Titanium Tubing
A Competitive solution for Heat Exchangers in Refineries

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50% of the energy consumption is coming from heat exchangers
Critical parameters in the choice of HEX tubing

- **Corrosion resistance**: fluids chemical composition / fouling / geometry / temperature / residual stresses
- **Thermal design**: fluids in presence / fouling / phase change /
- **Mechanical design**: vibration / mechanical properties
Some yellow metals used in refineries and petrochemical plants

- Ad Brass (UNS C44300) for clean water or non aggressive fluids
- Copper Nickel 90/10 (UNS C70600) for quite aggressive fluids
- Copper Nickel 70/30 (UNS 71500) for aggressive fluids such as brackish water

Although it is historical choice, is it really the best choice today?
Most usual corrosion in HEX tubes

- **General corrosion:** uniform loss of metal over an entire surface
- **Pitting Corrosion:** local corrosion attack, leading to the creation of small holes in the metal
- **Crevice Corrosion:** occurs in a confined spaces to which the access of the working fluid from the environment is limited
- **Microbiological Induced Corrosion:** some sulfate-reducing bacteria producing H2S
- **Stress Corrosion Cracking:** results from the combined action of temperature, corrosive agent and residual stresses
- **Erosion Corrosion:** degradation of surface material due to particles suspended in fast flowing liquid or gas, bubbles, droplets, cavitation
- **Flow Accelerated Corrosion:** protective oxide layer on a metal surface is dissolved by a fast flowing water. The underlying metal corrodes to re-create the oxide and the metal loss continues
- **Galvanic Corrosion:** corrosion damage induced when two dissimilar materials are coupled in a corrosive electrolyte. It occurs when two dissimilar metals are brought into electrical contact under water.
Basics of Titanium properties against corrosion

- Corrosion resistance achieved through the formation of titanium oxide layer
- Protective film is about 100Å very stable
- Protective layer is chemically and mechanically very resistant
- Not susceptible to pitting or stress corrosion cracking (unalloyed grades)
- Some limitations exist in temperature and pH for crevice corrosion
- Risk of hydriding

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Some examples of corrosion with brass tubes

- Abrasion
- Erosion corrosion

Heavier wall thickness can be used to predict metal loss
Comparison between Copper Alloys and Titanium in erosion/abrasion

- Sand erosion resistance of titanium and copper alloy in running seawater

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## Titanium versus Copper Alloys in Corrosion

<table>
<thead>
<tr>
<th></th>
<th>Pitting</th>
<th>crevice</th>
<th>MIC</th>
<th>SCC</th>
<th>Erosion-Corrosion</th>
<th>Galvanic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brass</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Cu-Ni</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><strong>Titanium</strong></td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>-</td>
</tr>
</tbody>
</table>
Can I improve the thermal design?

Q = \frac{1}{\frac{1}{h_i} + R_{fi} + R_{fo} + R_m + \frac{1}{h_o}} \times A \times LMTD

- To compare materials
- Usually small impact of overall heat transfer coefficient
Titanium versus Copper Alloys for Thermal Resistance of metal

<table>
<thead>
<tr>
<th>UNS</th>
<th>TRADE NAME</th>
<th>Thermal conductivity K W/(m°C)</th>
<th>WT standard (mm)</th>
<th>Thermal resistance (WT/K)x10⁻²</th>
</tr>
</thead>
<tbody>
<tr>
<td>C44300</td>
<td>B70/30AS</td>
<td>121</td>
<td>1.2 (1.65)</td>
<td>0.99 (1.36)</td>
</tr>
<tr>
<td>C70600</td>
<td>Cu-Ni 90/10</td>
<td>50</td>
<td>2.4 (3.3)</td>
<td></td>
</tr>
<tr>
<td>C71500</td>
<td>Cu-Ni 70/30</td>
<td>30</td>
<td>4.0 (5.5)</td>
<td></td>
</tr>
<tr>
<td>R50400</td>
<td>Ti Gr.2</td>
<td>22</td>
<td>0.9 (1.24)</td>
<td>4.0 (5.5)</td>
</tr>
</tbody>
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Titanium allows higher fluids velocity (heat transfer / fouling)

<table>
<thead>
<tr>
<th>Material</th>
<th>Maximum Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al Brass</td>
<td>1.8 m/s</td>
</tr>
<tr>
<td>90/10 CuNi</td>
<td>2.5 m/s</td>
</tr>
<tr>
<td>70/30 CuNi</td>
<td>3.6 m/s</td>
</tr>
<tr>
<td>Ti Gr2</td>
<td>&gt; 30 m/s</td>
</tr>
</tbody>
</table>
Vibration – Critical Span - Peake

MAXIMUM DISTANCE BETWEEN SPPT PLATES
L = 9.5 ( E I / ρ V² D)¹/⁴

<table>
<thead>
<tr>
<th>UNS N°</th>
<th>TRADE NAME</th>
<th>MODULUS E in GPa (106 ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C70600</td>
<td>Cu-Ni 90/10</td>
<td>130 (18.8)</td>
</tr>
<tr>
<td>C71500</td>
<td>Cu-Ni 70/30</td>
<td>149 (21.6)</td>
</tr>
<tr>
<td>R50400</td>
<td>Ti Gr.2</td>
<td>107 (15.5)</td>
</tr>
</tbody>
</table>

LEGEND
E: modulus of elasticity
I: moment of inertia
ρ: turbine exhaust density
V: average exhaust steam velocity at the condenser neck
D: tube diameter
MECHANICAL DESIGN – CLASSIC VIBRATION FAILURES

Mid-Span Fatigue Crack

Fatigue Failure

Mid-Span Collision Damage
Economical comparison: Ti vs Cu Alloys

- Based on standard condenser for petrochemical plant
- Penalty has been applied for heat transfer impact
- No issues of mechanical design has been considered
- Tube bundle cost has been evaluated (no cladded plates)

<table>
<thead>
<tr>
<th>Grade</th>
<th>Qty</th>
<th>Wall Thickness</th>
<th>Bundle cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Brass</td>
<td>10.8 kms</td>
<td>1.4mm</td>
<td>$74,975</td>
</tr>
<tr>
<td>CuNi9010</td>
<td>11.4 kms</td>
<td>1.2mm</td>
<td>$89,170</td>
</tr>
<tr>
<td>Titanium Gr 2</td>
<td>12 kms</td>
<td>0.9mm</td>
<td>$60,878</td>
</tr>
</tbody>
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Titanium substitution being expensive: the myth is no longer true
Stability of Titanium versus Copper

Titanium relative competitiveness

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SHOULD WE USE SEAMLESS OR WELDED TITANIUM TUBES?

Did you know that welded tubes

• Are used in the most critical application such as Nuclear Powerplant
• Are welded without filler metal
• Can be fabricated without any aggressive lubricant
• Have an adapted fabrication process to avoid internal damages
• Can have wall thickness upon Customer demand and very thin wall thickness can be achieved
• Have very long length feasibility
• Are non destructively tested 100% in Eddy Current and 100% in Ultrasonic as per B338
• Can be tested 100% in Helium as per ASTM B338 Supplementary S2
• Should be cheaper than seamless

Why would not use welded tubes?
When substitution is being considered:

- Check for domain of validity (temperature, pH, fluorides)
- Use the wall thickness reduction (no corrosion allowance with titanium)
- Check the connection tube / tubesheet (welding, expansion) / protection of tubesheet (cladded)
- Check if an upgrade with enhanced tubes is possible
- Perform realistic economical analysis

Some application where the step has been done

<table>
<thead>
<tr>
<th>Industry</th>
<th>Typical Areas</th>
<th>Titanium Equipment</th>
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</table>
| Chemical plants | Organic acid production  
Chlor-Alkali  
Salt Production  
Chlorinated Hydrocarbons | Heat exchangers, reactors, columns |
| Refineries | Crude Overheads  
Desulfurizing  
Process cooling water | Heat exchangers |
THANK YOU