Supercritical CO_2 Power Cycles Symposium

University Panel
Additive Manufacturing of sCO_2 Heat Exchangers-Opportunities and Challenges

Vinod Narayanan, Professor, University of California, Davis

Contributors:

Anthony Rollett, Professor, Carnegie Mellon University

Erfan Rasouli, Post-Doctoral Scholar, UC Davis

Samikshya Subedi, Graduate Student, CMU

Colt Montgomery, Graduate Student, CMU

Acknowledgements:

U.S. DEPARTMENT OF ENERGY NETL

grant # DE-FE0024064

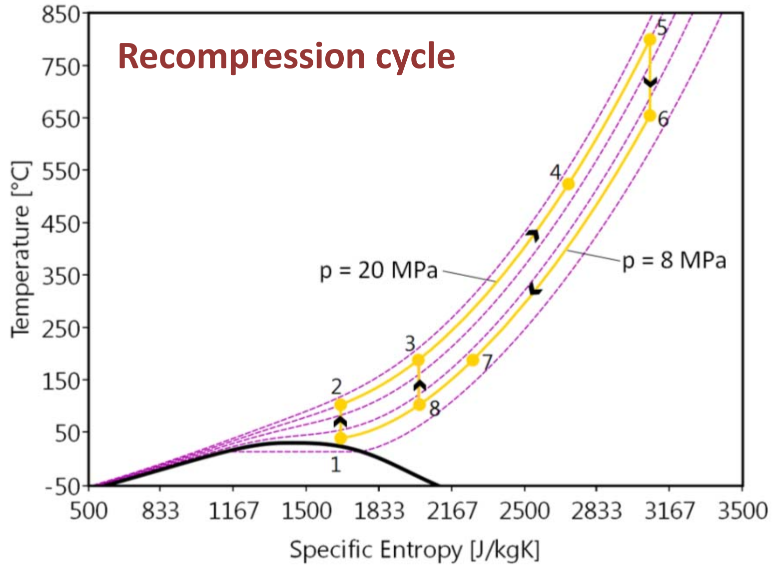
Office of Naval Research ONR Science & Technology

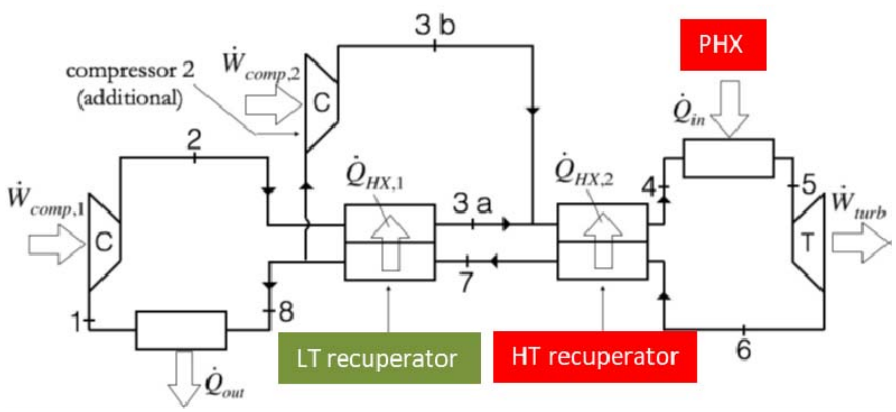
grant # N00014-16-1-2027

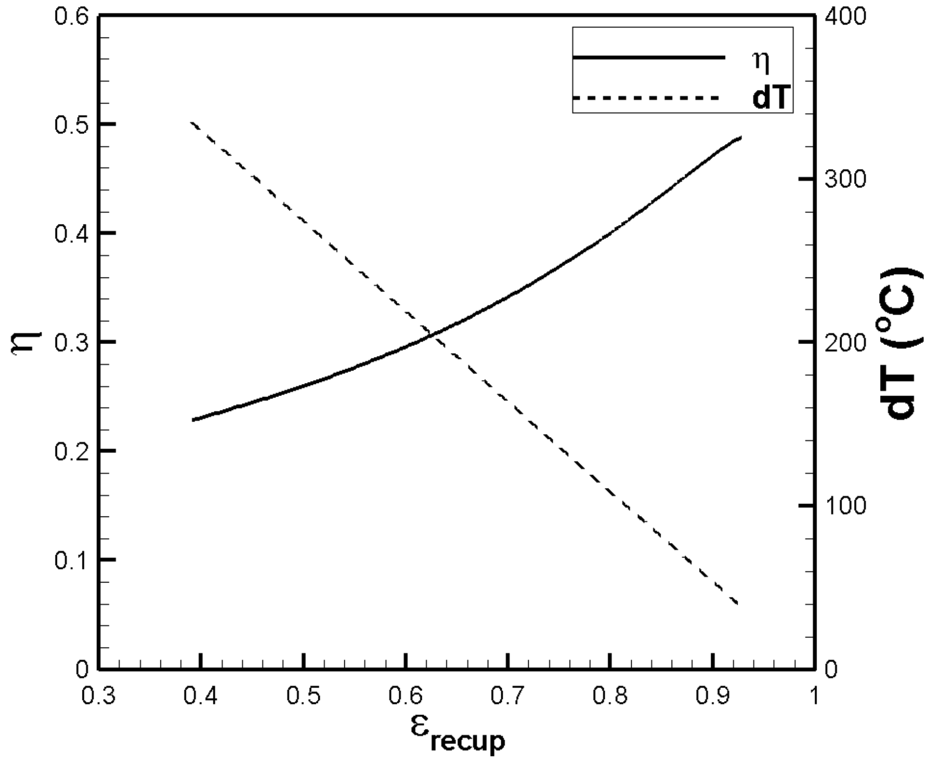
UC DAVIS UNIVERSITY OF CALIFORNIA

μTEEL Microscale Thermal Energy Enhancement Laboratory

Background- sCO_2 indirect cycle



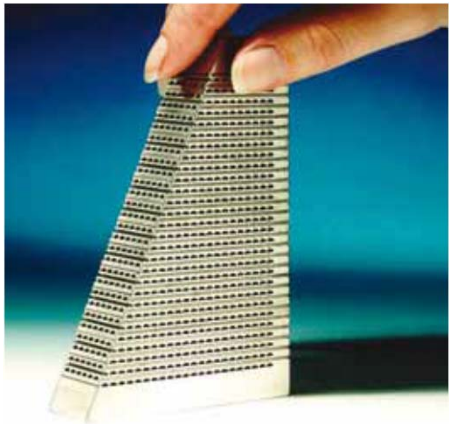




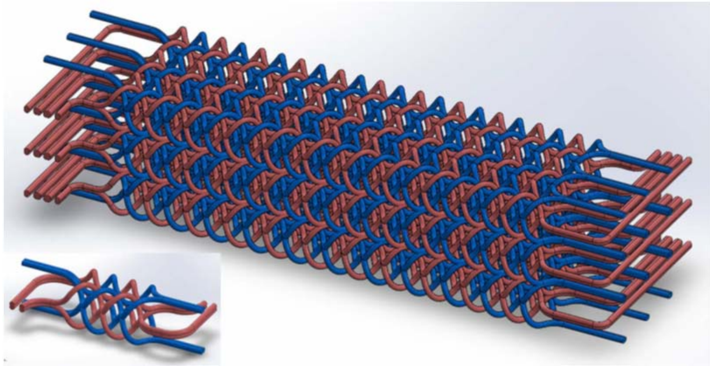
RCBC efficiency as a function of microchannel recuperator effectiveness

sCO_2 Recuperators

- High cycle efficiency achieved only through heat recuperation
- HT & LT recuperators account for ~20% of RCBC system cost
- Design constraints/ challenges
  - High temperatures on the hot side (500 - 600 C)
  - High pressures (>200 bar)
  - Large pressure differential between hot and cold sides
  - Low approach temperatures between fluid streams
  - Corrosion
  - Creep and fatigue



PCHE core (Heatric; accessed 03/2018)



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

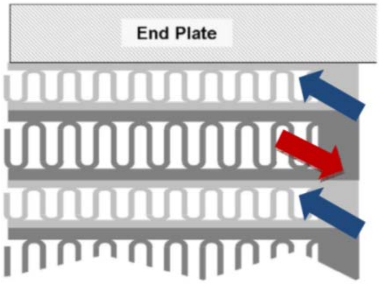
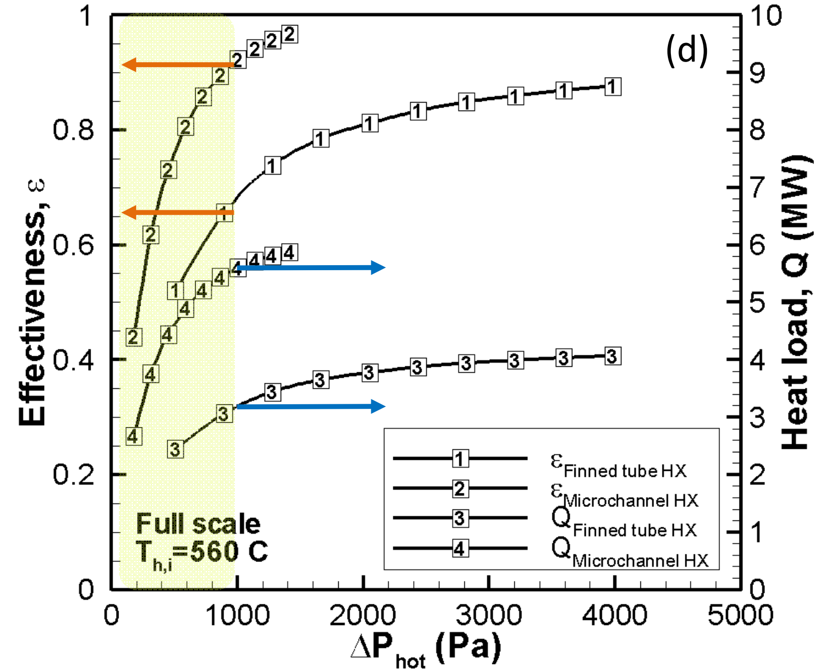


Figure 1 Sketch of the wavy-fin heat transfer surface and the associated flows

Folded wavy fin HX; Fourspring et al. (2014)- Bechtel Marine and Brayton Energy

Primary heat exchanger

- Solar- concentrated sunlight-sCO_2
- Fossil (indirect)- combustion gases-sCO_2
- Nuclear- sodium-sCO_2
- Waste heat- waste heat flue gas-sCO_2
- PHX accounts for ~20-25% of the system cost; typically finned tube designs for waste heat recovery



Opportunities exist to increase the effectiveness of the PHX for multiple heat sources

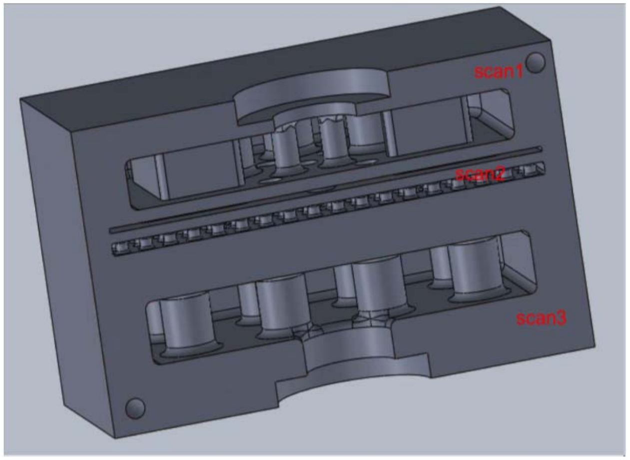
Constraints:

- Low pressure drop on the hot side (waste heat, fossil)
- Cyclic fatigue
- Creep
- Integrity of braze and weld joints

Additive Manufacturing for sCO_2 HXs

Advantages

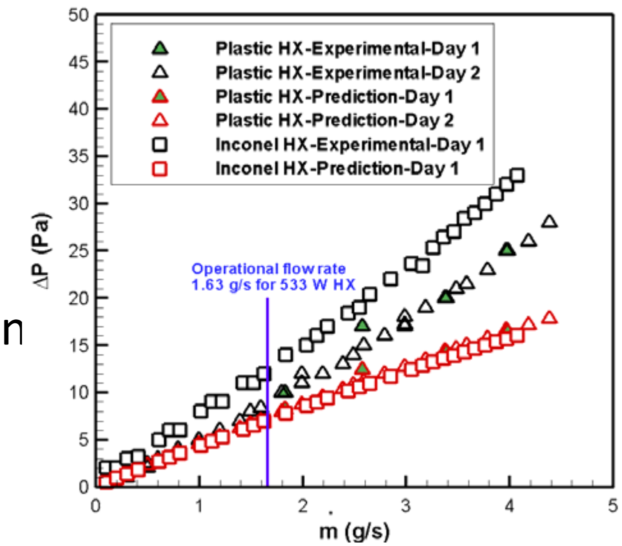
- “Monolithic”- No weld/braze joints
- Unique designs possible (with limitations imposed by the AM process)
- Not restricted to limitations imposed by diffusion bonding
- Not restricted by the limitations imposed by materials (subject to powder availability)
- Rapid customizable solutions
- Modular designs lend to scalability

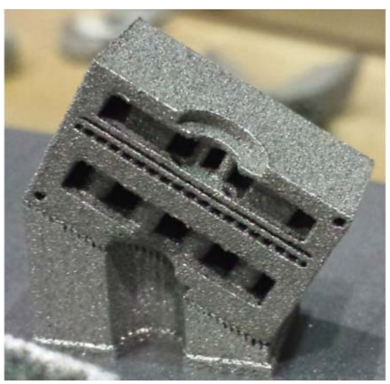


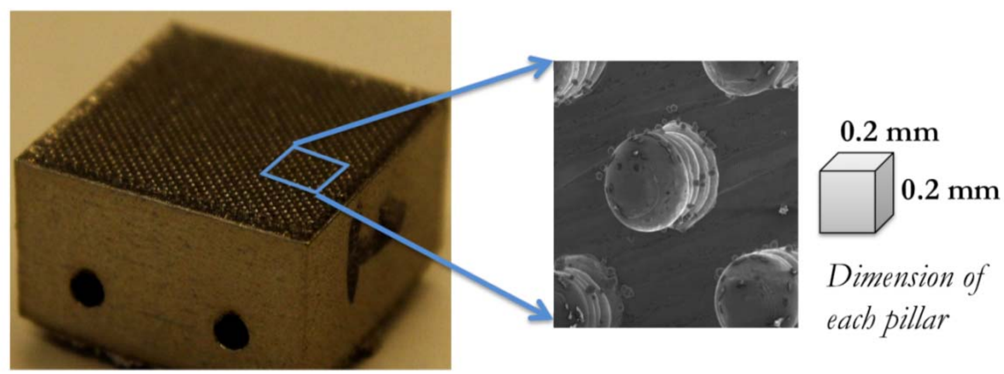
Fertile space for University/National lab researchers-
Relatively low TRL level – lots of basic questions to be answered; multidisciplinary area- materials science, advanced manufacturing, thermal science, computational sciences

Additive Manufacturing of sCO_2 HXs- Issues/Questions

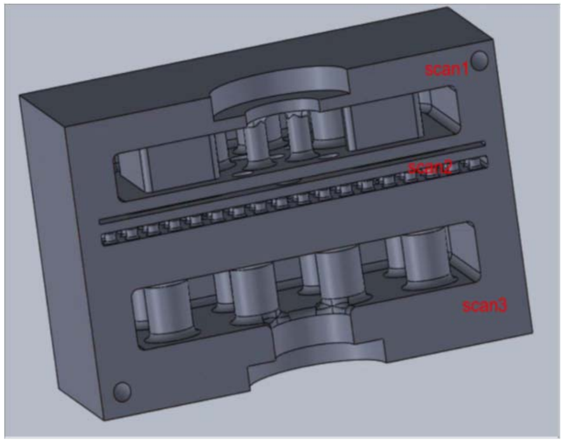
- Surface roughness (pressure drop concerns)
- Feature sizes (example of PCHE)
- Powder removal strategies
- AM process parameters
- Microstructure and mechanical properties (including relation to process parameters)
- Scale (tens of kW possible- what about larger?)
- Cost
- Fatigue and creep?

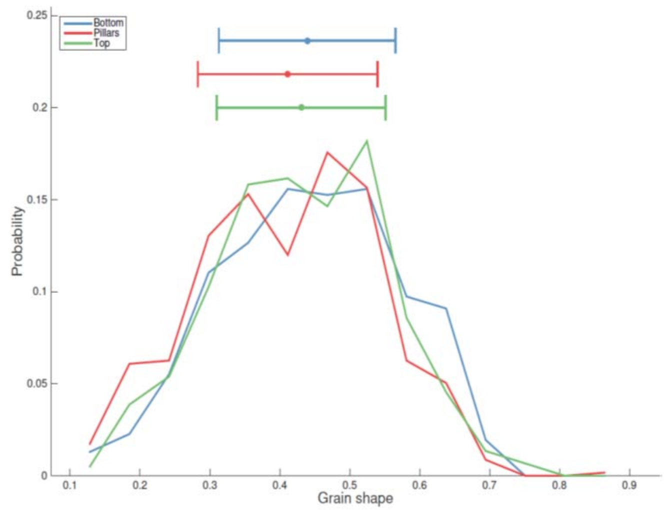


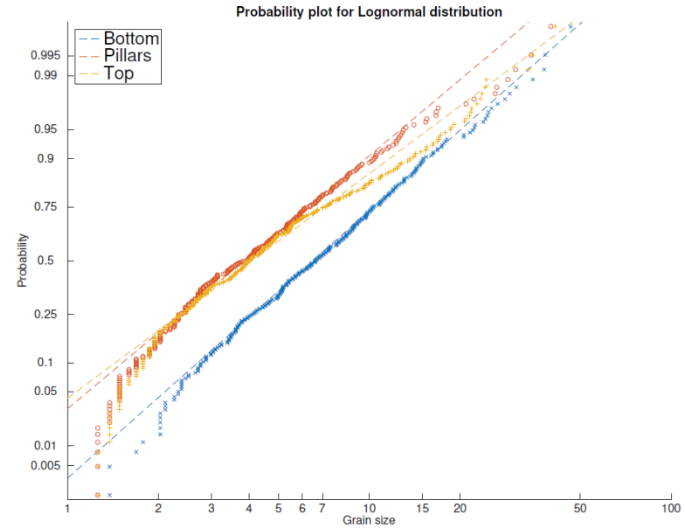




sCO_2 AM HX work by the group- Microstructure



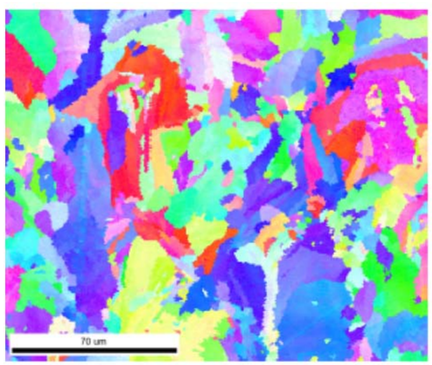




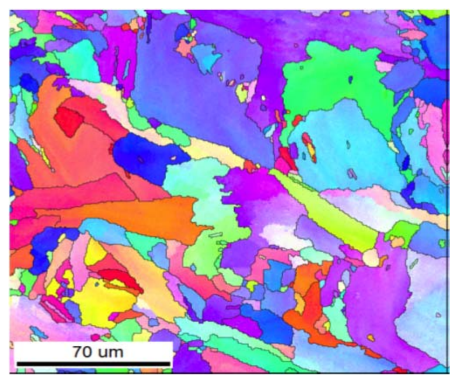
	Fraction of Σ3 boundaries*
Top	0.49%
Pillars	0.49%
Bottom	0.2%

*related to fatigue crack initiation

As fabricated



Post heat treatment

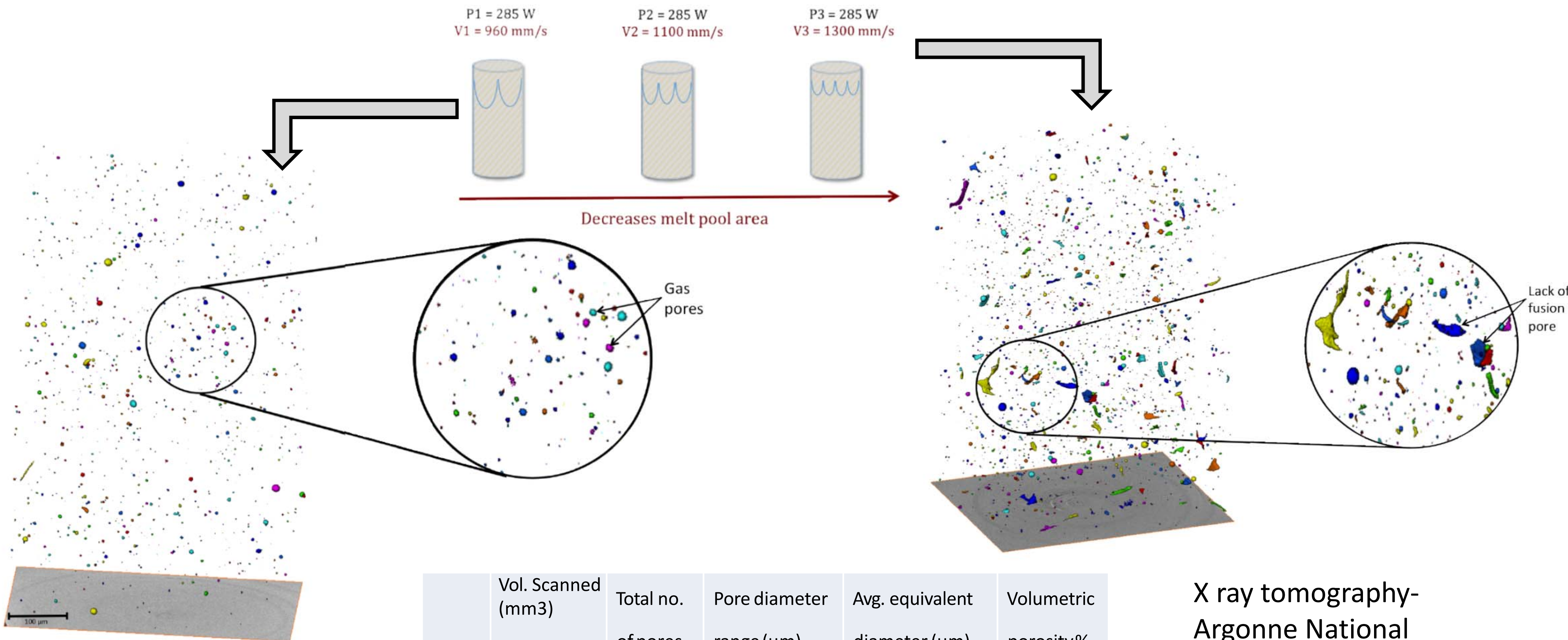


968 °C for 1.5 h, aged (718 °C for 8 h to 612 °C for 8 h and then cooled below 150 °C)

Pre- vs post- heat treatment:

- Grain size increased from 4-8 µm
- Orientation gradients reduced; however still present => partial to no recrystallization
- Hardness increased to wrought In718 levels

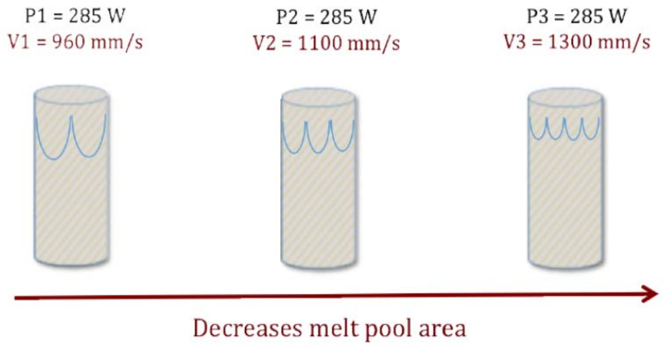
sCO2 AM HX work (cont.)- Bulk region porosity vs process parameters



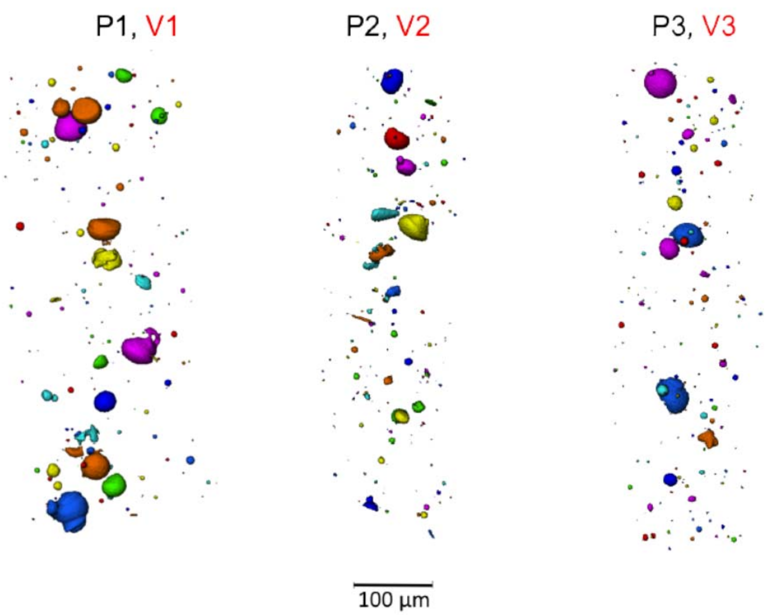
	Vol. Scanned (mm3)	Total no. of pores	Pore diameter range (µm)	Avg. equivalent diameter (µm)	Volumetric porosity%
P1V1	0.7841	1121	23.33 to 1.6	4.39	0.019
P2V2	0.8725	2210	31.433 to 1.6	4.613	0.051
P3V3	0.8463	2373	83.21 to 3.45	10.24	0.074

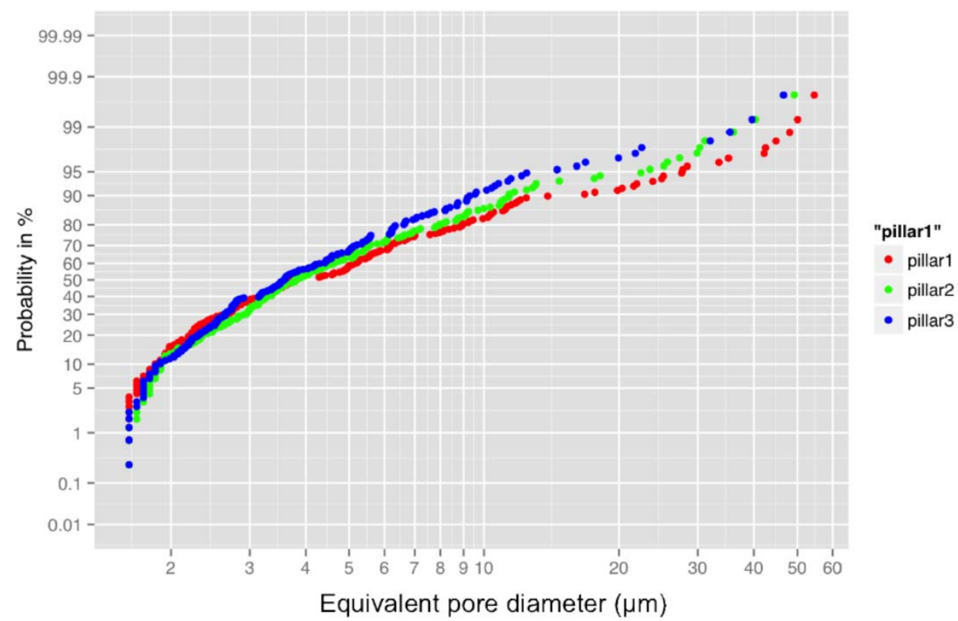
X ray tomography- Argonne National Lab APS

sCO2 AM HX work (cont.)- Micropillar porosity vs process parameters



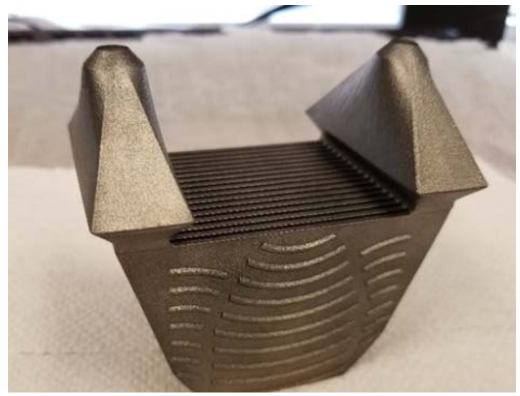
	Vol.Scanned (mm3)	Total no. of pores	Pore diameter range (µm)	Avg. equivalent diameter (µm)	Volumetric porosity %
P1V1	0.143	203	54.6-1.6	7.2	0.34
P2V2	0.143	205	49.2-1.6	6.19	0.17
P3V3	0.143	204	46.4-1.6	5.33	0.12



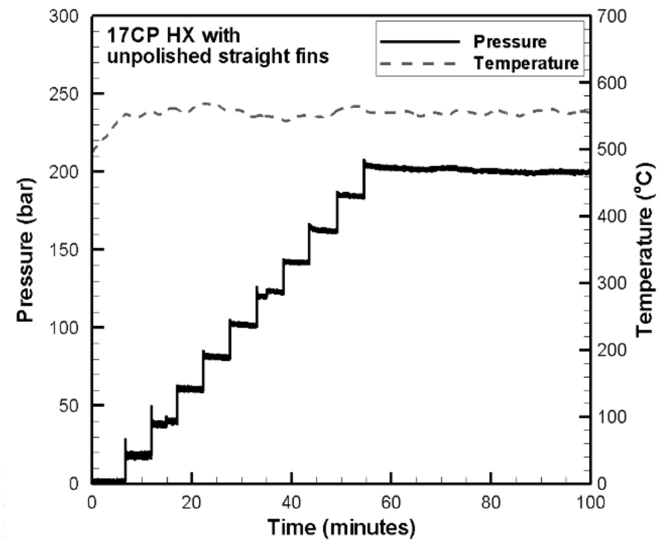


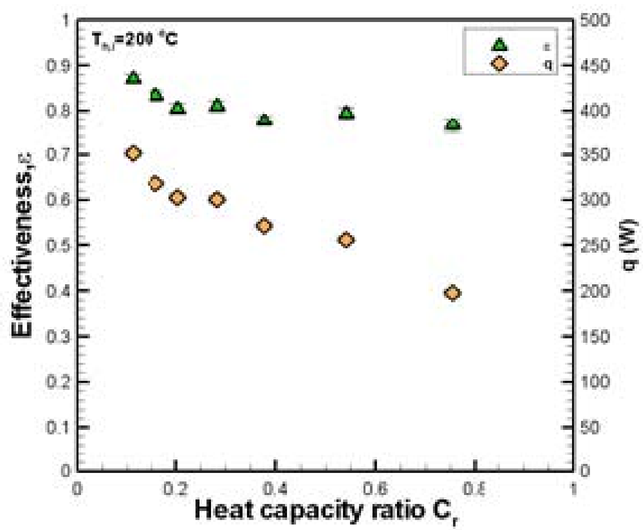
sCO_2 AM Primary Heat Exchanger

Patent Pending



Patent pending





Presentation on Primary HX for waste heat applications- Tomorrow 8-9:30 HX 1 Track B session- Paper 38 for more information

Summary

- AM has potential for sCO_2 HXs
- Lots of basic and applied research in multi-disciplinary areas needed to advance AM for sCO_2 cycles => Opportunities for university researchers
- Cost comparisons need to be performed vs other methods in conjunction with technical advances
- Scale-up needs to be addressed