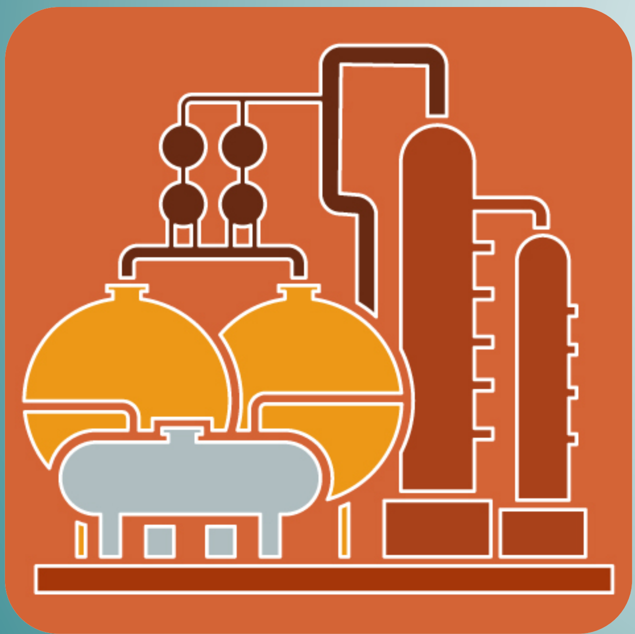
Chemical Process Design / Diseño de Procesos Químicos

Topic 5.5. Compressors and turbines



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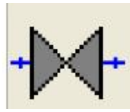
Shortcut for Compressor (or Turbine) Sizing

- **GAS:**
  - A Compressor is always necessary if you need to Increase **P** → High energy consumption (**W**)
  - An alternative to a Gas Turbine for decreasing **P** (especially for small decreases in **P**) is a VALVE → Isoenthalpic expansion.
  - If you have liquid phase, it is not possible to use a gas turbine.



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

$$T_2 = T_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} \right]$$

For ideal gas.

$$\gamma = Cp / Cv = 1.4$$

Theoretical power (ideal gas).
M = gmol/s; R = 8.314 J/gmol·K

$$W = \mu \, R \, T_1 \left(\frac{\gamma}{\gamma - 1} \right) \left[\left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]$$

- **Drivers:**

  1) Electric motors driving compressor; h_M = 0.9; h_C = 0.8 (compressor).

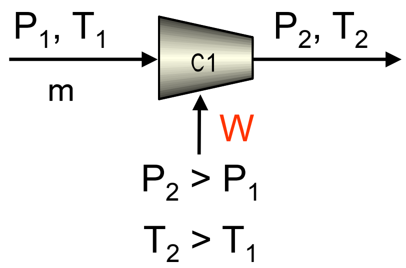
  Brake horsepower $W_b = W / \eta_M \eta_C$ = 1.39 W.

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

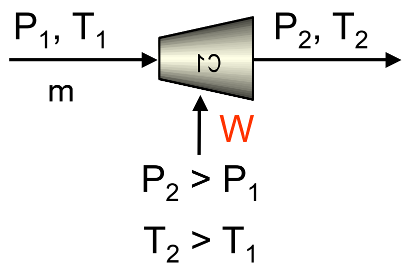
  Max. Horsepower compressor = 10.000 hp = 7.5 MW.

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

Gas Compressor

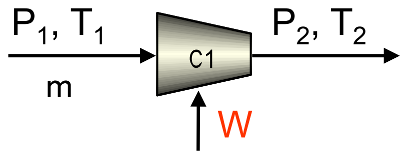


Gas Turbine



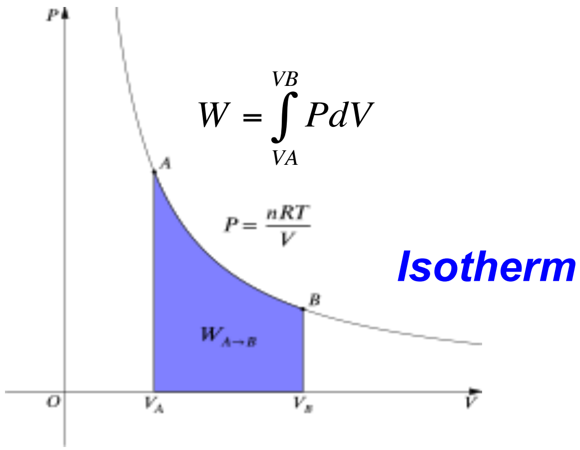
Shortcut for Compressor (or Turbine) Sizing

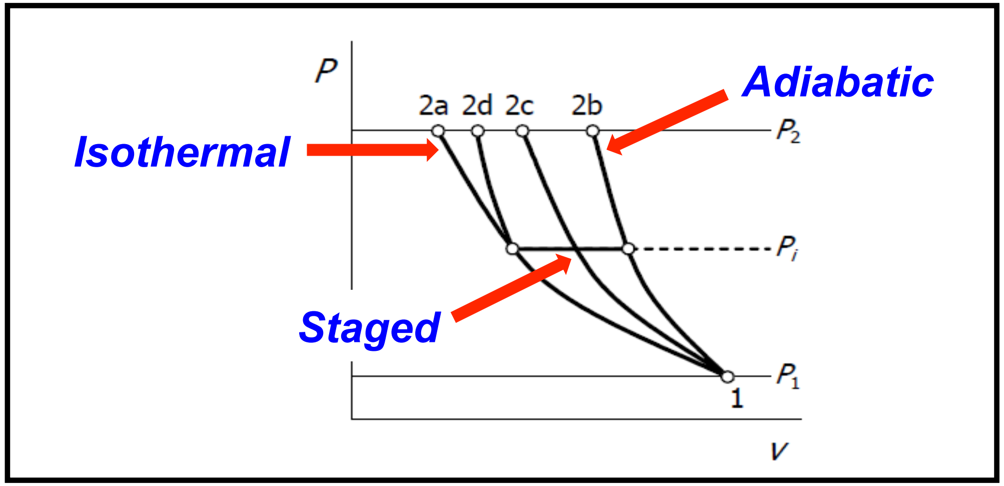
Compressor



$P_2 > P_1$

$T_2 > T_1$

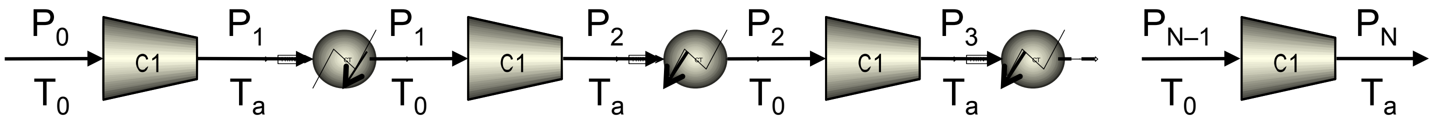




Four ways to Compress a Gas:

- **a)** Isothermal.
- **b)** Adiabatic.
- **c)** Polythropic with cooling.
- **d)** two adiabatic stages with intermediate cooling to initial Temperature.

Staged compressors → To decrease work using intercoolers in **N** stages:



Work is minimized when compression ratios are the same:

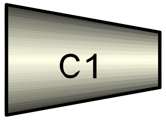
$P_1 / P_0 = P_2 / P_1 = \ldots. = P_N / P_{N-1} = (P_N / P_0)^{1/N}$

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

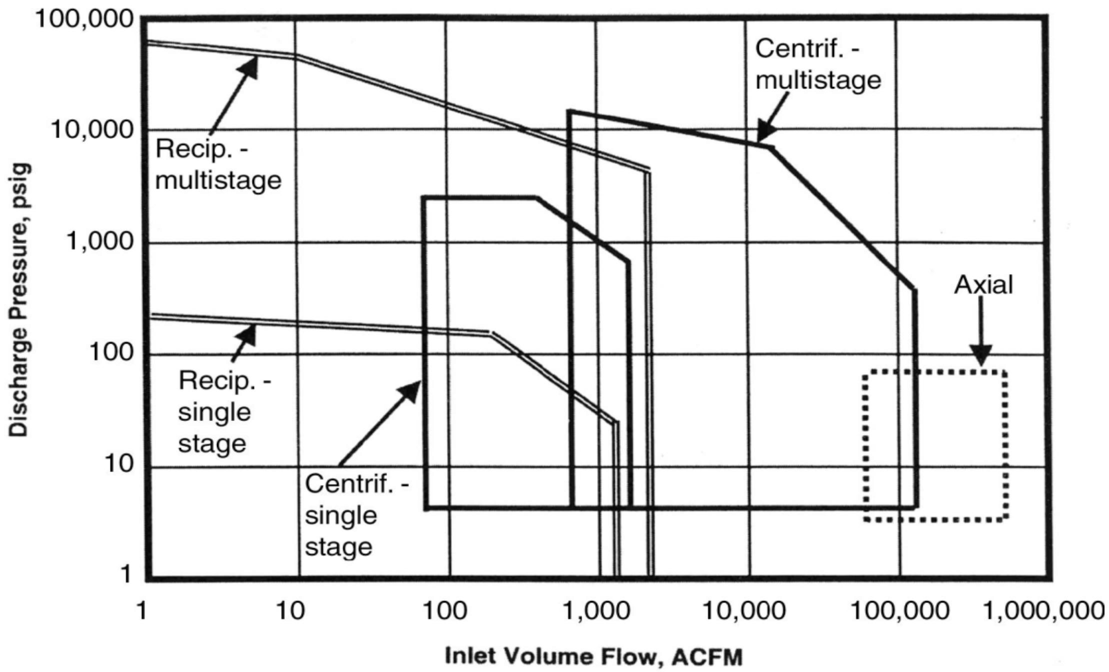
$$W = \mu\, N\, R\, T_0 \left(\frac{\gamma}{\gamma - 1}\right) \left[\left(\frac{P_N}{P_0}\right)^{\frac{\gamma-1}{N\gamma}} - 1 \right]$$

Guthrie Material and Pressure Factors for Compressors

Compressors



Guthrie MPF for Compressors	
$MPF = F_d$	
Design Type,	F_d
Centrifugal/motor	1.00
Reciprocating/steam	1.07
Centrifugal/turbine	1.15
Reciprocating/motor	1.29
Reciprocating/gas engine	1.82



Compressor selection. Areas indicate regions of best performance.
http://www.dresser-rand.com/.

Compressors

Equipment Type	C_0 (\$$10^3$)	S_0	Range (S)	a	MF2 / MF4 / MF6 / MF8 / MF10
Compressors	23	100	**30 - 10^4**	0.77	3.11 / 3.01 / 2.97 / 2.96 / 2.93

S = Brake horsepower

S ≡ Wb, Brake horsepower

$$C = BC = C_0\,(S / S_0)^{\alpha}$$

MF (Module Factor)

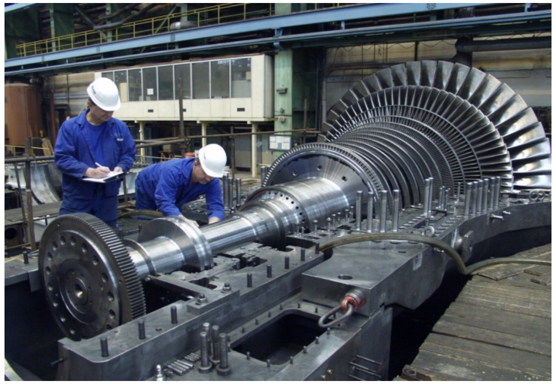
- MF 2: If C < 200.000 \$
- MF 4: If C = 200.000 - 400.000 \$
- MF 6: If C = 400.000 - 600.000 \$
- MF 8: If C = 600.000 - 800.000 \$
- MF 10: If C = 800.000 - 1.000.000 \$

Materials and Pressure correction Factor: MPF = F_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)

Steam Turbine



60 Mw Steam turbine.
http://www.beemtech.com/energy/toshiba-to-supply-steam-turbine-and-generators-for-sarulla-geothermal-power-plant-project/.

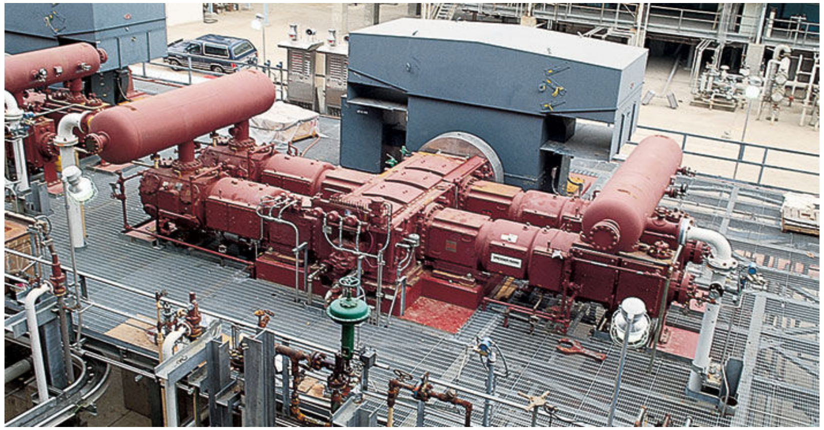
Gas Turbine

SGT-8000H gas turbine.
https://www.siemens.com/.

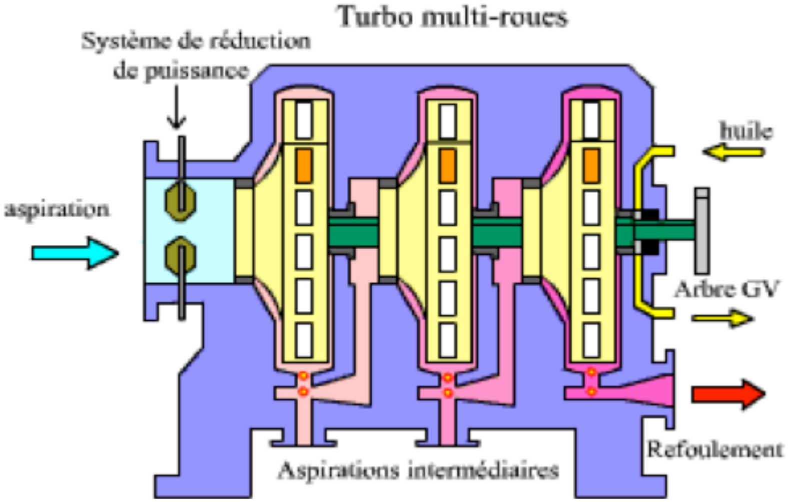
Multistage Centrifugal Compressor

AtlasCopco ZH4000-10000 Serie H.
http://www.aircompressor.es/4_AtlasCopco_air_compressor_4.html.

Reciprocating Compressor

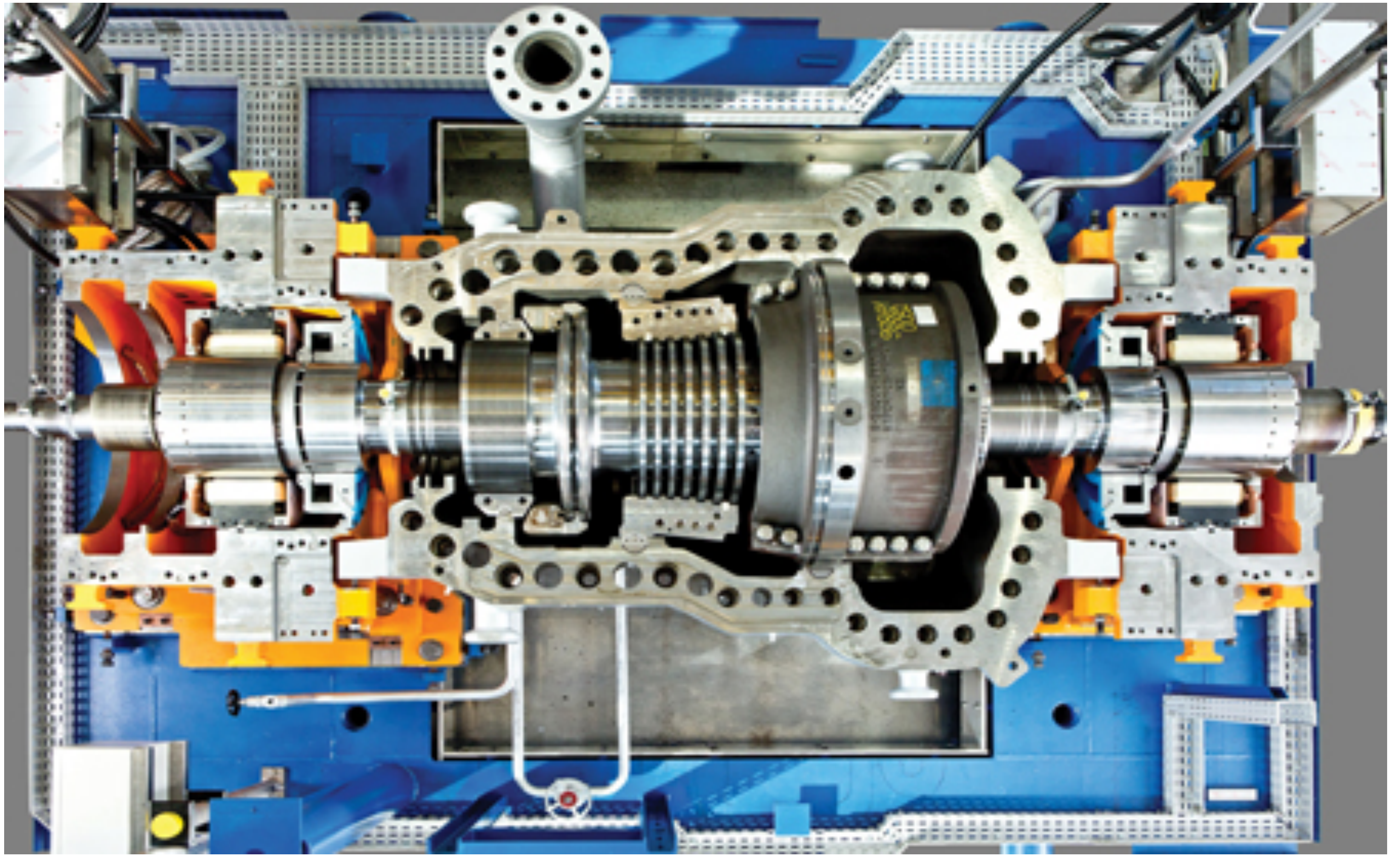


Process Gas Compressor Stationary Reciprocating Oil Injected.
http://www.dresser-rand.com/.



http://patcelte.chez-alice.fr/turbo.html.

Steam Turbine



http://www.powerengineeringint.com/articles/print/volume-24/issue-4/features/advancing-steam-turbine-technology.html.