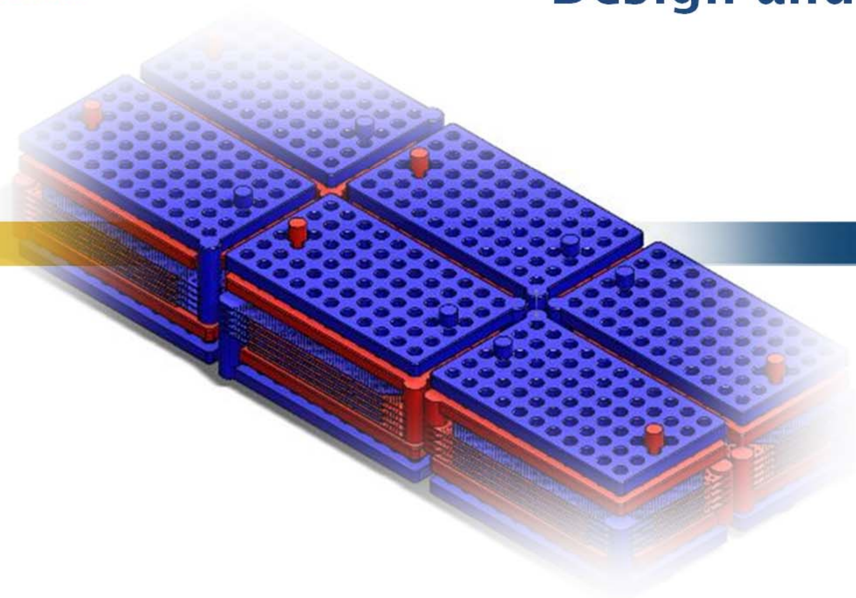
Supercritical CO_2 Power Cycles Symposium

Design and Performance Characterization of a Micro-pin-fin sCO_2 Recuperator



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sCO_2 Symposium, Pittsburg

Thursday, 03/29/2018

Sponsor: grant # DE-FE0024064

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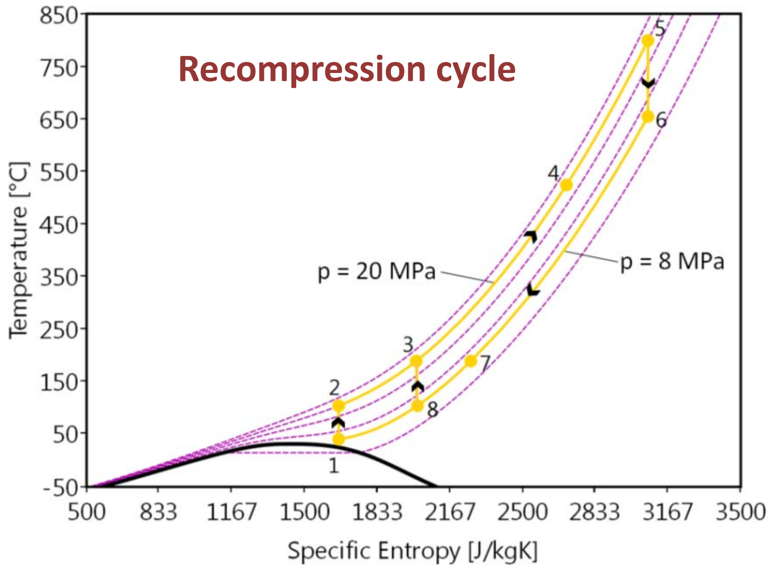
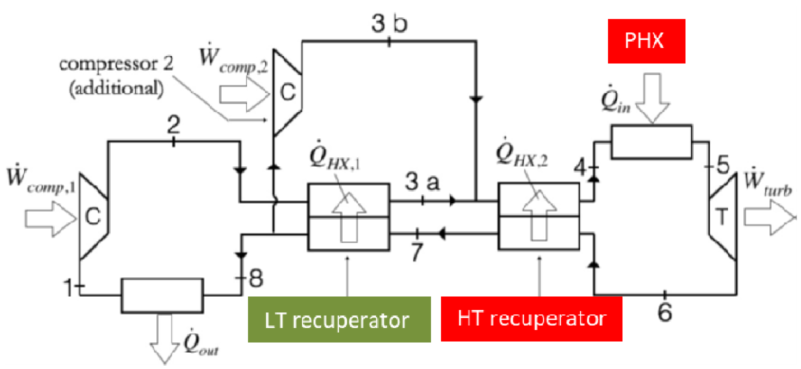
μTEEL Microscale Thermal Energy Enhancement Laboratory

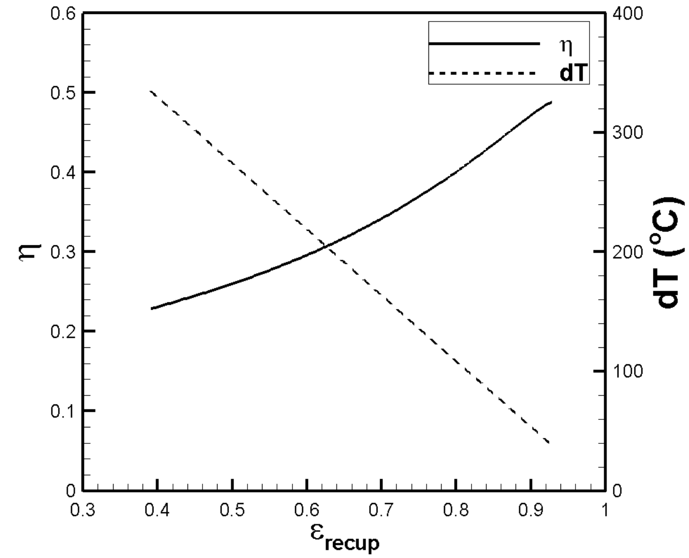
U.S. DEPARTMENT OF ENERGY

NETL

Background- sCO_2 cycle

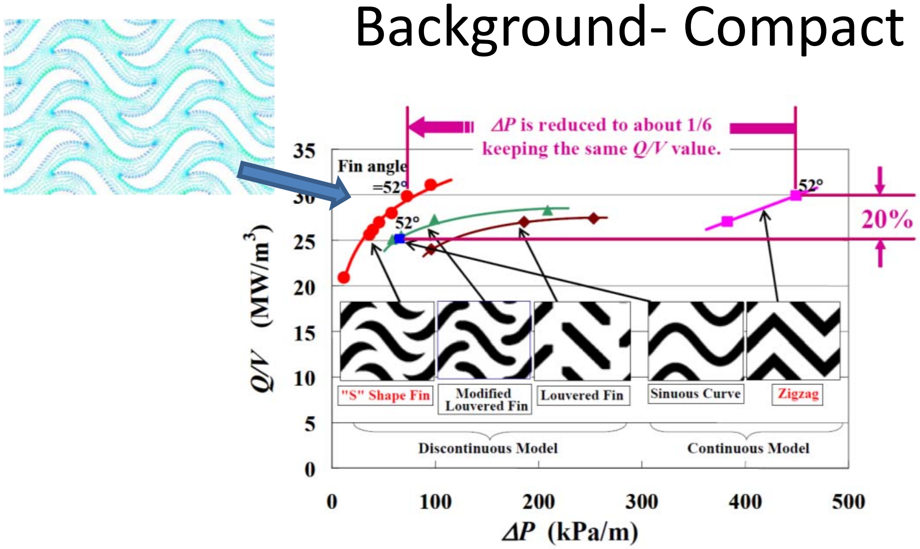




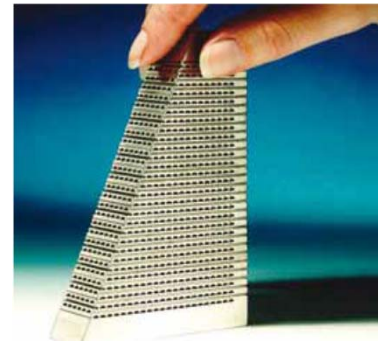


- High cycle efficiency achieved only through heat recuperation
- Currently >20% of system cost is attributed to recuperators
- Design constraints/ challenges
  - High temperatures on the hot side (500 -600 C)
  - High pressures (>200 bar)
  - High differential pressures
  - Corrosion
  - Low approach temperatures between fluid streams

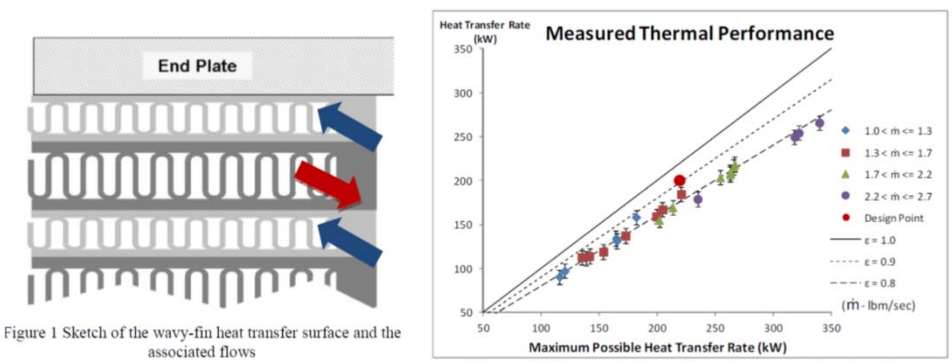
Background- Compact recuperators



Y. Kato, MCHE Institute, 2011 sCO2 symposium

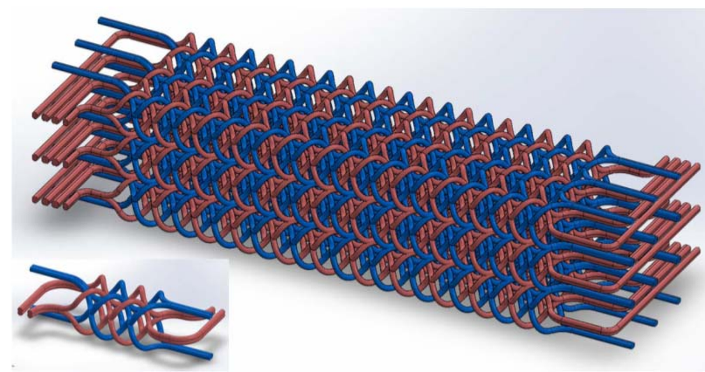


PCHE core (Heatric; accessed 03/2018)



200 kW; Folded wavy fin result- unit cell design

Fourspring et al. (2014)- Bechtel Marine and Brayton Energy



Cast metal heat exchangers (Sandia, Carlson et al. 2014)

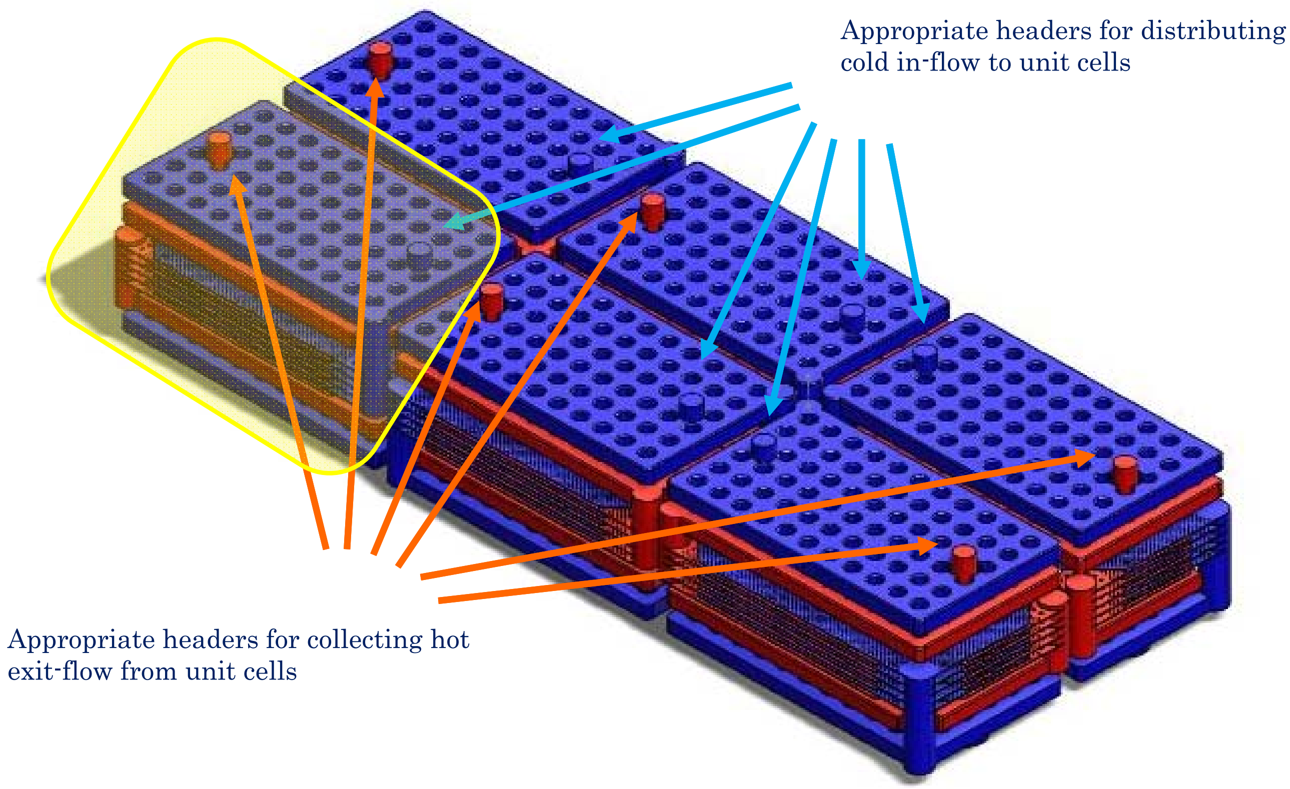
Goal

Design a HX with enhanced heat transfer rate and lower pressure drop by

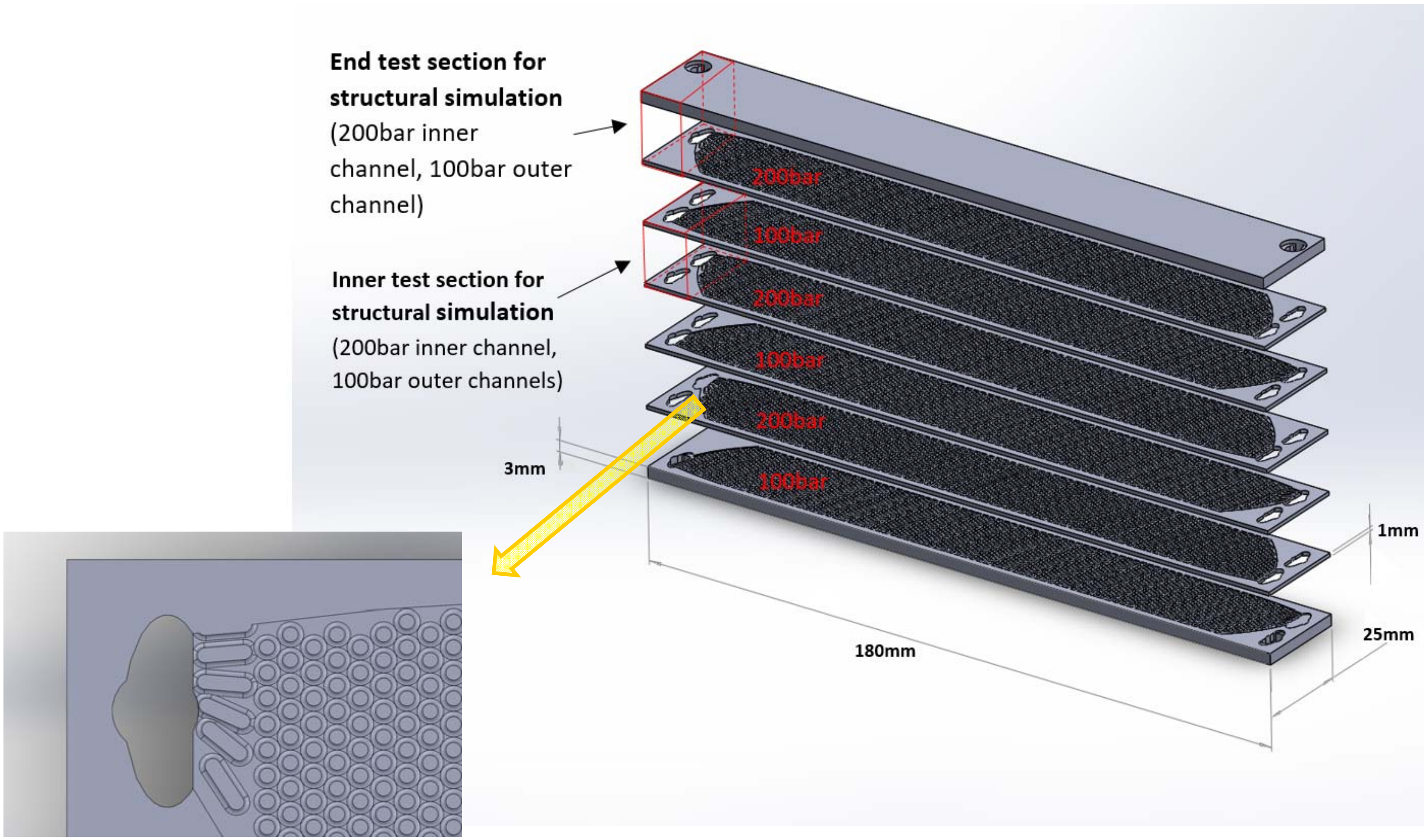
- Decreasing residence time by use of microscale passages
- Reducing pressure drop by parallelization of heat transfer paths

Approach

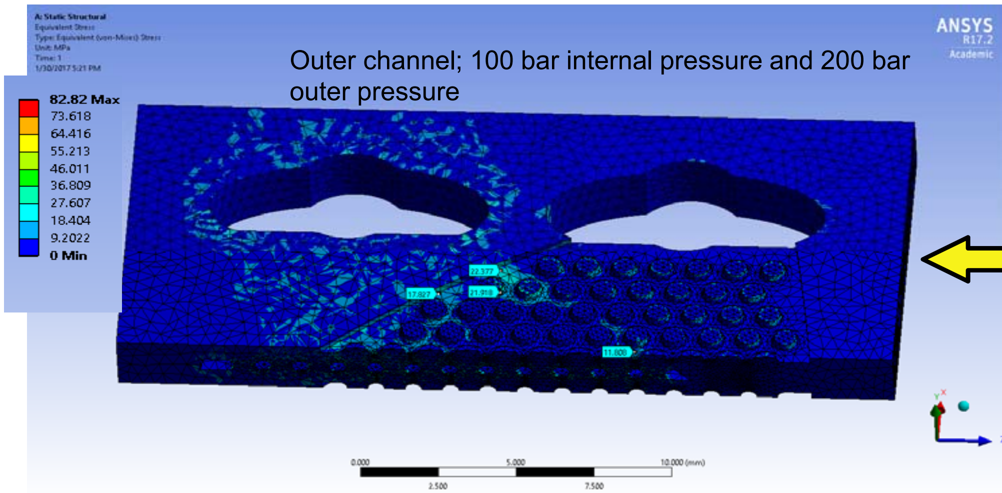
- Number of recuperator unit cells connected by headers



Unit cell design

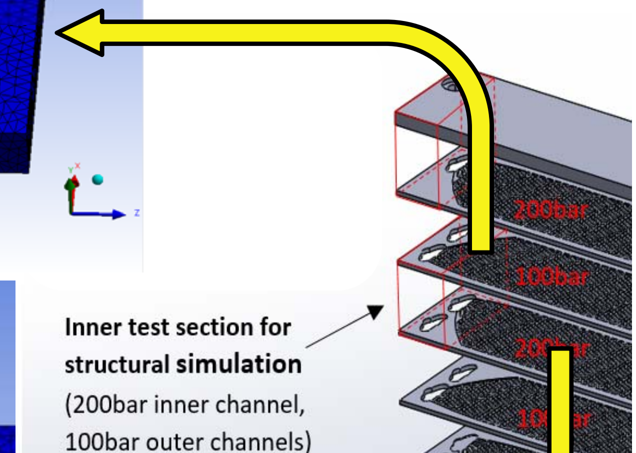


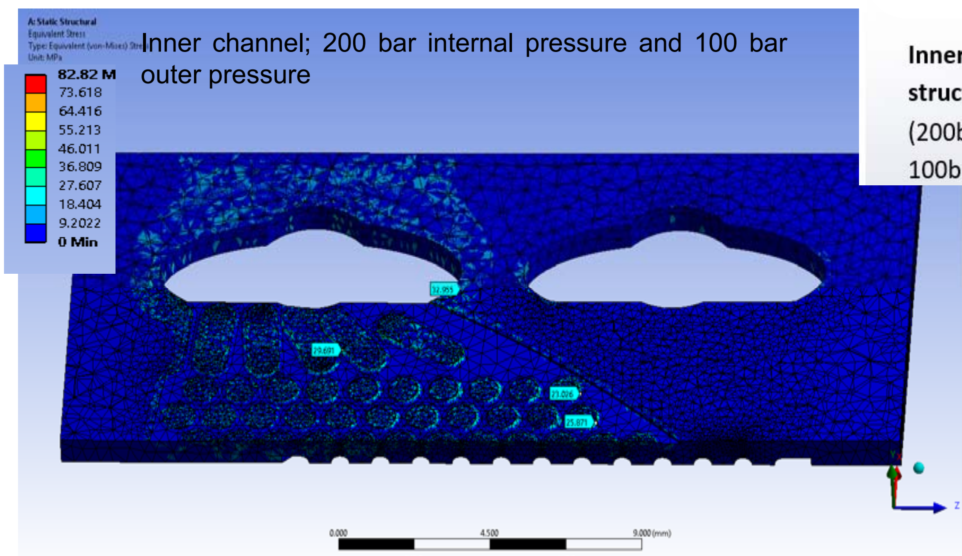
Unit cell design- Structural



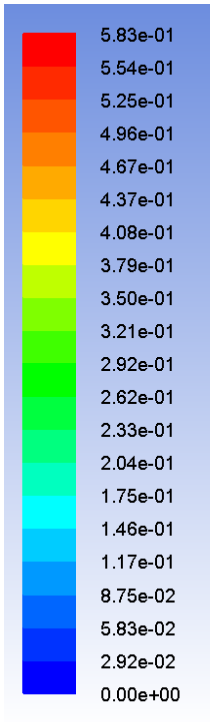
Stainless Steel 316 yield strength ~200MPa at 400˚C.

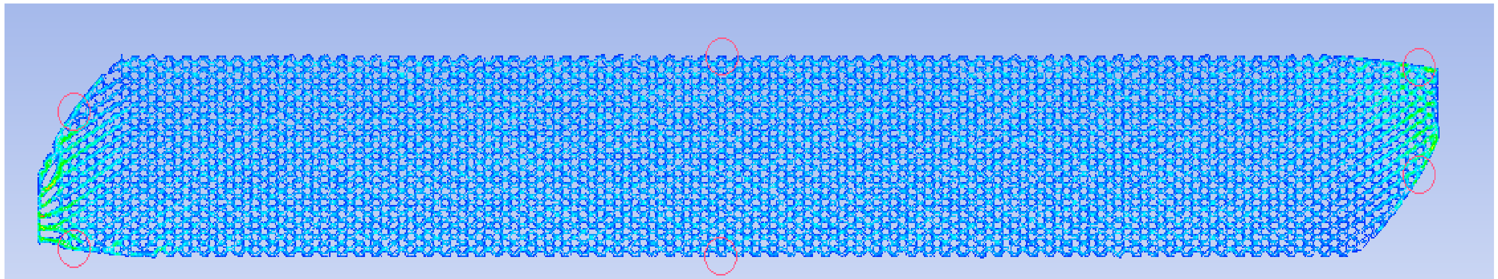
Simulation max stress:
83MPa for the inner sections
129MPa for the end sections



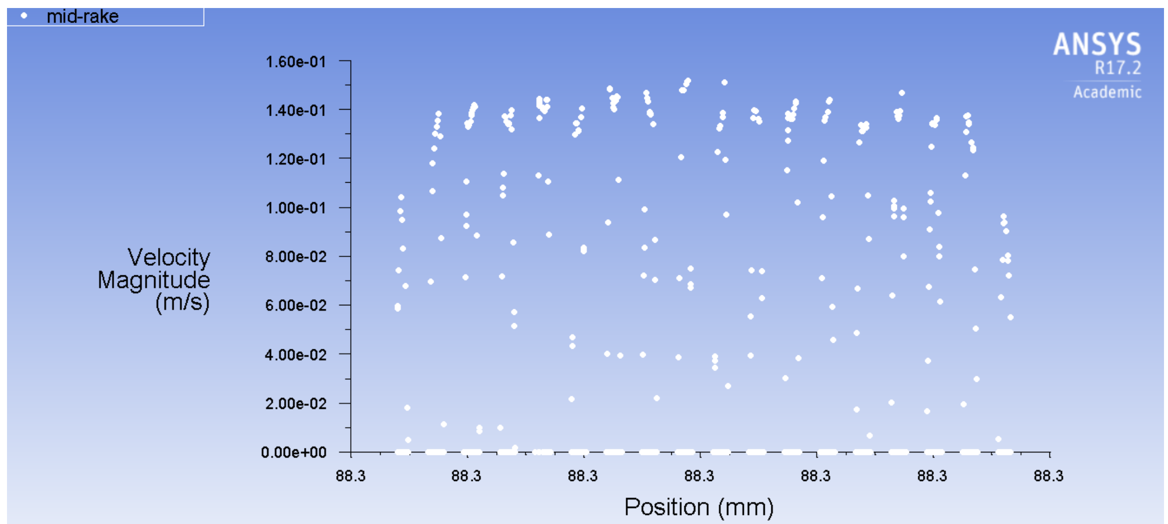


Unit cell design- flow distribution



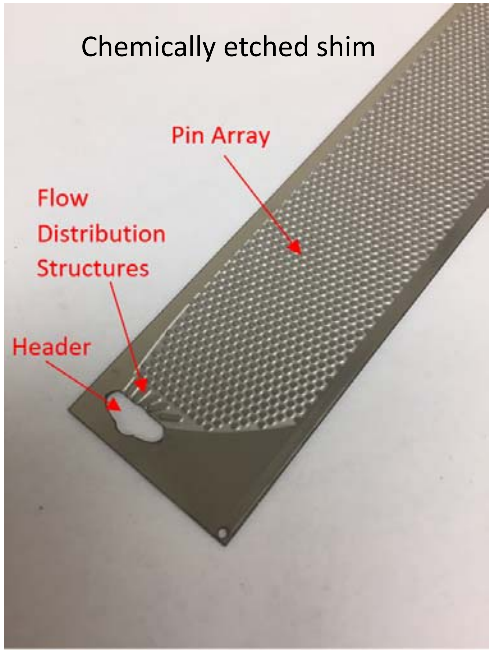


Inlet condition: uniform velocity of ~0.126 m/s
Outlet: pressure outlet

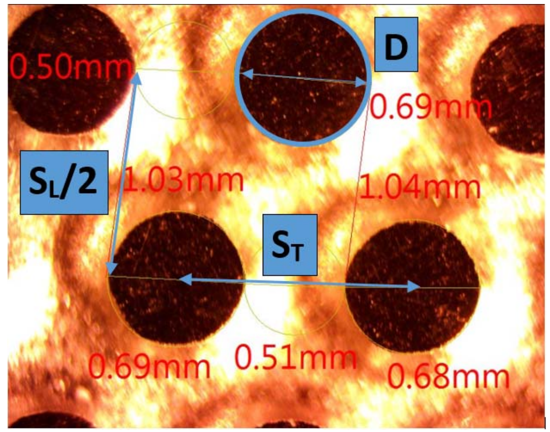


peak velocities fairly uniform across the span
at ~ 0.14 m/s with variation of ~0.01 m/s.

Fabrication

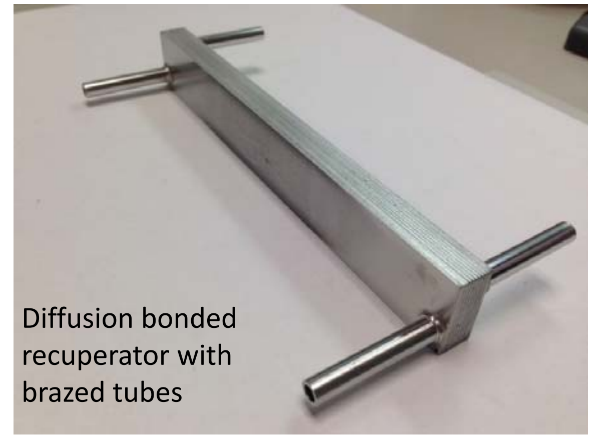


Etching by Great Lakes Engineering
Bonding & brazing by Vacuum Process Engineering

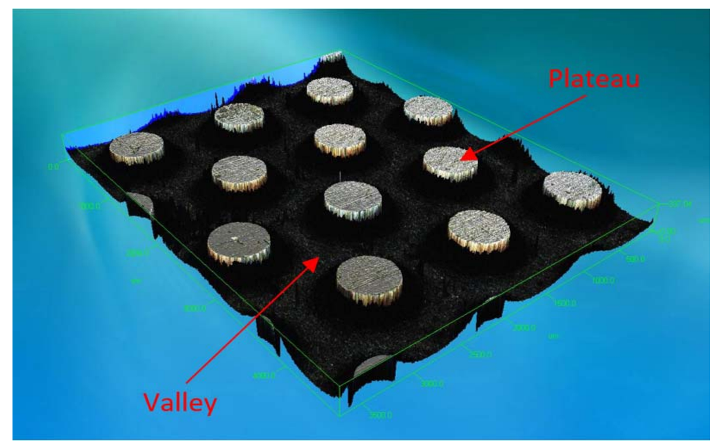


Olympus BX60 microscope image

Global average		Nominal	
Diameter	682 ± 3	Diameter	700
S_T	1186 ± 3	S_T	1200
S_L	2108 ± 23	S_L	2080

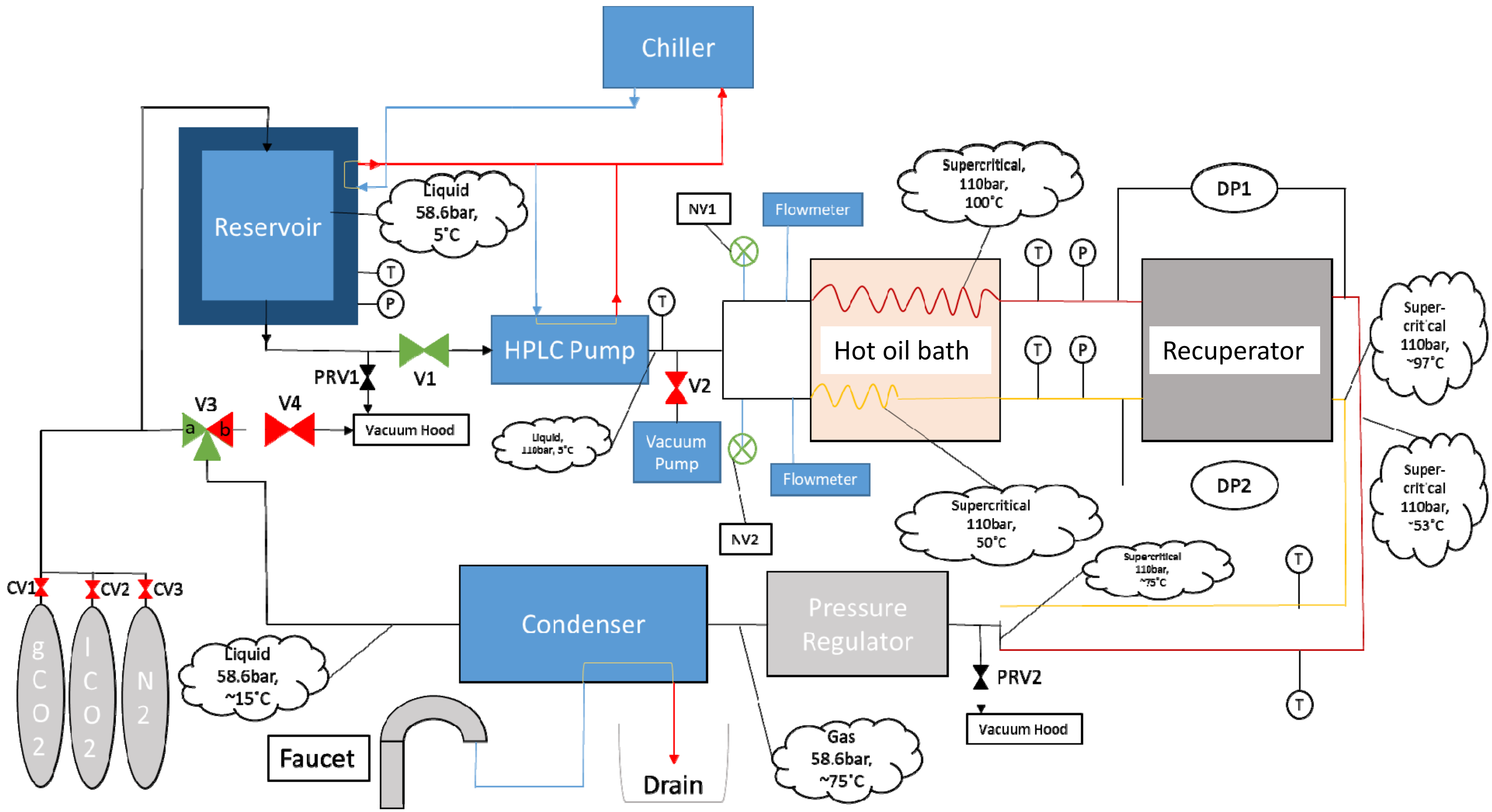


Zeiss CSM 700 confocal microscope image

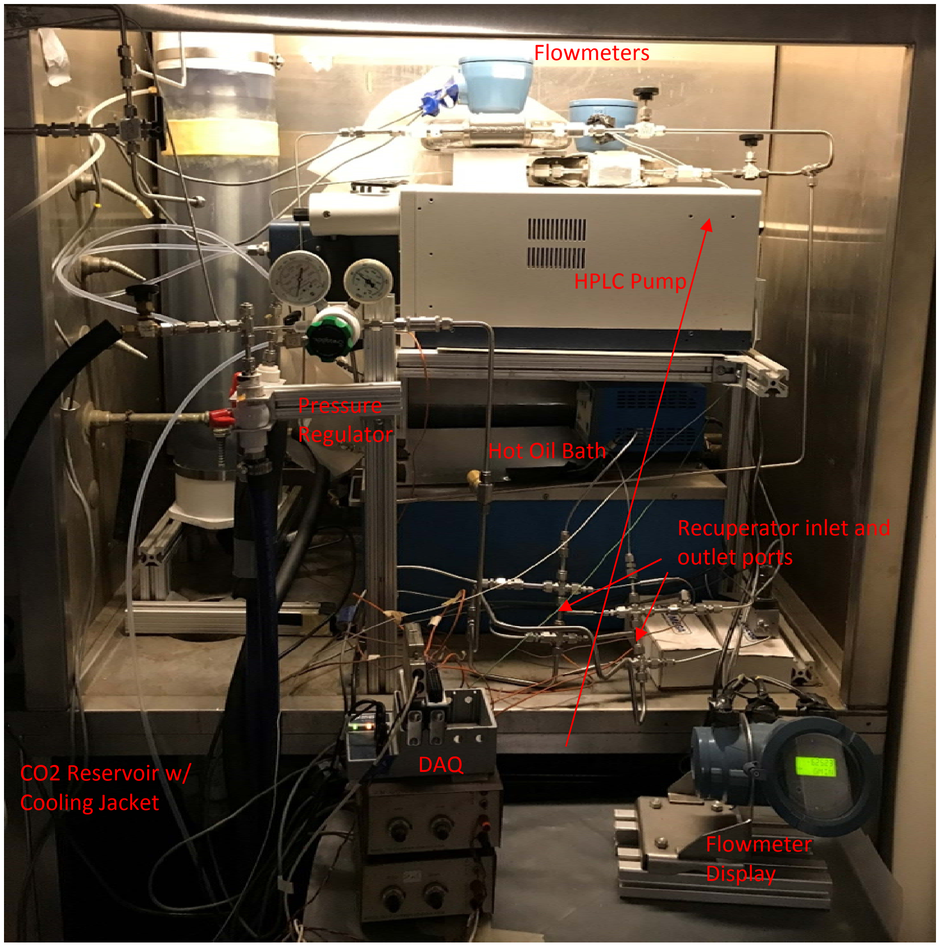


	Shim Region 1	Shim Region 2	Shim Region 3
Average Plateau Height [µm]	432.9 ± 3.9	332.0 ± 5.0	332.6 ± 4.6
Average Valley Depth [µm]	179.7 ± 0.0	81.9 ± 4.5	86.0 ± 2.6
Average Pin Depths [µm]	253 ± 3.9	250 ± 6.7	247 ± 5.3
Total Average Pin Depth [µm]	**250.0 ± 5.3**		
Nominal Pin Depth	**250**		

Experimental Facility

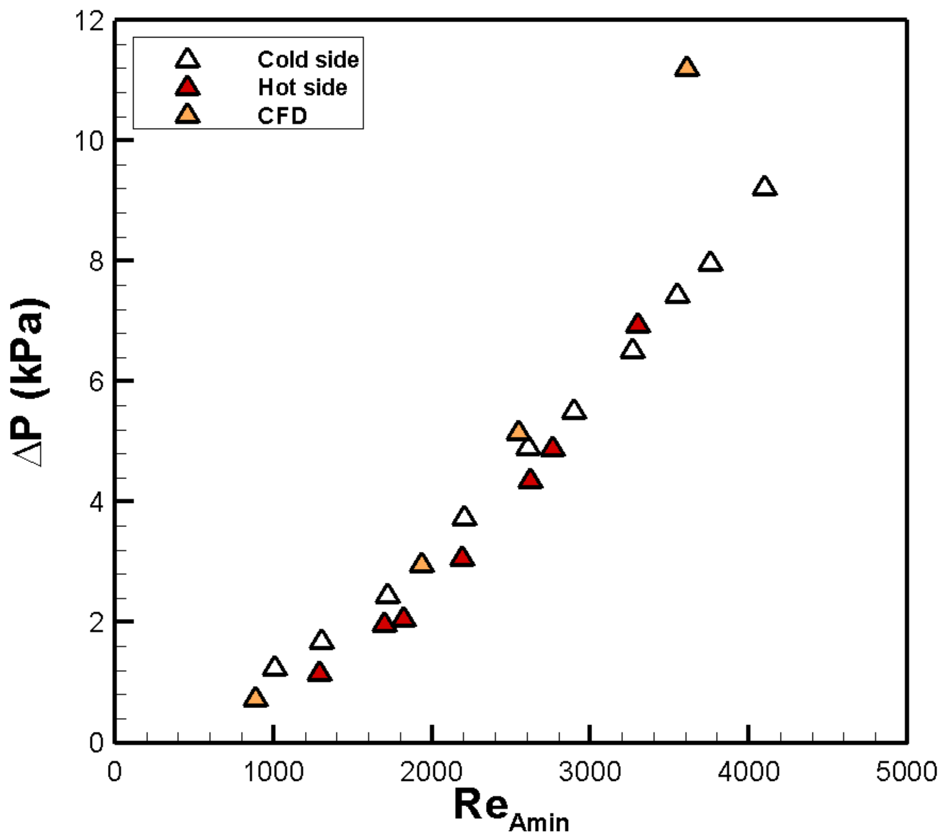


Experimental Facility

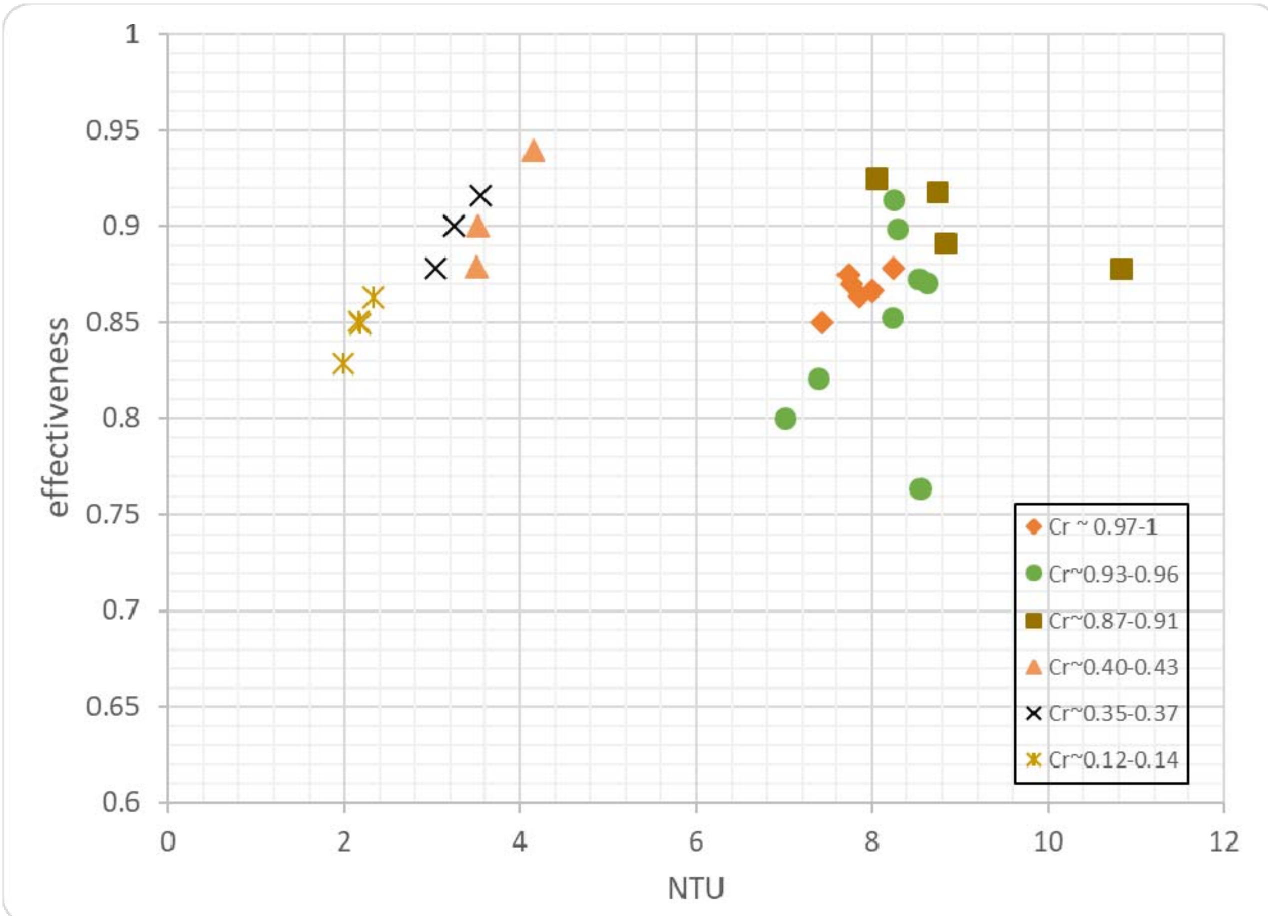


Measured variable/instrument	Uncertainty
Micro Motion Mass Flow Meters	0.1% of flow rate
Reservoir Temperature	0.025˚C
Pump Outlet Temperature	0.027˚C
Hot Inlet Temperature	0.023˚C
Cold Inlet Temperature	0.026˚C
Hot Outlet Temperature	0.030˚C
Cold Outlet Temperature	0.024˚C
HPLC Pump Outlet Pressure	N/A
Low range Differential Pressure Transducer	0.03 kPa
Mid range Differential Pressure Transducer	0.04 kPa
High range Differential Pressure Transducer	0.05 kPa
Overall heat transfer coefficient U	1.3%
Effectiveness, ε	0.15%
Number of Transfer Units, NTU	1.2%

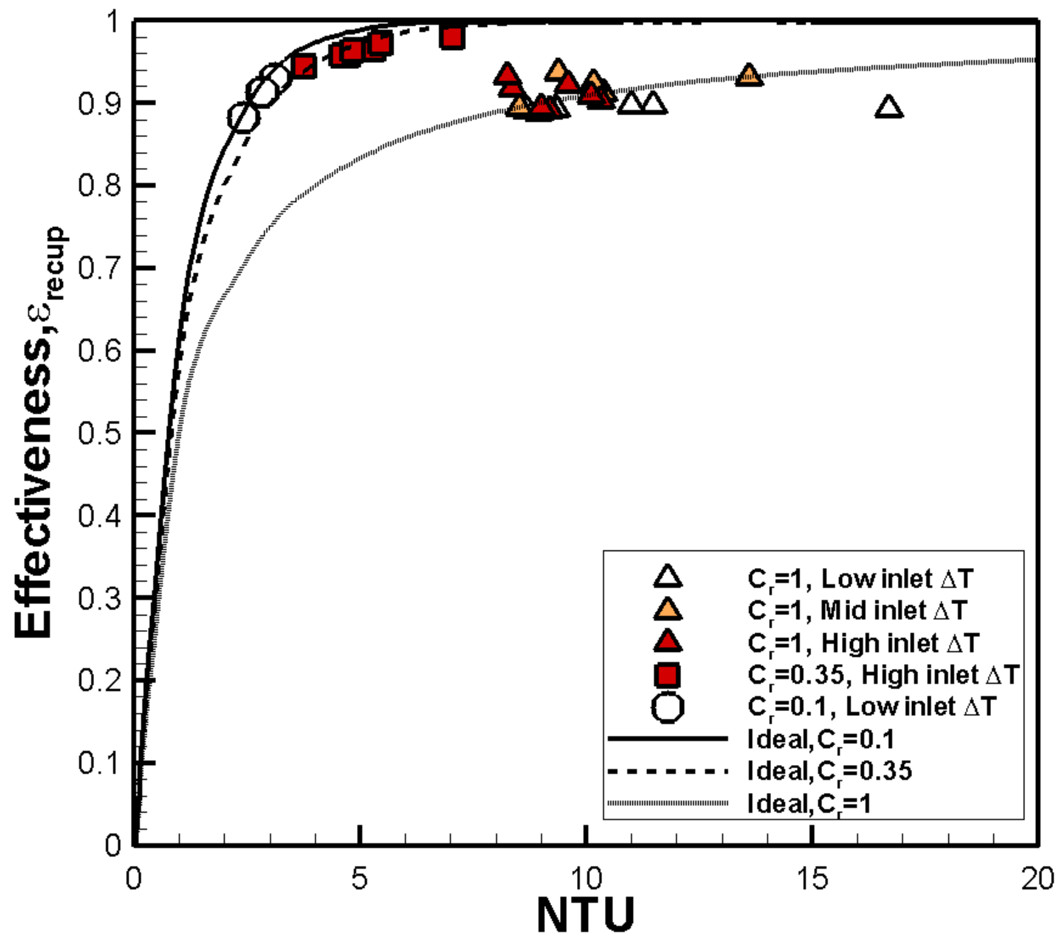
Pressure Drop results



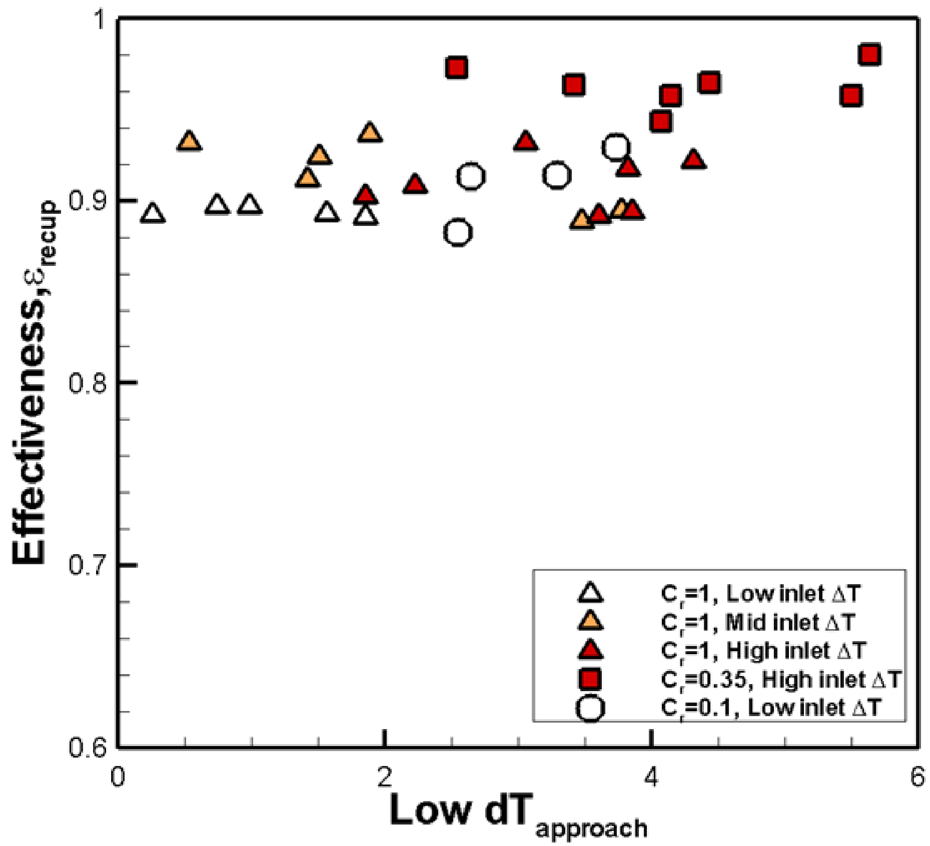
Heat Transfer Results- effectiveness-NTU



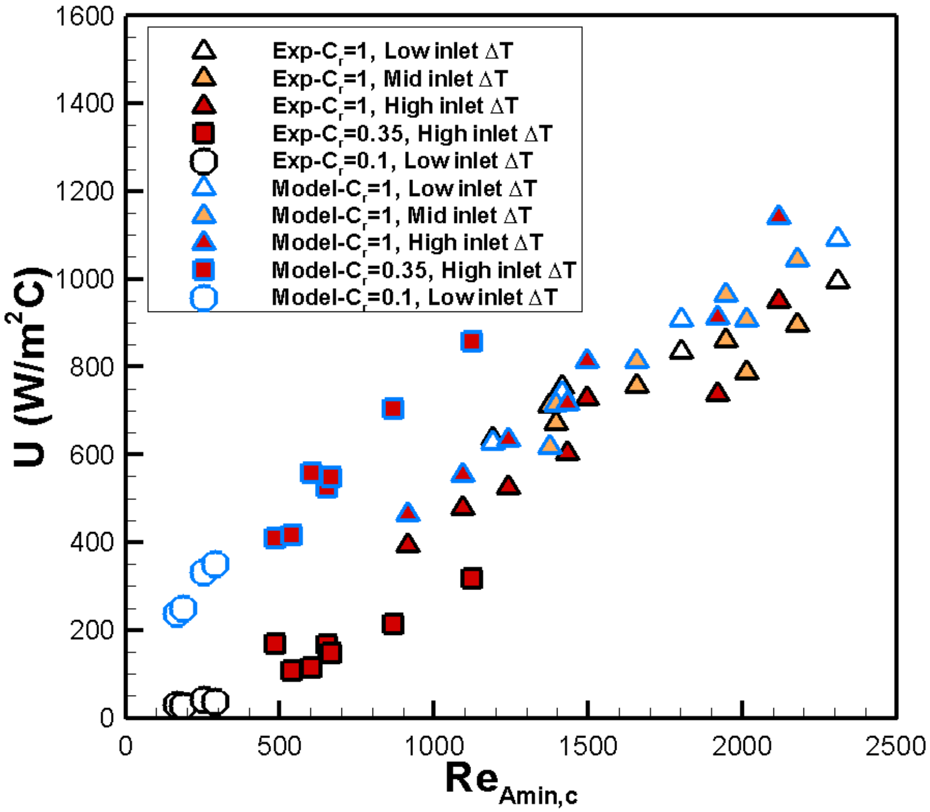
Heat Transfer Results- corrected effectiveness-NTU



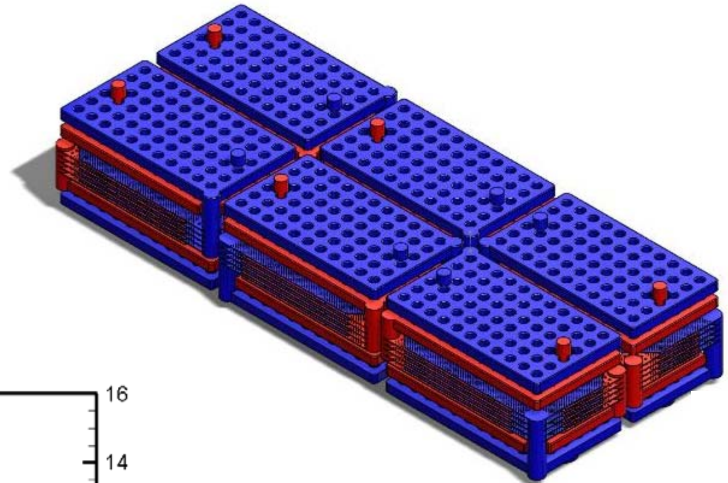
Heat Transfer Results



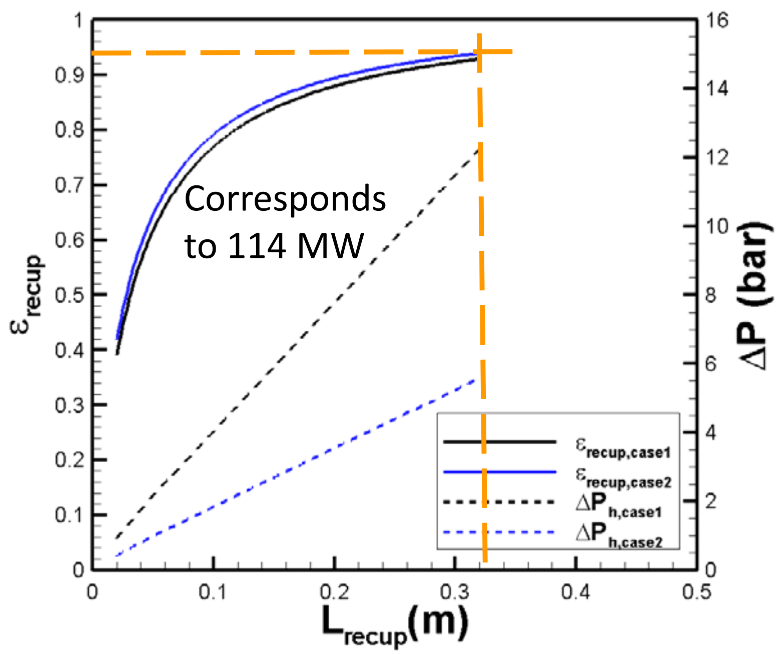
Heat Transfer Results



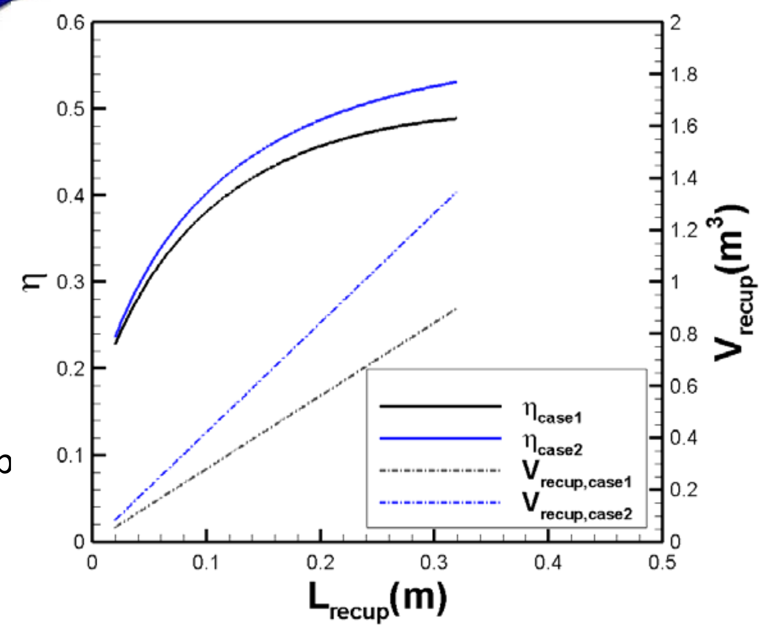
Example of scaling up for higher rating- preliminary estimate



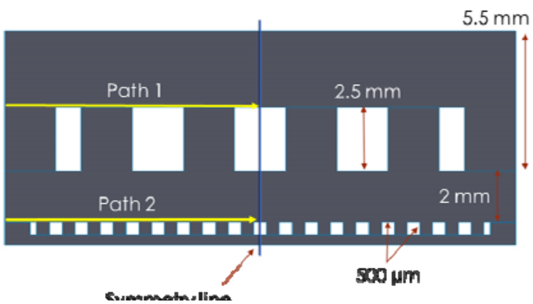
Fixed:
sCO_2 mass flow rate
Microchannel unit cell geometry
$T_{in, turbine}$ = 800 C
$T_{in, comp}$ = 40 C
m_{dot}=200kg/s

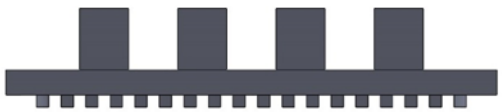


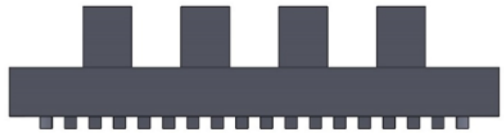
Higher efficiency can be obtained by increasing size and decreasing pressure drop
Case 2 has 1.5 times the number of unit cells as in Case 1

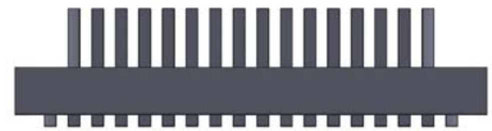


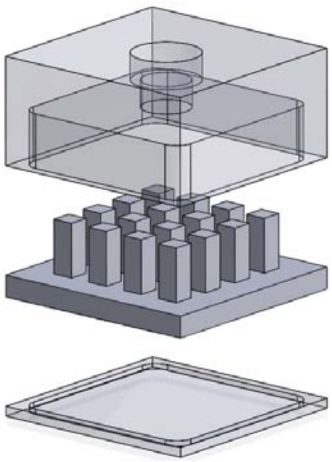
Diffusion Bonding of Headers to Micro-pin fin regions

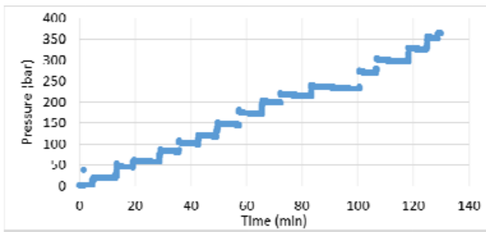


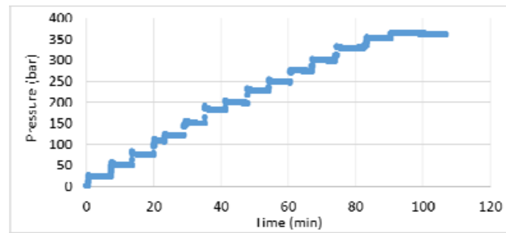


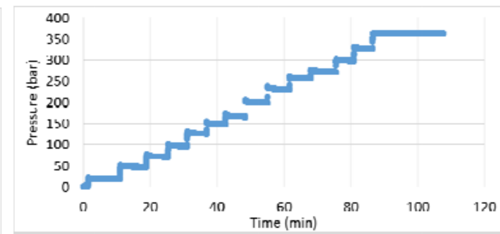


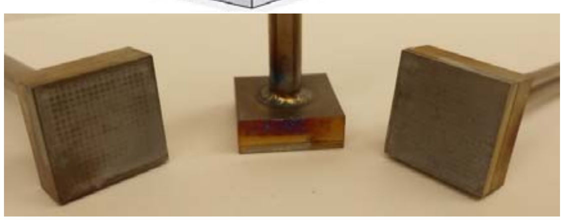


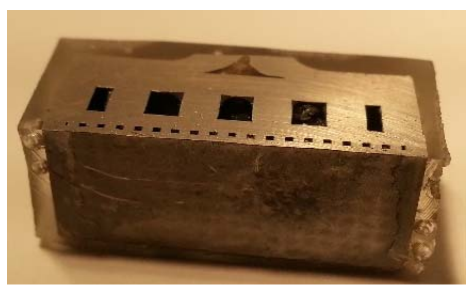


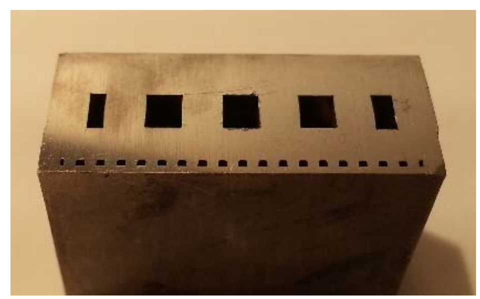


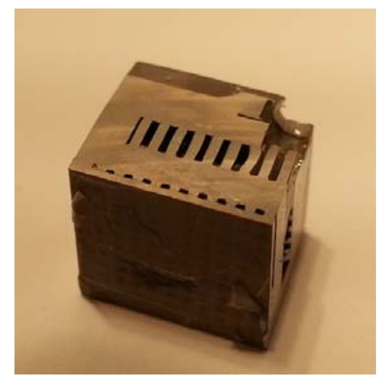












Conclusions

- High effectiveness recuperators are key for cycle efficiency
- Microchannel recuperator designed for scO_2 applications
- Unit cell performance characterized
- Preliminary diffusion bonding studies indicate that it is possible to bond headers and micro pin fin plates in a single step

QUESTIONS?

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Heat loss area vs heat transfer area