Approximate Expressions for AMR Performance

University of Victoria

IESVic integrated energy systems

Why Less Can Sometimes Mean More

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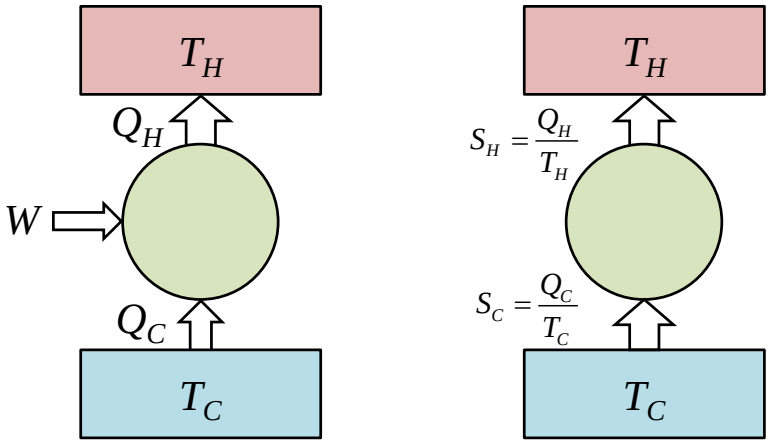
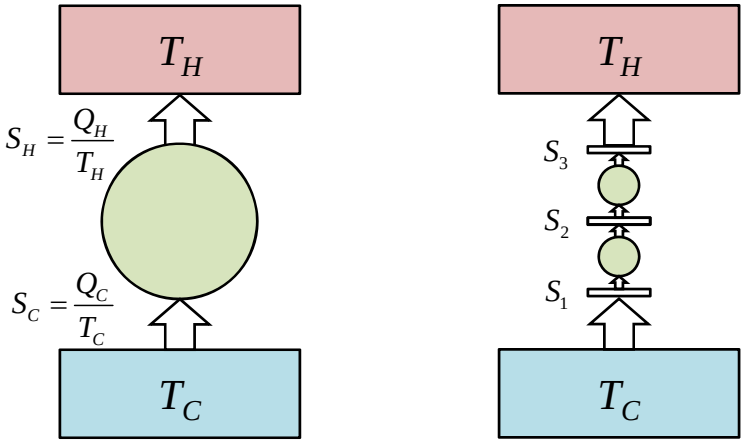
enSYS

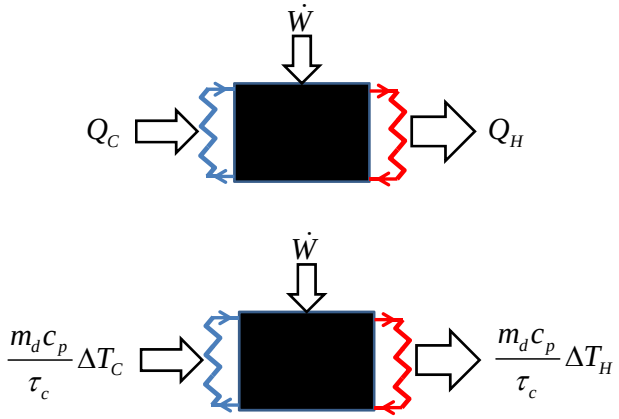
An Ideal Heat Pump



An Ideal Series of Heat Pumps



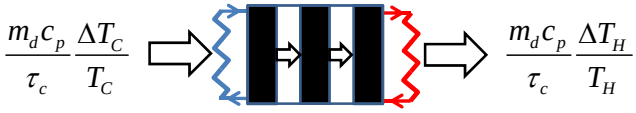
The Black Box – Heat Transfer Fluid



The Black Box HTF – Entropy Flow

An Ideal Series of Black Boxes

Maximum entropy flow determined by the <u>minimum capacity</u>.

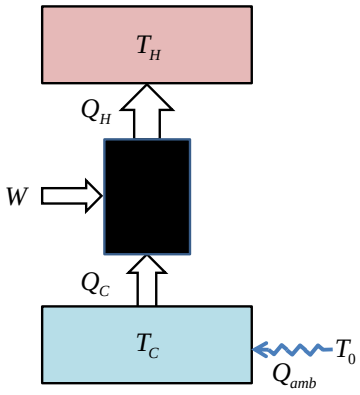


Ideal: $\dot{S}_C = \dot{S}_H$ $\quad \frac{\Delta T_C}{T_C} = \frac{\Delta T_H}{T_H}$ $\quad \frac{\Delta T}{T} = \text{constant}$

So far, all temperatures are with respect to the heat transfer fluid.

Black Box with External Heat Leak

- Load due to applied and parasitic leaks (from ambient)



$$Q_C = Q_{net} + Q_p$$

$$Q_p = K_{ext}\left(T_0 - T_C\right)$$

Black Box is AMR

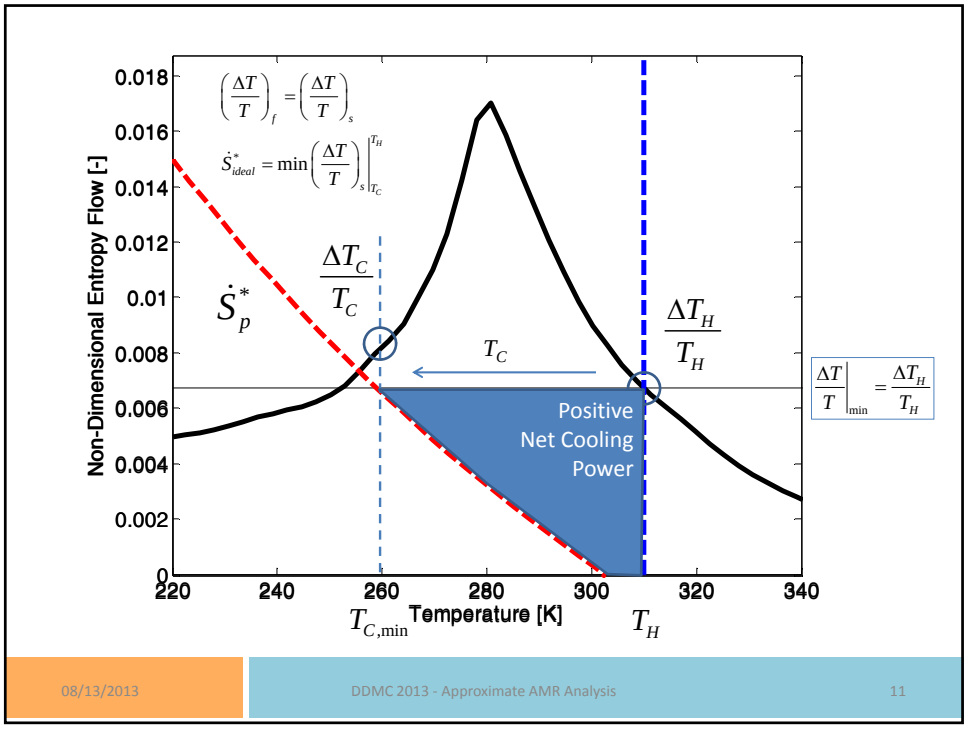
- Assume fluid temperature equals solid (perfect regenerator)

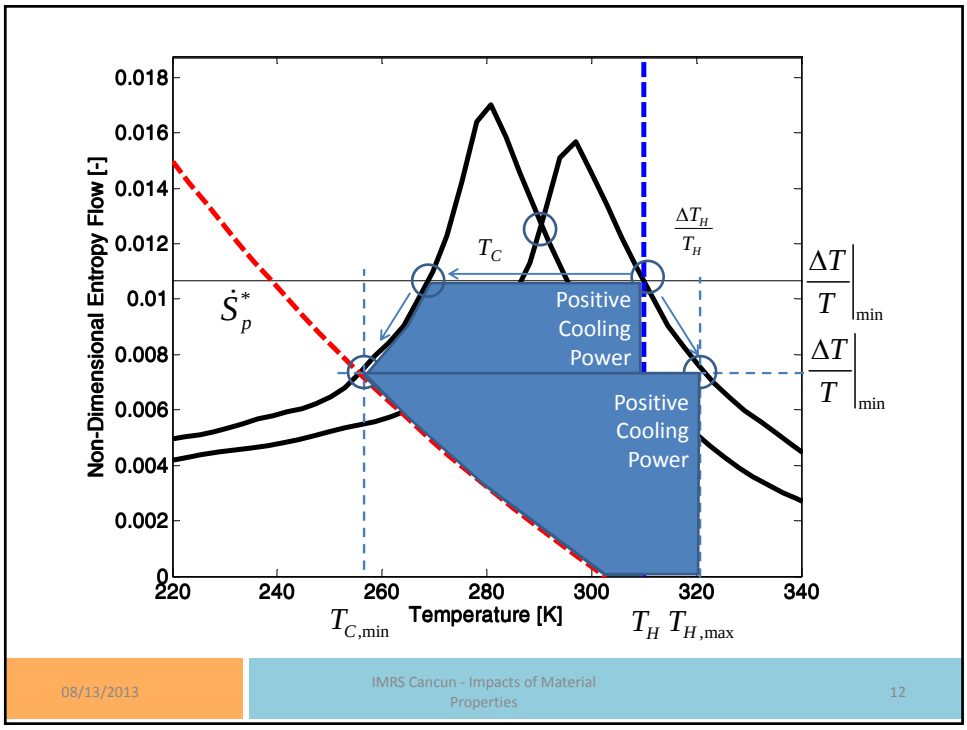
$$\left.\frac{\Delta T}{T}\right|_{\text{fluid}} = \left.\frac{\Delta T}{T}\right|_{\text{solid}}$$

- Preferred material characteristic for ideal entropy flow

$$\left.\frac{\Delta T}{T}\right|_{MCM} = \text{constant}$$

- What do experiments show?


$\left(\frac{\Delta T}{T}\right)_f = \left(\frac{\Delta T}{T}\right)_s$
$\dot{S}^*_{ideal} = \min\left(\frac{\Delta T}{T}\right)_s\Big|_{T_C}^{T_H}$
$\frac{\Delta T_C}{T_C}$
$\dot{S}^*_p$
T_C
$\frac{\Delta T_H}{T_H}$
$\left.\frac{\Delta T}{T}\right|_{\min} = \frac{\Delta T_H}{T_H}$
Positive Net Cooling Power
Non-Dimensional Entropy Flow [-]
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
220
240
260
280
300
320
340
$T_{C,\min}$
Temperature [K]
T_H


$\dot{S}^*_p$
T_C
$\frac{\Delta T_H}{T_H}$
$\left.\frac{\Delta T}{T}\right|_{\min}$
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Positive Cooling Power
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240
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280
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320
340
$T_{C,\min}$
Temperature [K]
T_H $T_{H,\max}$

Real AMR Performance

- We have found the following to be true for a single material*

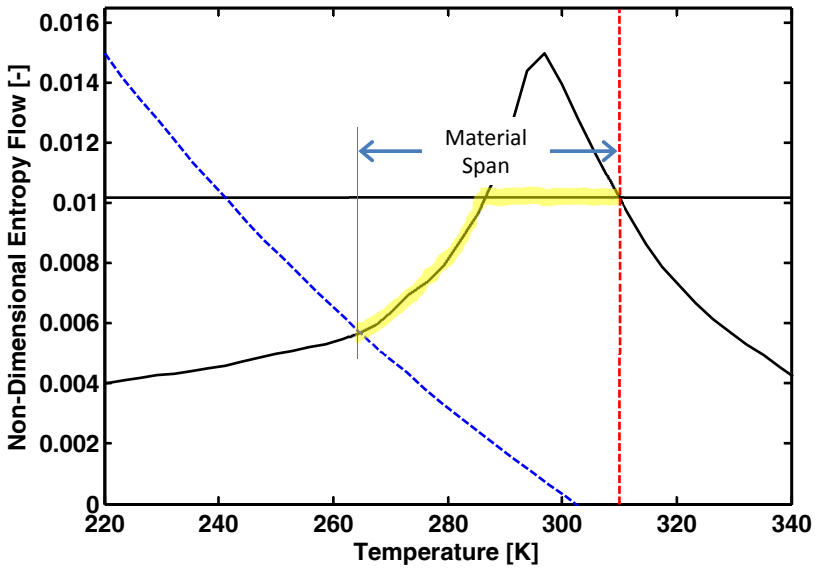
$$Q_C = \frac{m_d c_p}{\tau_C}\frac{1}{R}\frac{\Delta T}{T}T_C\left[1-\left(\frac{\Phi}{2R}+\left(\frac{\Phi}{\kappa R}\frac{\Delta T}{T}\right)^{-1}\right)\left(\frac{T_H}{T_C}-1\right)\right]$$

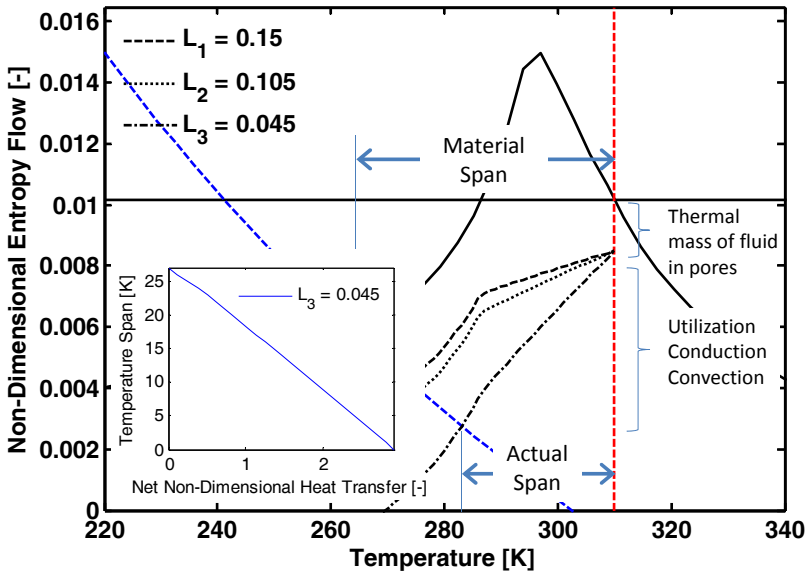
where,

$$\frac{\Delta T}{T} = \min\left[\frac{\Delta T_C}{T_C}, \frac{\Delta T_H}{T_H}\right]$$

- The maximum cooling power is determined by the minimum boundary condition

Rowe, A., "Thermodynamics of Active Magnetic Regenerators: Part II," Cryogenics, 52, pp. 119-128, 2012.
See Burdyny, T., et al. "Performance Modeling of AMR Refrigerators" International Journal of Refrigeration, (http://dx.doi.org/10.1016/j.ijrefrig.2013.08.007) for parameter definitions.





Summary

- Analytic expression tends to well approximate actual performance using $\left.\frac{\Delta T}{T}\right|_{\min}$
- Performance includes system external losses, internal regenerator losses, and system characteristic B_L, B_H and $\langle N_d \rangle$
- AMR effectiveness characterized by an effective internal heat leak, K_{int}

THERMAG VI
Victoria, BC, CANADA
Sept 7 – 10, 2014

- Expanded Program
  - Cryogenics to Near Room Temperature
  - Parallel tracks: Materials and Systems
  - Applications: Heat pumps, refrigeration, liquefaction, power generation
- Opening plenary by Dr. John Barclay
  - One of the original inventors of the AMR cycle.
- Email me and I will add you to the notification list
  - arowe@uvic.ca

Save the date.
I hope to see you in Victoria!