High Effectiveness, Compact, High Pressure and Low Cost Super-Critical CO₂ Recuperator

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Introduction
- 400 MWe RCBC plant requires 2,500 MWe of 200bar and 600C capable recuperative heat exchangers
- Minichannels with small hydraulic diameter (dh) and surface enhancements needed for compactness and low cost – Effectiveness (Ntu), and Ntu (L, dh)
- Many millions of channels of 1mm dh required
- Must connect channels together – manifolding important
- Need high strength under all operating temperatures
- Recuperators must have lifetimes of 30 years – limited corrosion, erosion and fouling

Altex HELC Recuperator

50 KW Test Article Array
- Plates and frames with integral manifolds and novel inserts
- Inserts optimized for high and low pressure channels
- Load Assisted Braze and Corrosion Barrier (LAB-CB) bonding process to limit surface preparation cost ahead of bonding components and provide corrosion protection
- Insert surface features used to enhance heat transfer at high thermal efficiency
- Altex Case 3 surface features have better heat transfer performance than smooth and wavy channels typically used in printed circuit heat exchangers

Results Summary
- Can design 316 SS unit to meet 200 bar pressure requirement
- Can use LAB bonding to build 200 bar capable unit
- High base heat transfer rates tested
- Model predictions fit test results to within 10%
- High nickel braze compounds have compositions similar to high strength and corrosion resistant high nickel alloy
- Low cost iron base materials can produce oxides that are poorly adhering, spall and expose underlying base material to rapid corrosion
- Some expensive high nickel base materials have strongly adhering chrome, silicon and aluminum oxide layers that form barriers that slow subsequent oxygen diffusion and corrosion
- High nickel braze material has potential for strong joints and corrosion resistance
- Butt and peel type braze joints are utilized in HELC
- High nickel braze compounds with chrome, silicon and aluminum can provide good strength and corrosion resistance
- NiCR33 and NiCr152 selected for testing because of chrome and silicon content
- NiCr152 has 82% and 75% of base 316 stainless steel material strength for butt and peel joints at room temperature
- At 910C, NiCr butt joints are 101% the strength of base 316 stainless steel material
- Can use LAB bonding to build 200 bar capable unit
- High base heat transfer rates tested
- Model predictions fit test results to within 10%
- High nickel braze compounds

Channel Surface Features Smooth 1 2 3 Wavy

<table>
<thead>
<tr>
<th>Heat Transfer (kWt)</th>
<th>4,904</th>
<th>5,006</th>
<th>5,006</th>
<th>5,122</th>
<th>5,143</th>
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<tbody>
<tr>
<td>Hot Side Pressure Drop (Bar)</td>
<td>0.20</td>
<td>0.40</td>
<td>0.35</td>
<td>0.71</td>
<td>0.91</td>
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<tr>
<td>Cold Side Pressure Drop (Bar)</td>
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<td>0.66</td>
<td>0.58</td>
<td>1.17</td>
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<tr>
<td>Effectiveness (%)</td>
<td>89.8%</td>
<td>93.6%</td>
<td>93.6%</td>
<td>97.4%</td>
<td>96.1%</td>
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<tr>
<td>Cubic Meter/UA</td>
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<td>0.00152</td>
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<td>Kilograms/UA</td>
<td>28.0</td>
<td>22.3</td>
<td>22.3</td>
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</tbody>
</table>

Higher effectiveness with Case 3 will increase cycle efficiency

Conclusions and Plans
- HELC heat transfer performance better than smooth and wavy channel performance, used in PCHE heat exchangers
- Using high nickel braze, LAB-CB process can produce strong HELC component joints
- When components fully coated, corrosion resistance is as good as expensive high nickel alloys, at a much lower cost.
- Planning to optimize bonding and surface treatment material to minimize corrosion with lowest cost base material with the needed joint strength

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The 6th International Supercritical CO₂ Power Cycles • March 26-29, 2018 • Pittsburgh, PA, USA