Vessels, Materials Selection, Design Pressures & Temperatures

Briefing for 3 year design module

Vessels

- What is a vessel
- Why is this important
- What do we need to know for 3rd year module
- What do you need to know further
CHEMECON – Vessel Input

- All Dimensions should be rounded (up usually) to the nearest 6”
- Then convert to M for CHEMECON
Horizontal vs Vertical

- Packed Bed – Short circuit

Which do we want to use?

Why Is Material Selection Important?

- Poor choices in materials selection have historically been a problem in process design
  - Has caused significant process hazards to occur
  - Has caused significant business interruption due to premature failures
  - Very expensive to fix later!
- Because it’s not part of the ‘fun’ part of process design it can often be relegated as an afterthought – one that can really come back to haunt you.
Why Is Material Selection Important?

• Engineers must ensure:
  – Equipment Life meets expectations of process life
  – Failures do not occur - can cause significant loss of property and/or life
  – Contamination of product does not occur

• Chemical engineers must be aware of the issues so that the relevant information may be passed along to the specialists

Why Worry?

• Corrosion Caused this Pipe Elbow to Fail

Public report of the fire and explosion at the conocophillips humber refinery on 16 April 2001
By the Health and Safety Executive
The Steps

• Who?
  – Chemical Engineers & Mechanical /Metallurgical engineers

• How do you do it?
  – Use knowledge/experience from prior systems
  – Fundamental understanding of corrosion mechanisms
  – Tables of Material Selection / compatibility
  – rules of thumb

Some Considerations

• Process fluids / materials – normal and upset
  – i.e. a plastic might be perfect for the fluid corrosiveness, but will melt when the operators ‘steam’ the equipment our during cleaning.
• Operating temperature and pressure, fluid velocity
• Contamination of product
• Required life of the equipment
  – May choose to incur shorter life and replace more often
• Cost of the materials of construction (base material + fabrication costs)
Process Design For Materials Selection

• The Choices that the process engineer is making (i.e. fluids, temperature, pressure) are affecting the materials selection.
• The Process Engineer can turn that thinking around:
  – Consider how you might change the process to allow for a cheaper material selection
    • Use concentrations that self passivate the surface
    • Use other temp, press, compositions
  – Consider how you might minimize an expensive choice in metallurgy – keep the piping short, make the equipment smaller...

General Types of Materials

• Carbon steel – strength & moderate corrosion resistance
• Low-alloy steels – strength at high temperatures
• Stainless steels – corrosion resistance
• Nickel alloys – corrosion resistance
• Copper alloys – sea water resistance
• Aluminum – light, low temperature toughness
• Titanium – sea water, chemical resistance
• Refractories – very high temperatures
• Non-metallics – aqueous corrosion & chemicals
Approximate Cost of Materials Used in Pressure Vessel Construction (as of January 1988)

<table>
<thead>
<tr>
<th>Type</th>
<th>Cost (dollars/lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon steel</td>
<td>0.30</td>
</tr>
<tr>
<td>Low-alloy steel</td>
<td>0.75</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>0.90 - 2.50</td>
</tr>
<tr>
<td>Aluminum</td>
<td>1.50</td>
</tr>
<tr>
<td>Copper, bronze</td>
<td>1.75</td>
</tr>
<tr>
<td>Incoloy</td>
<td>4.00</td>
</tr>
<tr>
<td>Monel</td>
<td>5.00</td>
</tr>
<tr>
<td>Inconel</td>
<td>6.00</td>
</tr>
<tr>
<td>Hastelloy</td>
<td>15.00</td>
</tr>
<tr>
<td>Titanium</td>
<td>15.00</td>
</tr>
<tr>
<td>Zirconium</td>
<td>20.00</td>
</tr>
<tr>
<td>Tantalum</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Chemical Resistance Charts

Source: Gormann Rupp Chemical Resistance Chart
Failure Mechanisms

- Fatigue
- Brittle Fracture
- Creep
- Corrosion
  - General (even) corrosion
  - Localized corrosion
    - Pitting
    - Crevice
    - Erosion
    - Cavitation
    - Dealloying
    - Galvanic
    - Environmentally induced cracking
      - Chloride Stress Corrosion Cracking – aka Chloride Cracking - aka Stress Corrosion Cracking
- High Temperature Hydrogen Attack (hydrogen embrittlement)

Chart from: Turton et al
Chloride Stress Corrosion Cracking in Stainless Steel

Photo: D. Mody

Crevice Corrosion

Stainless steel bolt used to support corrosion samples in a sea-water tests. The plastic sleeves used as insulators stimulated crevice corrosion.

Exposure in Halifax Harbour at HMCS Shearwater site from November 12, 1954 to June 26, 1956.

Photo: D. Mody
Stress Corrosion Cracking

Three samples of stress corrosion cracking in which premature failure occurred due to the combined effects of stress Vs. corrosion.

Errosion

Erosion Corrosion of a carbon steel valve caused by water flow.
High Temperature Hydrogen Attack

- Results from exposure to hydrogen at elevated temperatures & pressures.
- H reacts with carbides in steel to form methane which cannot diffuse out.
- Methane pressure builds up, forming bubbles or cavities, microfissures and finally fissures that combine to form cracks.
- Carbon & low-alloy steels are most susceptible.

Operating limits for three steels in hydrogen service to avoid hydrogen attack (Nelson Curves). Dashed lines show limits for decarburization, not hydrogen attack.
3rd year design module considerations

- There is Hydrogen gas present in our process
- Consider operating temperatures (maximum expected)
- Utilities: Ask yourself what utilities will be used.

Heat Exchangers

- Rules of Thumb:
  - Heat Exchanger tubes are usually SS (even if CS could be used) allows for thinner steel to be used for better heat transfer.
Sources of Information

• Definition: mil = 1/1000 of an inch
• Sources of Corrosion tables information:
  – Analysis, Synthesis, and Design of Chemical Processes; Turton et. al.; pg 170
  – Warren Rupp Pumps
    • http://www.warrenrupp.com/pdf/CHART%20MARATHON.pdf
  – Perry’s Chemical Engineers Handbook
    • Only older editions provide corrosion tables
    • Edition currently available through Queen’s Library online at Knovel no longer has material selection tables:

Vessels - General

• Wall Thickness
  – determined by required pressure
• Process Engineer Determines Design Pressure
Design Pressure

- Excessive design pressure causes equipment to be more expensive than is required

\[ t = \frac{P \cdot r_i}{S \cdot E_j - P} + C_c \]

\( S = \) Allowable Stress for the Material
\( t = \) metal thickness, \( P = \) Design Pressure
\( C_c = \) Corrosion Allowance, \( E_j = \) Joint Efficiency

ChemEcon uses this for its pressure correction

General - Design Temperatures

- Allowable Stress Values are dependant on Temperature
- Temperature at Design Pressure must be stated
- Materials become brittle below certain temperatures - minimum design metal temperature
- ChemEcon assumes moderate temperatures
3rd Year Design

- Take Simulator Operating Pressure as Normal
  - Group equipment that is at same operating pressure
    - examples?
  - Maximum OP. Pressure = Normal + 25 psi
  - Design Pressure = lesser of 10% or 50 psi + Maximum Operating Pressure

3rd Year Design

- Keeping it SAFE!

- What occurs to temperatures if Reactor Conversion increases?
  - What's worst case?
  - What Material selection for worst case?
  - How can we avoid more expensive materials?
Vessels - Safety

• A Vessel that can be isolated requires a Relief Valve