0.25	0.52	0.55

Shell/Tube Materials, Fm

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

FURNACES and DIRECT FIRED HEATERS (boilers,reboilers, pyrolysis, reformers)

Q = Absorbed duty from heat balance

• Radiant section (q_r=37.6 kW/m^2 heat flux) + Convection section (q_c=12.5 kW/m^2 heat flux). Equal heat transmission (kW) → A_{rad}=0.5 x kW/q_r; A_{conv}=0.5 x kW/q_c

• 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 P. 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.

Guthrie MPF for Furnaces: MPF= Fm+Fp+Fd

Design Type	Fd
Process Heater	1.00
Pyrolisis	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, Fm	
Carbon Steel	0.00
Chrome/Moly	0.35
Stainless Steel	0.75

Guthrie MPF for Direct Fired Heaters

MPF: Fm + Fp + Fd

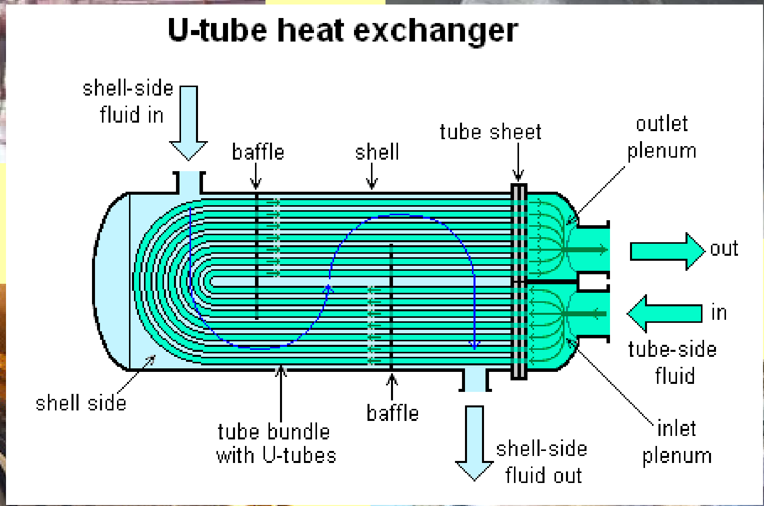
Design Type	Fd
Cylindrical	1.00
Dowtherm	1.33

Vessel Pressure (psig)

Up to	500	1000	1500
Fp	0.00	0.15	0.20

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

HEAT EXCHANGERS



SHORT CUT for DISTILLATION COLUMS SIZING

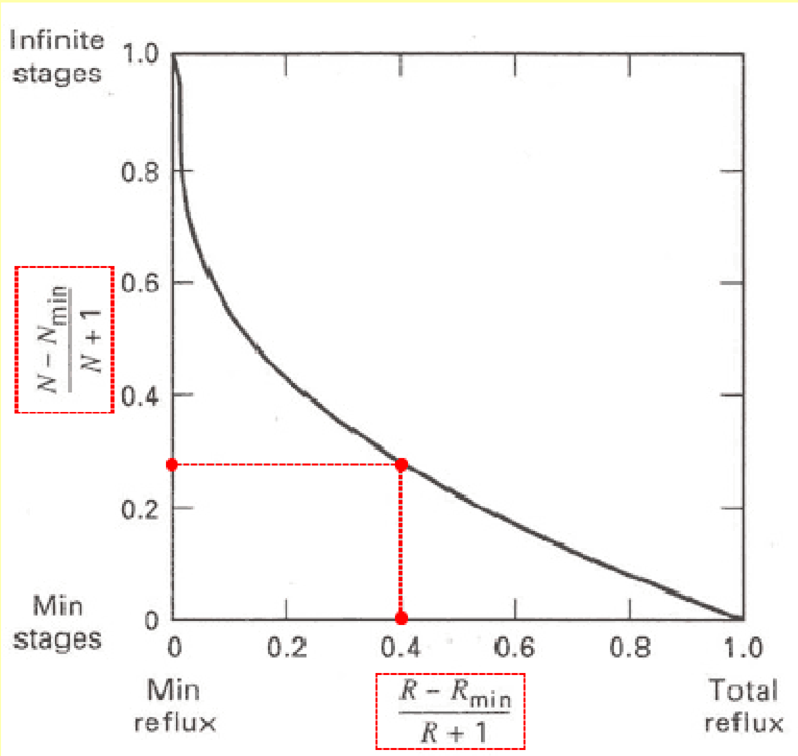
Fenske's equation applies to any two components lk and hk at infinite reflux and is defined by N_{min}, where αij is the geometric mean of the α's at the T of the feed, distillate and the bottoms.

$$N_{\min} = \frac{\log\left(\dfrac{x_{Dlk}/x_{Blk}}{x_{Dhk}/x_{Bhk}}\right)}{\log\left(\overline{\alpha}_{lk/hk}\right)} \qquad \overline{\alpha}_{lk/hk} = \left(\alpha_{D\,lk/hk}\,\alpha_{F\,lk/hk}\,\alpha_{B\,lk/hk}\right)^{1/3}$$

R_{min} is given by **Underwood** with two equations that must be solved, where q is the liquid fraction in the feed..

$$1 - q = \sum \frac{\alpha_i\, x_{Fi}}{\alpha_i - \phi} \qquad R_{min} + 1 = \sum \frac{\alpha_i\, x_{Di}}{\alpha_i - \phi}$$

Gilliland used an empirical correlation to calculate the final number of stage N from the values calculated through the Fenske and Underwood equations (N_{min}, R, R_{min}). The procedure use a diagram; one enters with the abscissa value known, and read the ordinate of the corresponding point on the Gilliland curve. The only unknown of the ordinate is the number of stage N.



SHORT CUT for DISTILLATION COLUMS SIZING

Simple and direct correlation for (nearly) ideal systems (Westerberg, 1978)

- Determine $\alpha_{lk/hk}$; $\beta_{lk} = \xi_{lk}$; $\beta_{hk} = 1- \xi_{hk}$
- Calculate tray number Ni and reflux ratio Ri from correlations (i= lk, hk):

Ni $= 12.3 / (\alpha_{lk/hk}-1)^{2/3} \cdot (1-\beta_i)^{1/6}$ **Ri** $= 1.38 / (\alpha_{lk/hk}-1)^{0.9} \cdot (1-\beta_i)^{0.1}$

- Theoretical nº of trays $\mathbf{N_T}$ = 0.8 max[Ni] + 0.2 min[Ni]; **R**= 0.8 max[Ri] + 0.2 min[Ri]
- Actual nº of trays **N** = $N_T/0.8$
- For **H** consider 0.6 m spacing (H=0.6 N); Maximum H=60 m → else, 2 columns

* Calculate column diameter, **D,** by internal flowrates and taking into account the vapor fraction of F. Internal flowrates used to sizing condenser, reboiler

Design column at 80% of linear flooding velocity

$$U_f = C_{sb}\left[\frac{\rho_L - \rho_G}{\rho_G}\right]^{0.5}\left(\frac{20}{\sigma}\right)^{0.2}$$

$$A = \frac{\pi D^2}{4} = \left[\frac{\overline{V}}{0.8\,U_f\,\varepsilon\,\rho_G}\right]$$

If D> 3m → Parallel columns

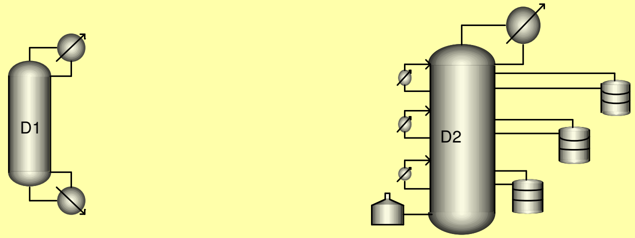
* Calculate heat duties for reboiler and condenser

$$Q_{cond} = H_V - H_L = \sum_{k=1}^{n}\left(\mu_D^k + \mu_L^k\right)\Delta H_{vap}^k = \frac{V}{D}\sum_{k=1}^{n}\mu_{dk}\Delta H_{vap}^k$$

$$Q_{reb} = V\ \Delta H_{vap}^k$$

* Costing vessel and stack trays (24” spacing)

DISTILLATION COLUMNS



Guthrie MPF for Tray Stacks

MPF: Fm + Fs + Ft

Tray Type	Ft
Grid	0.0
Plate	0.0
Sieve	0.0
Valve o trough	0.4
Bubble Cap	1.8
Koch Kascade	3.9

Tray Spacing, Fs

(inch)	24"	18"	12"
Fs	1.0	1.4	2.2

Tray Material, Fm

Carbon Steel	0.0
Stainless Steel	1.7
Monel	8.9

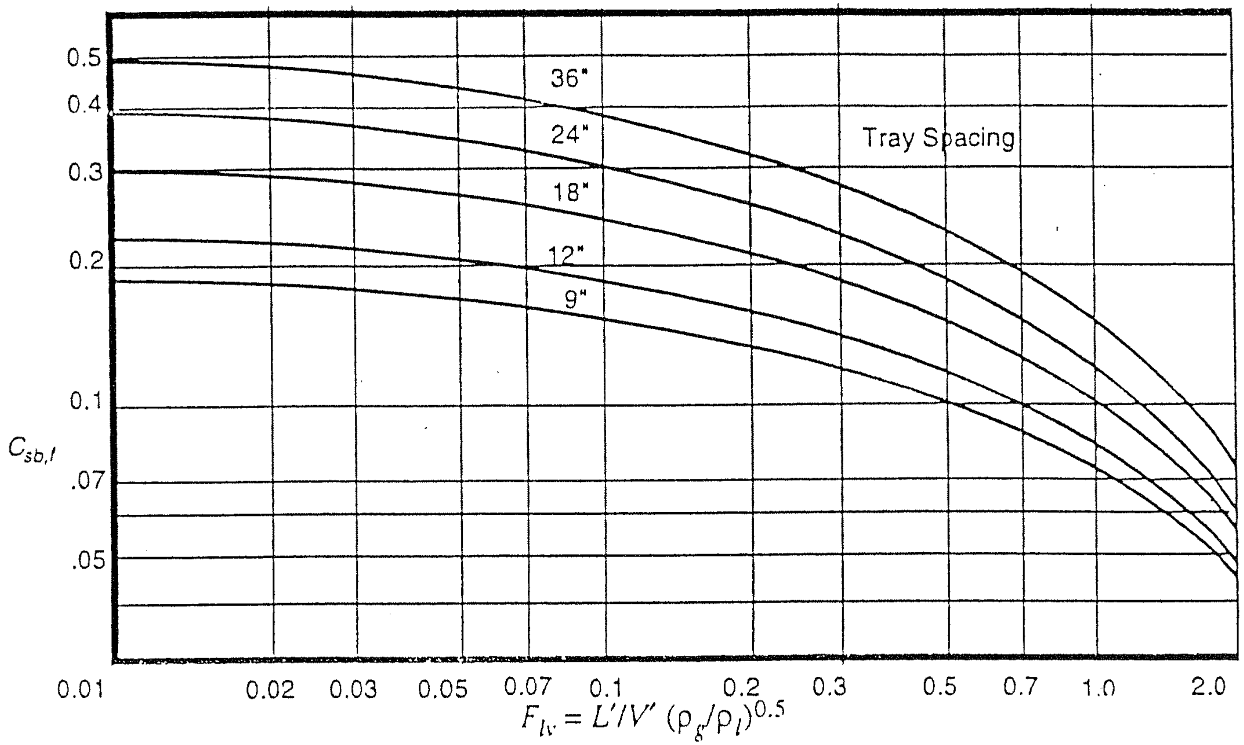
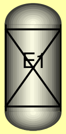


FIGURE 4.4 Flooding limits for bubble cap and perforated trays. L'/V' is the liquid/gas mass ratio at the point of consideration. (Data taken from Fair, 1961.)

DISTILLATION COLUMNS

SHORT CUT for ABSORBERS COLUMS SIZING



Sizing similar to the distillation columns

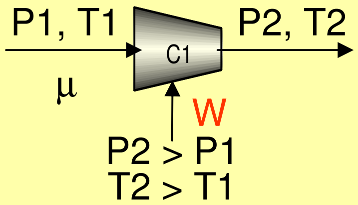
N_T → Kremser equation

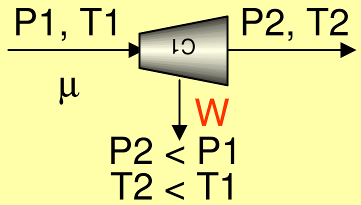
$$N = \ln\left[\frac{l_0^n + (r^n - A_E^n)\, v_{N+1}^n}{l_0^n - A_E^n (1 - r^n) v_{N+1}^n}\right] / \ln(A_E^n)$$

- Assumption: v-l equilibrium → but actually there is mass transfer phenomena (e.g. simulation of CO_2- MEA absorption) → 20% efficiency in nº trays → **$N = N_T/0.2$**

- Calculate H and D for costing vessel and stack trays (24” spacing)

SHORT CUT for COMPRESSORS (or TURBINES) SIZING





Centrifugal compressors are the most common compressors (High capacities, low compression ratios –r-) *vs.* Reciprocating compressors (Low capacities, high r)
Assumptions: Ideal behavior, isentropic and adiabatic

Drivers

1) Electric motors driving compressor; η_M=0.9; η_C=0.8 (compressor)

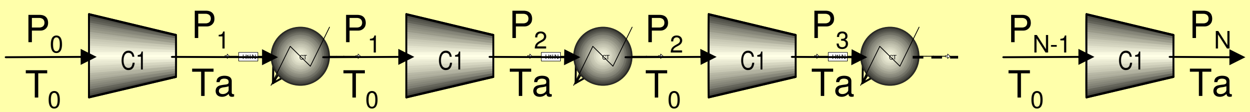
   Brake horsepower $W_b = W/\eta_M \eta_C = 1.39\ W$

2) Turbine diving compressor (e.g.IGCC where need decrease P); η_T=0.8; W_b=1.562 W

   Max. Horsepower compressor = 10.000 hp = 7.5 MW

   Max Compression ratio $r = P_2/P_1 < 5$.

Staged compressors → to decrease work using intercoolers in N stages



Work is minimised when compression ratios are the same

$P_1/P_0 = P_2/P_1 = \ldots = P_N/P_{N-1} = (P_N/P_0)^{1/N}$

Rule of thumb → $(P_N/P_0)^{1/N} = 2.5$ → **N**

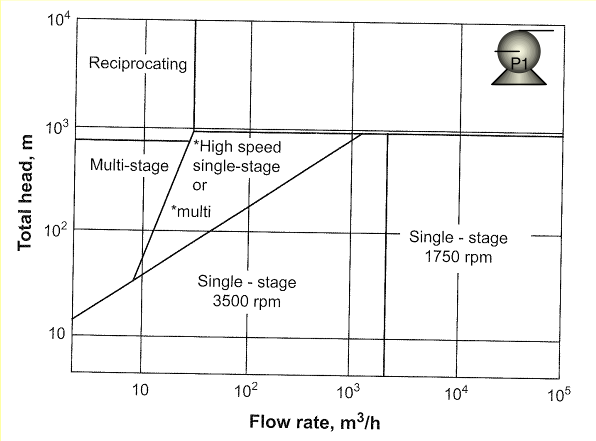
$$W = \mu N R T_0 \left(\frac{\gamma}{\gamma-1}\right)\left[\left(\frac{P_N}{P_0}\right)^{\frac{\gamma-1}{N\gamma}} - 1\right]$$

STEAM TURBINE

SH-25 GAS TURBINE

COMPRESSORS

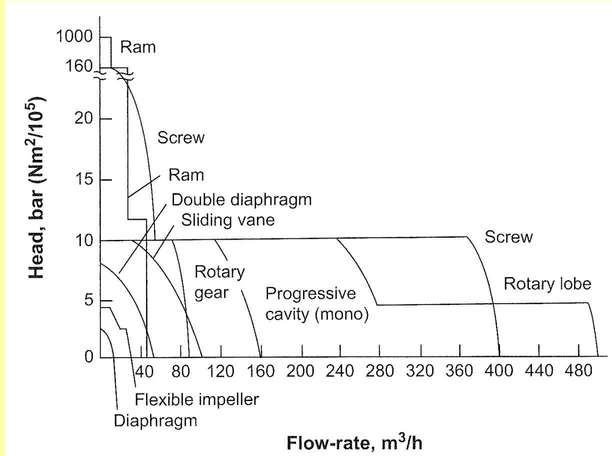
SHORT CUT for PUMPS SIZING



Centrifugal pumps selection guide.
(*)single-stage > 1750 rpm, multi-stage 1750 rpm
(Sinnot, R, Towler, G., 2009)

Normal operating range of pumps

Type	Capacity Range (m³/h)	Typical Head (m of water)
Centrifugal	0.25 - 10^3	10-50 3000 (multistage)
Reciprocating	0.5 - 500	50 - 200
Diaphragm	0.05 - 500	5 - 60
Rotary gear and similar	0.05 - 500	60 - 200
Rotary sliding vane or similar	0.25 - 500	7 - 70



Selection of positive displacement pumps
(Sinnot, R, Towler, G., 2009)

Centrifugal pumps the most common. **Assumptions:** Isothermal conditions

Brake horsepower: $W_b = \mu \frac{(P_2 - P_1)}{\rho \, \eta_P \, \eta_M}$

Pump: η_P=0.5 (less than η_C=0.8 because frictional problems in L); Motor: η_M=0.9

$W_b << W_c$ → €$_b$ << €$_c$ in 2 orders of magnitude → Change P in pumps during heat integration in distillation columns is not much money

Use electrical motors not turbine as drivers in pumps

PUMPS

SPECIFICATIONS

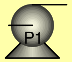
Pump Type: Centrifugal
Flow / P Specifications
Liquid Flow: 170.000 GPM
Discharge P: 43.0 psi
Inlet Size: 2.000 inch
Discharge Size: 1.500 inch
Media Temperature; 250 F
Power Specifications
Power Source AC; 100/200Single
Market Segment: General use; Paper Industry

Pump Type: Centrifugal
Flow / P Specifications
Liquid Flow:1541.003 GPM
Discharge P: 507.6 psi
Media Temperature: 662 F
Power Specifications: Power Source DC **Market Segment:** General use; Petrochemical or Hydrocarbon; Chemical Industry.

Pump Type: Centrifugal
Flow / P Specifications
Liquid Flow 15400.000 GPM
Discharge P: 212.0 psi
Inlet Size 16.000 inch
Discharge Size 16.000 inch
Media T: 572 F
Power Specifications:
Power Source AC; Electric Motor
Market Segment General use**;** Mining; Chemical Industry

Material and Pressure Factors for Centrifugal Pumps and Drivers, Compressors and Mechanical Refrigeration.

PUMPS



Guthrie MPF for Centrifugal Pumps and Drivers

MPF: Fm.Fo

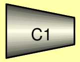
Material Type, Fm

Cast iron	1.00
Bronze	1.28
Stainless	1.93
Hastelloy C	2.89
Monel	3.23
Nickel	3.48
Titanium	8.98

Operating Limits, Fo

Max. Suction P (psig)	150	500	1000
Max. T (ºF)	250	550	850
Fo	1.0	1.5	2.9

COMPRESSORS



Guthrie MPF for Compressors

MPF: Fd

Design Type, Fd

Centrifugal/motor	1.00
Reciprocating/steam	1.07
Centrifugal/turbine	1.15
Reciprocating/motor	1.29
Reciprocating/gas engine	1.82

REFRIGERATION

Guthrie MPF for Mechanical Refrigeration

MPF: Ft

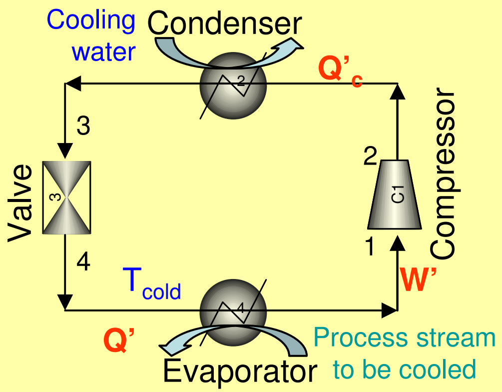
Evaporator Temperature, Ft

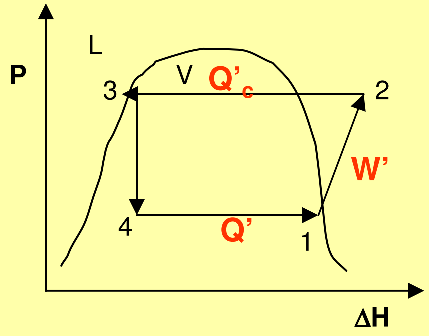
278 K / 5 C	1.00
266 K / -7 C	1.95
255 K / -18 C	2.25
244 K / -29 C	3.95
233 K / -40 C	4.54

SHORT CUT for REFRIGERATION SIZING

Short cut model (one cycle/one stage)

1 cycle for process stream T not too low
Coefficient of performance (CP)





CP = Q/W, typically CP ≈ 4 → Compressor W=Q/4

For h=0.9; hcomp=0.8 → Wb = W/0.72; Cooling duty Qc= W+Q = 5/4 Q

Short cut model (multiple stages)

Multiple stages for low T process stream
Refrigerant R must satisfy

a) $T_{cond} < T_c^R$ max T_{cond} = 0.9 Tc (critcal component)

b) $T_{evap} > T_{boil,R}$ → $P_{evap} = P_R^0 > 1$ atm. (To prevent decreasing η due to air in the system)

c) T_{evap} and T_{cond} must be feasible for heat exchange; ΔT ≈ 5K

More steps → Less energy vs. More capital investment (compressors) → Trade-off

Rule of Thumb: One cycle for 30 K below ambient →**Nº cycles = N = (300-T_{cold})/30**

$$W = Q\left[\left(1+\frac{1}{CP}\right)^N - 1\right]; \qquad Q_c = \left[1+\frac{1}{CP}\right]^N Q$$

3.- COST ESTIMATION OF EQUIPMENT: Base Costs for equipment units

[Tables 4.11-4.12; p.134 (Biegler et al., 1997) → Table 22.32; p.591-595 (Seider et al., 2010)]

Base Costs for Pressure Vessels

Equipment Type	C_0 ($)	L_0(ft)	D_0(ft)	α	β	MF2/MF4/MF6/MF8/MF10
Vertical fabrication 1≤D ≤10 ft; 4 ≤ L ≤100 ft	1000	4.0	3.0	0.81	1.05	4.23/4.12/4.07/4.06/4.02
Horizontal fabrication 1≤D ≤10 ft; 4 ≤ L ≤100 ft	690	4.0	3.0	0.78	0.98	3.18/3.06/3.01/2.99/2.96
Tray stacks 2≤D ≤10 ft; 1 ≤ L ≤500 ft	180	10.0	2.0	0.97	1.45	1.0/1.0/1.0/1.0/1.0

Base Costs for Process Equipment

Equipment Type	C_0 ($\$10^3$)	S_0	Range (S)	α	MF2/MF4/MF6/MF8/MF10
Process furnaces *S=Absorbed duty (10^6Btu/h)*	100	30	100-300	0.83	2.27/2.19/2.16/2.15/2.13
Direct fired heaters *S=Absorbed duty (10^6Btu/h)*	20	5	1-40	0.77	2.23/2.15/2.13/2.12/2.10
Heat exchanger *Shell and tube, S=Area (ft^2)*	5	400	100-10^4	0.65	3.29/3.18/3.14/3.12/3.09
Heat exchanger *Shell and tube, S=Area (ft^2)*	0.3	5.5	2-100	0.024	1.83/1.83/1.83/1.83/1.83
Air Coolers *S=[calculated area (ft^2)/15.5]*	3	200	100-10^4	0.82	2.31/2.21/2.18/2.16/2.15
Centrifugal pumps *S= C/H factor (gpm x psi)*	0.39	10	10-2.10^3	0.17	3.38/3.28/3.24/3.23/3.20
	0.65	2.10^3	2.10^3 -2.10^4	0.36	3.38/3.28/3.24/3.23/3.20
	1.5	2.10^4	2.10^4 -2.10^5	0.64	3.38/3.28/3.24/3.23/3.20
Compressors *S=brake horsepower*	23	100	30-10^4	0.77	3.11/3.01/2.97/2.96/2.93
Refrigeration *S=ton refrigeration (12,000 Btu/h removed)*	60	200	50-3000	0.70	1.42

3.- COST ESTIMATION OF EQUIPMENT

´ modular method to preliminary design.

Updated Bare Module Cost = UF · BC · (MPF + MF -1)

BC

Williams Law: $C = BC = Co\ (S/So)^{\alpha}$

Non-linear behaviour of Cost, C *vs.,* Size, S → Economy of Scale (incremental cost decrease with larger capacities

$$C = BC = Co\ (S/So)^{\alpha} \qquad\qquad \log C = \log\ (Co/So)^{\alpha} + \alpha \log S$$

Tables for each equipment

Co, So. Parameters of Basic configuration Costs and Capacities

α. Parameter < 1 → economy of scale

Base Cost for Pressure Vessels: Vertical, horizontal, tray stack

$$C = Co\ (L/Lo)^{a}\ (D/Do)^{b}$$

Base Cost for Process Equipment

$C = Co\ (S/So)^{\alpha}$; Range of S

MF: Module Factor, affected by BC, taking into account labor, piping instruments, accessories, etc.

MF 2 : < 200.000 $ MF 4 : 200.000 - 400.000 $

MF 6 : 400.000 - 600.000 $ MF 8 : 600.000 - 800.000 $

MF 10 : 800.000 - 1.000.000 $

MPF: Materials and Pressure correction Factors Φ (Fd, Fm, Fp, Fo, Ft)

Empirical factors that modified BC and evaluate particular instances of equipment beyond a basic configuration: Uninstalled Cost = (BC x MPF)

Fd: Design variation

Fm: Construction material variation

Fp: Pressure variation

Fo: Operating Limits (Φ of T, P)

Ft: Mechanical refrigeration factor (Φ T evaporator)

UF: Update Factor, to account for inflation.

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

CI: Chemical Engineering Plant Cost Index (www.che.com)			
YEAR	CI	YEAR	CI
1957-59	100	1996	382
1968	115 (Guthrie paper)	1997	386.5
1970	126	1998	389.5
1983	316	2003	402
1993	359	2009	539.6
1995	381	2010	532.9