High Effectiveness, Compact, High Pressure and Low Cost Super-Critical CO_2 Recuperator

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Supercritical CO_2 Power Cycles Symposium

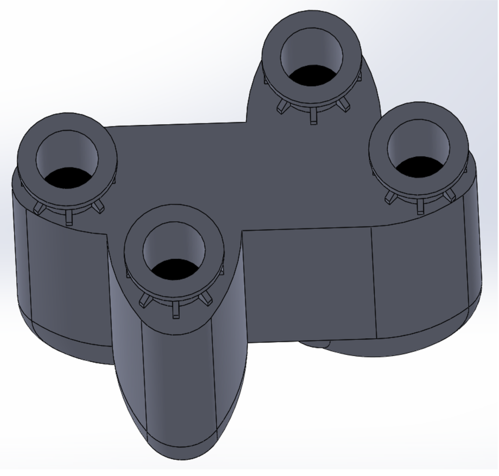
SwRI

Introduction

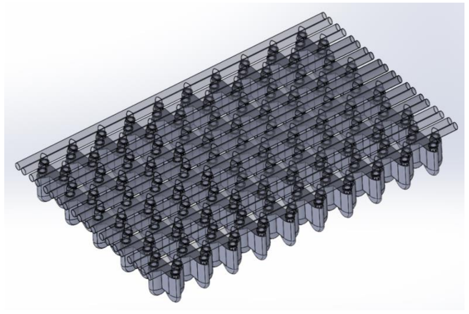
- 400 MWe RCBC plant requires 2,500 MWt of 200bar and 600C capable recuperative heat exchangers
- Minichannels with small hydraulic diameter (dh) and surface enhancements needed for compactness and low cost – Effectiveness (Ntu), and Ntu (L, dh)
- Many millions of channels of 1mm dh required
- Must connect 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



50 MW Module



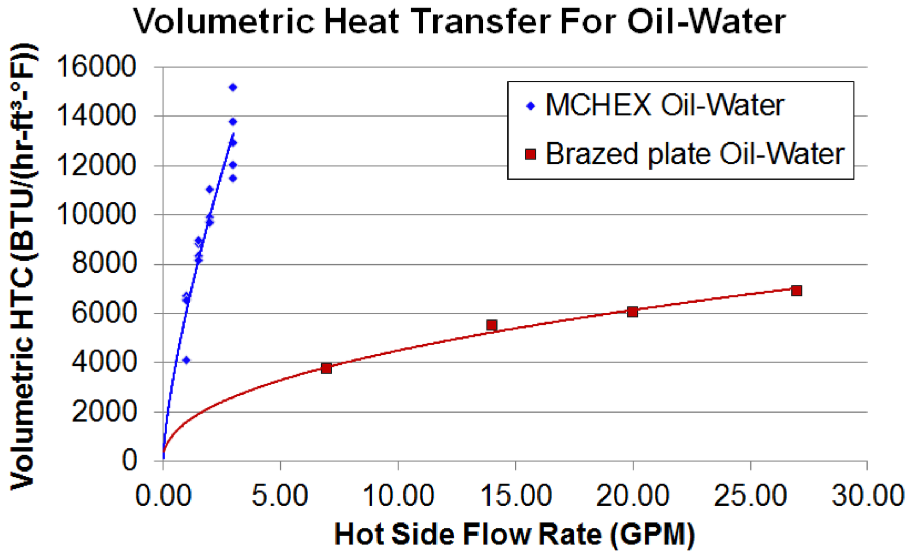
50 Module

- 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

Channel Surface Features	Smooth	1	2	3	Wavy
Heat Transfer (kWt)	4,804	5,006	5,006	5,212	5,143
Hot Side Pressure Drop (Bar)	0.20	0.40	0.35	0.71	0.91
Cold Side Pressure Drop (Bar)	0.34	0.66	0.58	1.17	1.51
Effectiveness (%)	89.8%	93.6%	93.6%	97.4%	96.1%
Cubic Meter/UA	0.00191	0.00152	0.00152	0.00107	0.00123
Kilograms/UA	28.0	22.3	22.3	15.6	18.1

Higher effectiveness with Case 3 will increase cycle efficiency

Results Summary

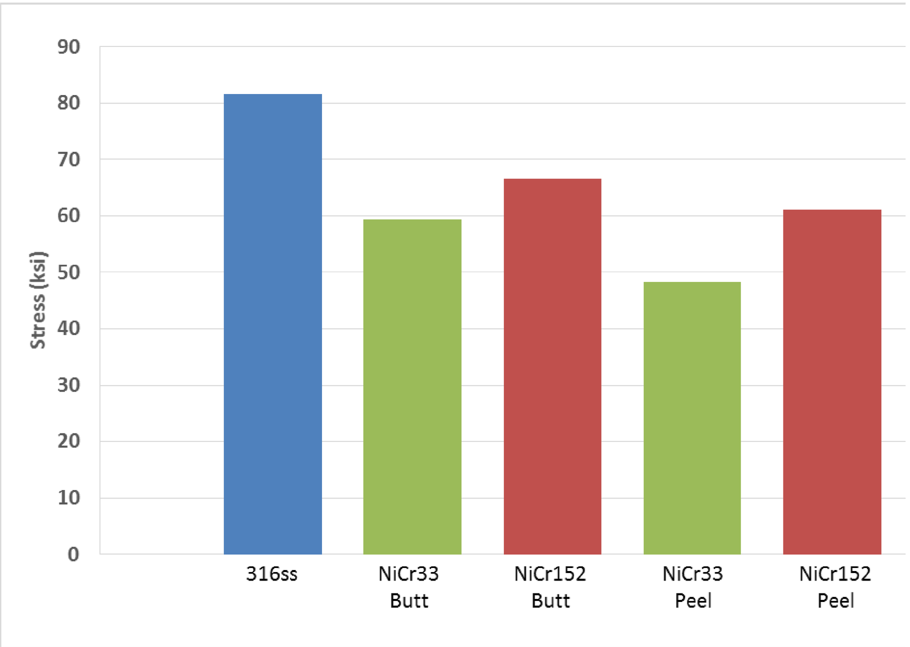


- Can design 316 SS unit to meet 200 bar pressure requirement
- Can use LAB bonding to build 200 bar capable unit
- High base heat transfer rates tested
- Model predictions fit test results to within 10%

- 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

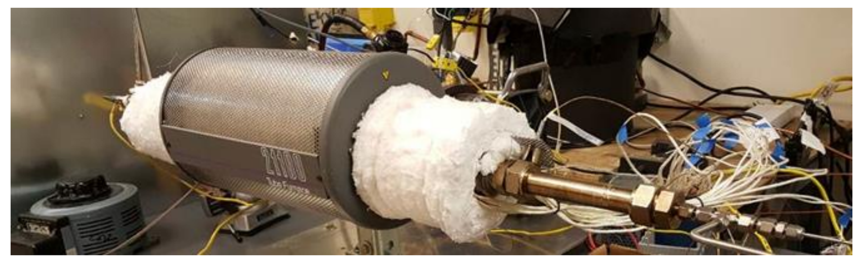
Alloy	Fe	Ni	Cr	Al	Mo	Mn	Si	W	Co	Ti	Nb	Ta	Hf	P	Trace Elements
Gr. 91	89.7	0.1	8.3		1	0.3	0.1								
HR230	1.5	60.5	22.6	0.3	1.4	0.5	0.4	12.3							
HR282	0.2	58	19.3	1.5	8.3	0.1	0.06		10.3	2.2					
IN740	1.9	48.2	23.4	0.8		0.3	0.5		20.2	2	2.1				
HR214	3.5	75.9	15.6	4.3		0.2	0.1								.02 Zr
CM247	0.07	59.5	8.5	5.7	0.7			9.9	9.8	1		3.1	1.4		
NiCr 31		71.5	22				6.5							4.5	
NiCr 33		64.5	29				6.5							6	
NiCr 152		66	30				4							6	
316SS	65.705	12	17		2.5	2	0.75							0.045	0.08 C, 0.03 S, 0.1 N

- 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



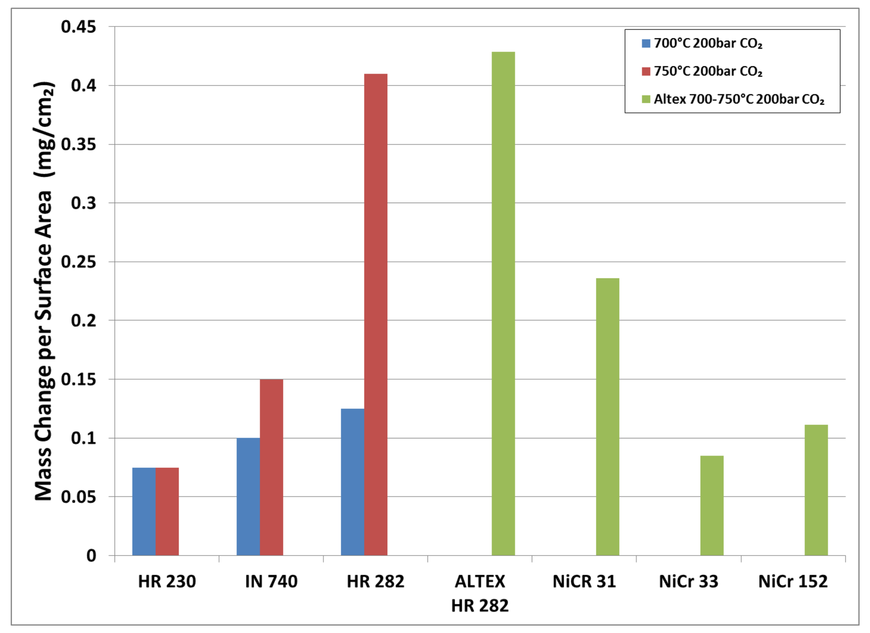
- Braze compound for joint bonding migrates upon melting
- Some areas still not completely covered
- Must fully coat parts ahead of braze furnace process for corrosion protection

Results Summary



- Corrosion test apparatus automatically operates at 200 bar and 750C, with gas flow
- Can simultaneously test 50 samples
- Uses industrial grade CO2, or research grade CO2, or mixtures of gases
- Standard material weight gain corrosion test results consistent with literature values

- 316 SS corrosion on the order of 10 mg/cm2
- High nickel alloys have orders of magnitude lower corrosion weight gains
- Altex LAB-CB process reduces 316 SS base material corrosion to that consistent with high nickel alloys, at low cost



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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