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 \( P \) \( \rightarrow \) High energy consumption \((W)\)
  - An alternative to a Gas Turbine for decreasing \( P \) (especially for small decreases in \( P \)) is a VALVE \( \rightarrow \) 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.

\[
T_2 = T_1 \left( \frac{P_2}{P_1} \right)^{\frac{\gamma - 1}{\gamma}} \quad \text{For ideal gas.}
\]

\[
\gamma = \frac{C_p}{C_v} = 1.4
\]

Theoretical power (ideal gas).

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

\[
\gamma = \frac{C_p}{C_v} = 1.4
\]

For ideal gas. Theoretical power (ideal gas).

\[ M = \text{gmol/s}; \ R = 8.314 \text{ J/gmol·K} \]

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

\[ \gamma = \frac{C_p}{C_v} = 1.4 \]

• Drivers:

1) Electric motors driving compressor; \( h_M = 0.9; \ h_C = 0.8 \) (compressor).
   
   Brake horsepower \( W_b = W / \eta_M \eta_C = 1.39 \text{ W} \).

2) Turbine driving compressor (e.g. IGCC where need to decrease \( P \)); \( \eta_T = 0.8; \ W_b = 1.562 \text{ W} \).
   
   Max. Horsepower compressor = 10.000 \( \text{hp} = 7.5 \text{ MW} \).
   
   Max Compression ratio \( r = \frac{P_2}{P_1} < 5 \).
Shortcut for Compressor (or Turbine) Sizing

Compressor

\[ W = \int_{V_A}^{V_B} P dV \]

\[ W = \frac{nRT}{V} \]

\[ W_{A-B} \]

\[ P_2 > P_1 \]

\[ T_2 > T_1 \]

Staged compressors → To decrease work using intercoolers in \( N \) stages:

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

Work is minimized when compression ratios are the same:

\[ W = \mu N RT_0 \left( \frac{\gamma}{\gamma-1} \right) \left[ \left( \frac{P_N}{P_0} \right)^{\frac{\gamma-1}{N \gamma}} - 1 \right] \]

Rule of thumb → \( (P_N / P_0)^{1/N} = 2.5 \) → \( N \).
## Guthrie Material and Pressure Factors for Compressors

**Compressors**

### Guthrie MPF for Compressors

\[ MPF = F_d \]

<table>
<thead>
<tr>
<th>Design Type</th>
<th>( F_d )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centrifugal/motor</td>
<td>1.00</td>
</tr>
<tr>
<td>Reciprocating/steam</td>
<td>1.07</td>
</tr>
<tr>
<td>Centrifugal/turbine</td>
<td>1.15</td>
</tr>
<tr>
<td>Reciprocating/motor</td>
<td>1.29</td>
</tr>
<tr>
<td>Reciprocating/gas engine</td>
<td>1.82</td>
</tr>
</tbody>
</table>

Compressors

Materials and Pressure correction Factor: \( MPF = F_d \)

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

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

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**Equipment Type**

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>( C_0 (\times 10^3) )</th>
<th>( S_0 )</th>
<th>Range (S)</th>
<th>( a )</th>
<th>( MF2 / MF4 / MF6 / MF8 / MF10 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressors</td>
<td>23</td>
<td>100</td>
<td>30 - 10^4</td>
<td>0.77</td>
<td>3.11 / 3.01 / 2.97 / 2.96 / 2.93</td>
</tr>
</tbody>
</table>

\( S = \) Brake horsepower

\( C = BC = C_0 \left( \frac{S}{S_0} \right)^\alpha \)

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 \( C = 800,000 - 1,000,000 \) $

\( S = Wb, \) Brake horsepower
Steam Turbine

60 Mw Steam turbine.

Gas Turbine

SGT-8000H gas turbine.

Multistage Centrifugal Compressor

AtlasCopco ZH4000-10000 Serie H.

Reciprocating Compressor

Process Gas Compressor Stationary Reciprocating Oil Injected.
