



VACUUM PROCESS ENGINEERING

Overview of the state-of-the-art heat exchanger development

Recuperators, Primary HXers, and Air Coolers

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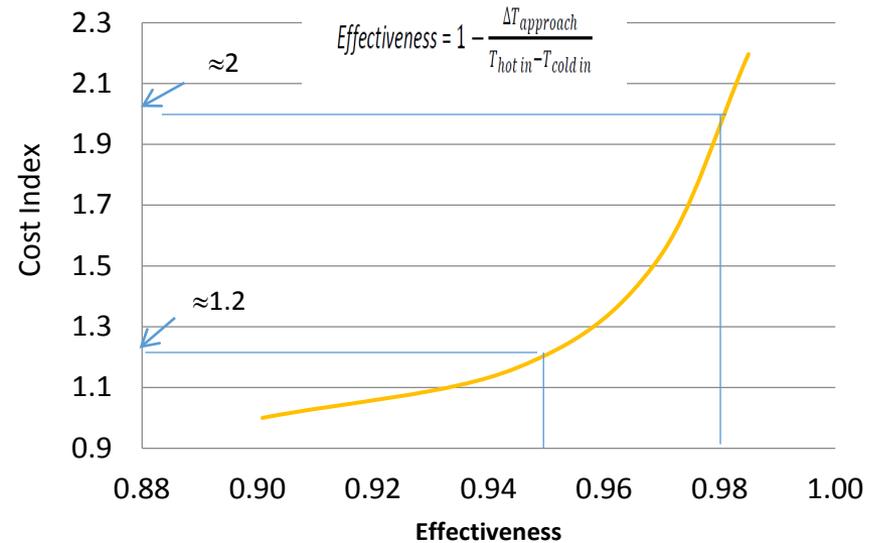
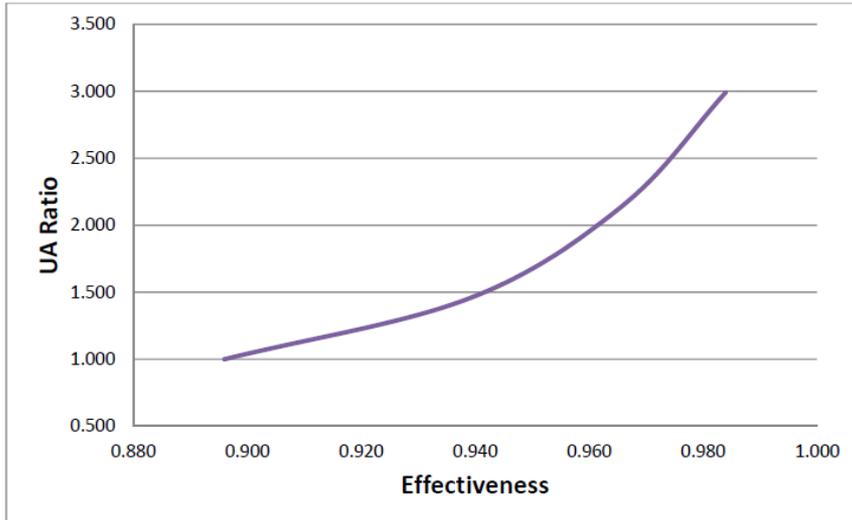
US Department of Energy sCO₂ Workshop 2019, NREL, Golden, Colorado

Overview of sCO₂ Power Cycle Development

- Despite their clear benefit of sCO₂ based cycles for CSP and other applications, and extensive study, their commercialization progress for use in large scale power generation is in its early stage.
- Relatively, there are better commercialization attempts in their use for waste heat recovery applications.
- Challenges contributing to their lack of industrial integration include:
 - Capital cost of components including heat exchangers (primary and recuperators)
 - Limited experience in long term operating dynamics.
 - Lack of long term material characteristics in terms of corrosion.
 - Limited mechanical performance related knowledge including high temperature creep and fatigue interactions.

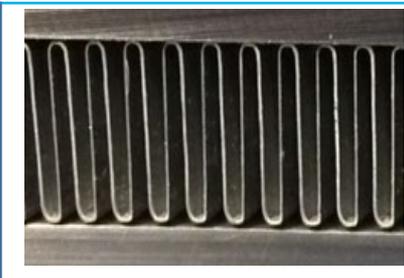
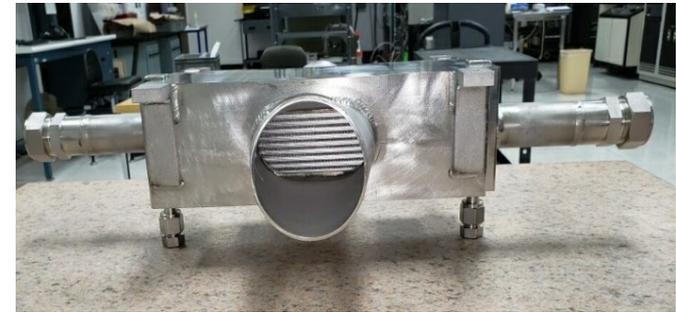
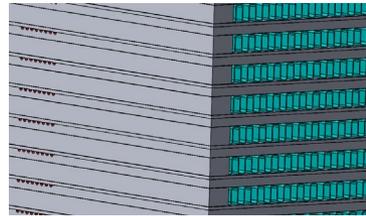
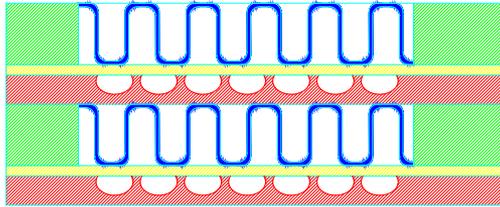
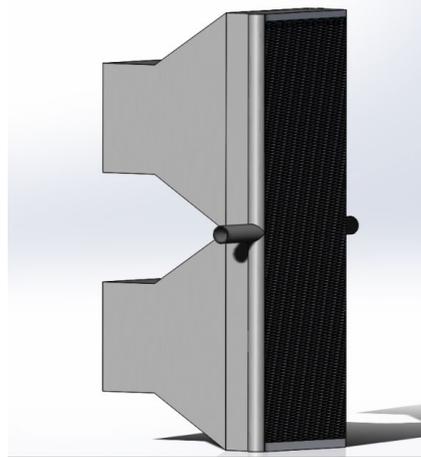
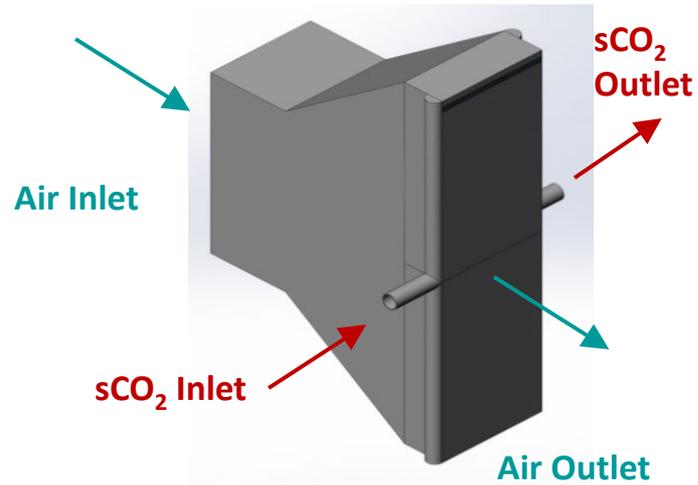
Exchangers cost influenced by effectiveness

⊕ The size and cost of these heat exchangers are tightly linked to the design and process conditions –e.g. exponentially related to the required effectiveness.

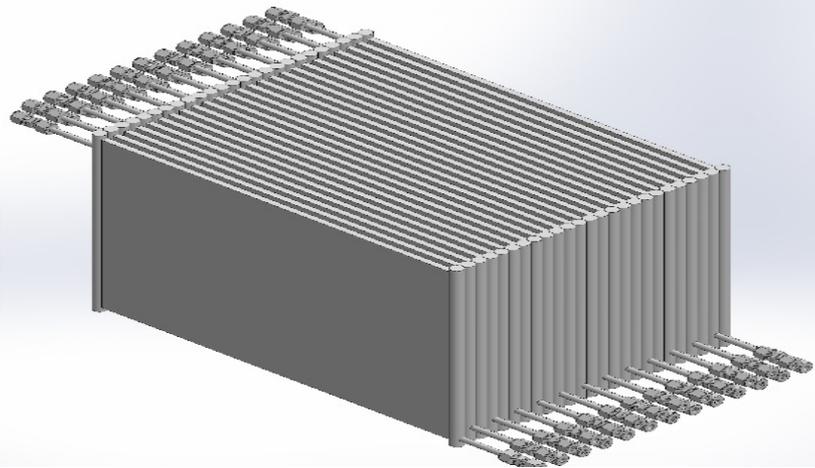


- Cost of exchanger is also dependent pressure drop, and mechanical design conditions.
- Due to economies of scale the higher the duty the lower the cost per duty

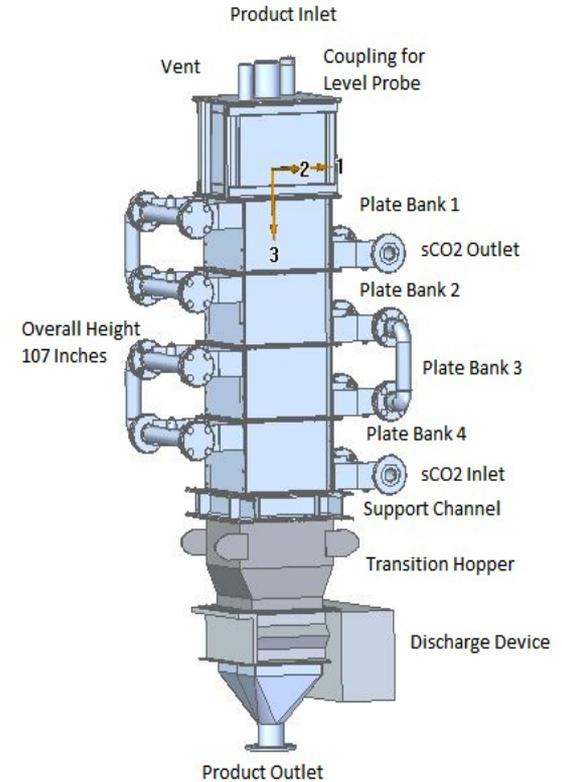
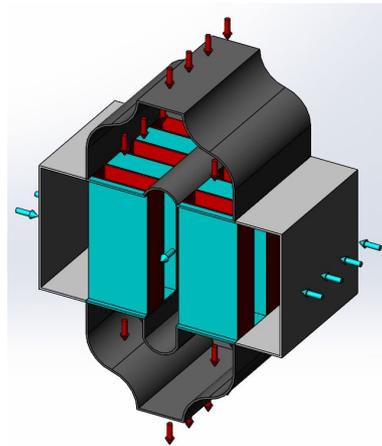
Cheaper, compact high performing dry coolers – CSP enablers



Primary Heat Exchangers, particle / CO2



Can be improved to avoid multiple header welds, optimize solid side heat transfer and variable flow gaps, using combination of brazing and diffusion bonding of integral headers



Shell-and-Plate Moving Packed Bed HX Design (Solex and VPE)

Primary Heat Exchangers, Molten salt / sCO₂

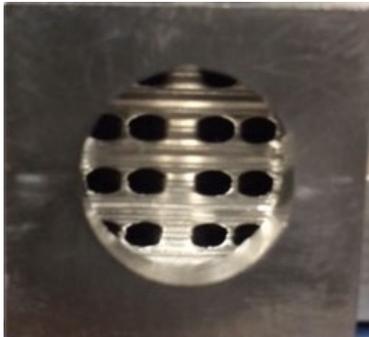


VPE provided compact heat exchangers for molten salt/CO₂ application under IRP program.

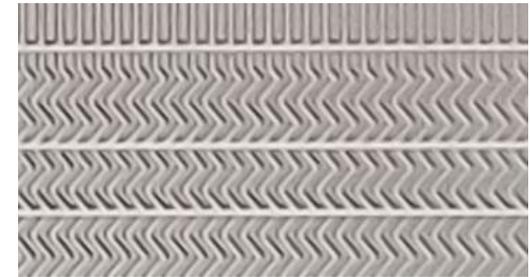
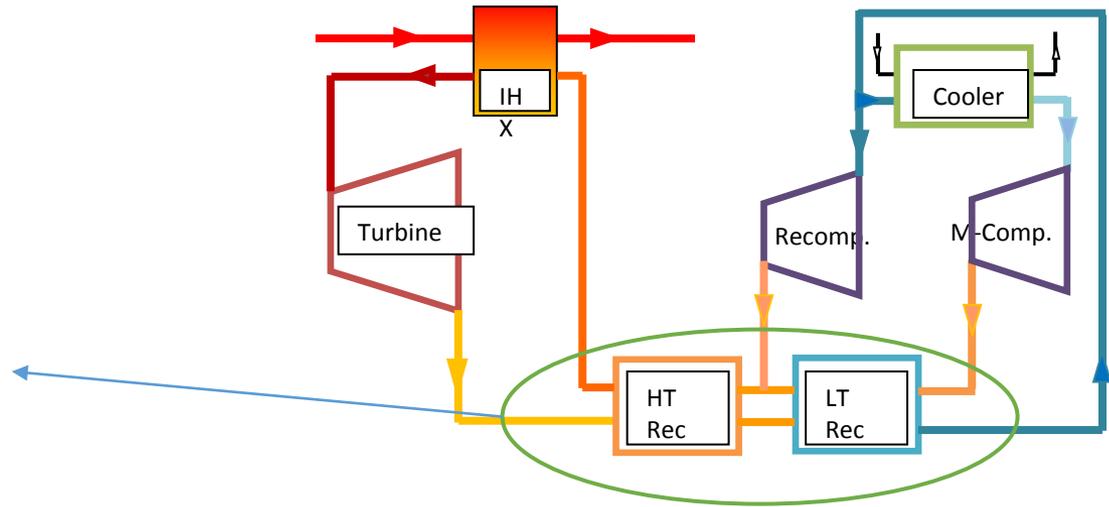
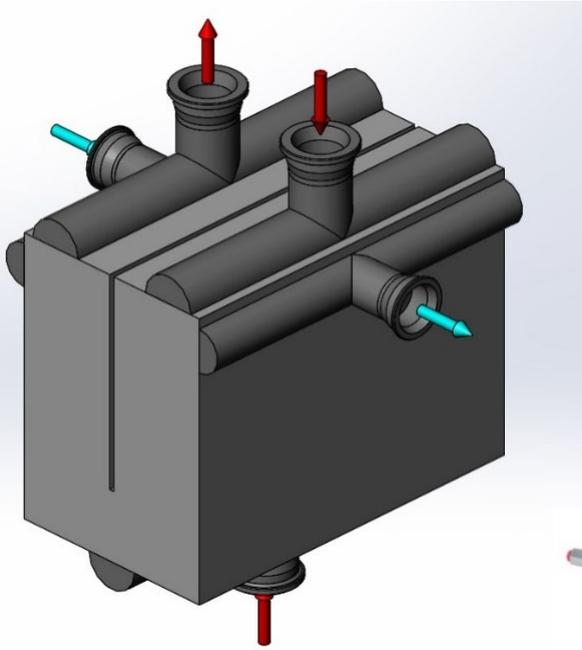
High temperature Alloy 800H units build and tested to run FliNaK (alkaline metal fluoride salt), at high temperature

Moderate HT SS 316 heat exchangers also built and tested using 0.6NaNO₃-0.4KNO₃ salt.

Flow channel size can be increased by facing typical PCHE channels each other – a cost effective approach than deep etching to create larger channel



Path for large recuperators...



Heat exchanger network multi-stream integration to save header cost and reduce pressure loss- ideal for modular power generation.

Cost is optimized using innovative channel layout that utilize pure multi-pass, counter flow.

Superior design freedom with fluid flow path topologies nearly unlimited. Enhancement combining zig-zag with hard-ways / lanced

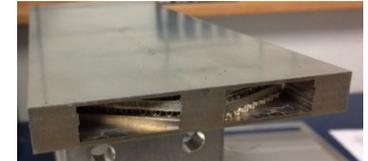
....path for large recuperators



**World's Largest Vacuum Hot Press
Diffusion Bonding Furnace**

- With the use of the largest furnace, we see possibility of integrating the high and low temperature recuperators into single core as well as reducing the number of parallel connected heat exchanger cores.
- The impact is not only in reducing cost but also minimizing piping pressure losses that influence the overall plant efficiency.

VPE provides small low cost off-the-shelf PCHEs for the research community



Summary

- ⊕ We still see diffusion bonded plate technology being key to meeting mechanical and operating life challenges of exchangers for sCO₂ based CSP power plants.
- ⊕ And the understanding of their long term operation both in material compatibility and mechanical performance including transient ramp up rates, fatigue and long terms creep behavior requires further test.
- ⊕ There will be a need to scaling up power blocks to a large multi-mega watt range - requiring even large size, multiple and parallel recuperators.
- ⊕ Industrial investment and funding support continue to be valuable to address the various technological challenges.
- ⊕ VPE is committed to further develop heat exchanger technology in the effort to provide a low cost and high effectiveness exchangers that benefits cycle viability.



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