Measurement of Convective Heat Transfer Coefficients with Supercritical CO_2 in Novel Additively Manufactured Helically Patterned Pin Fin Tubes Using the Wilson Plot Technique

NATIONAL ENERGY TECHNOLOGY LABORATORY

Matthew Searle[1,3], Jim Black[2], Doug Straub[1], Ed Robey[1,3], Joe Yip[1], Sridharan Ramesh[1,3], Arnab Roy[1,3], Adrian S. Sabau[4], Fred List III[4], Keith Carver[4], Darren Mollot[5]

[1] National Energy Technology Laboratory, Morgantown, WV
[2] National Energy Technology Laboratory, Pittsburgh, PA (Retired)
[3] NETL Support Contractor
[4] Oak Ridge National Laboratory, Oak Ridge, TN
[5] US Department of Energy, Washington, DC

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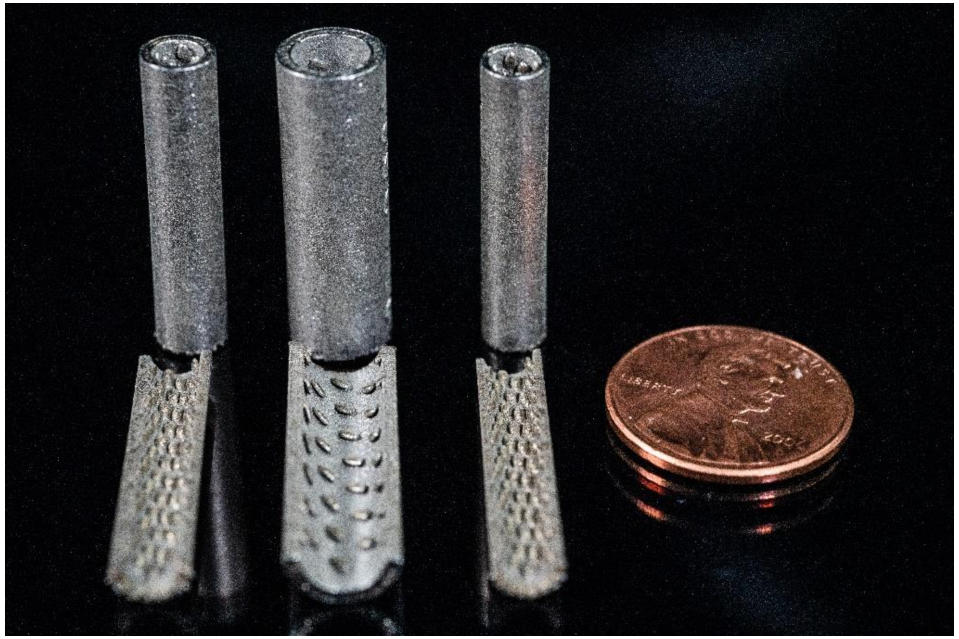
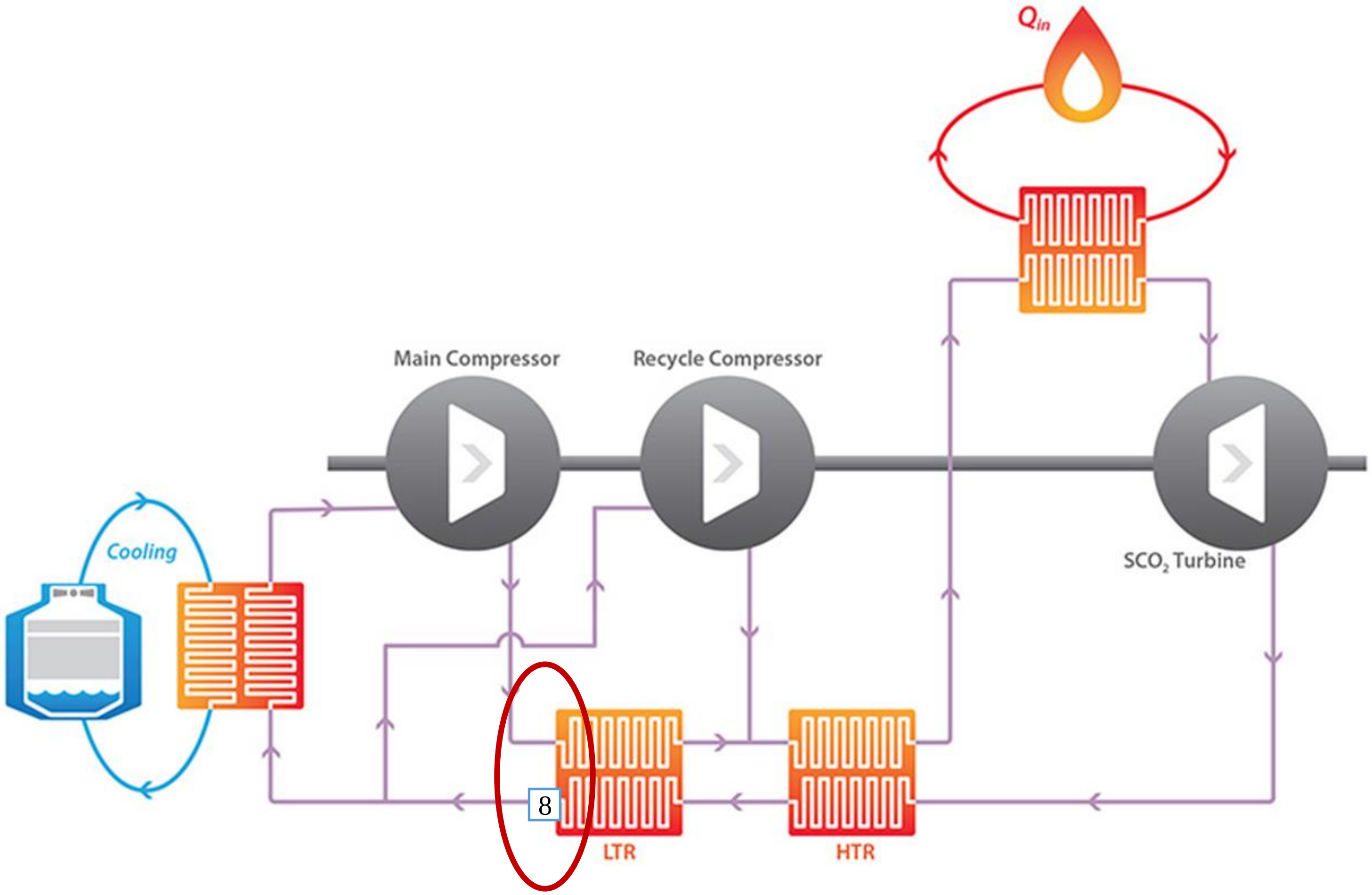
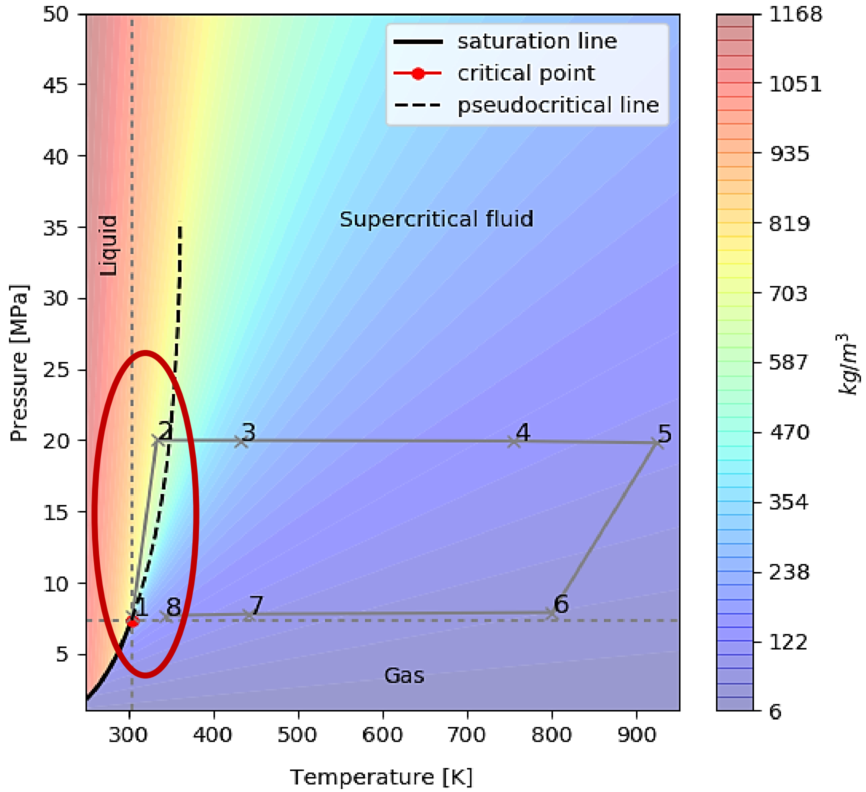
Outline

- **sCO2 Heat Exchanger Experiments**
- **AM Pin Fin Tube Designs**
- **Design Performance**
  - Heat Transfer
  - Pressure Drop



Indirect Cycle Conditions

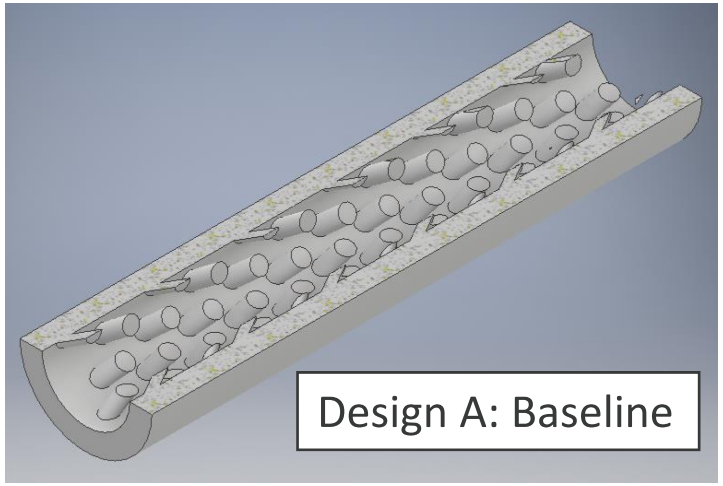


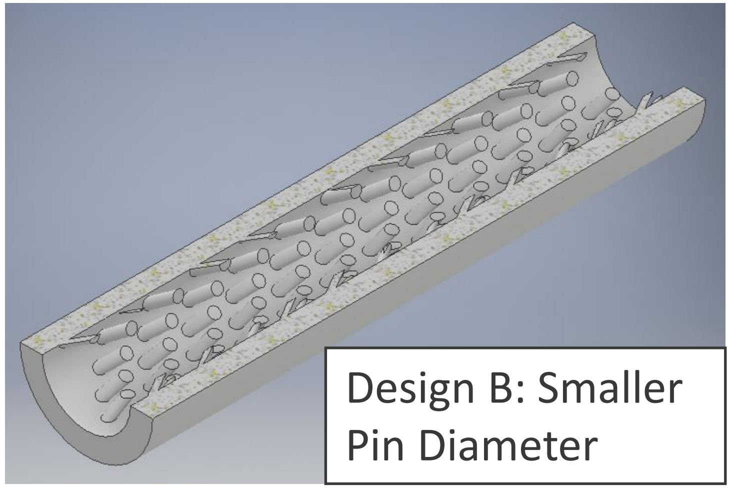


	Low Temperature Recuperator: Low Pressure Outlet [1]
Cycle Condition	8
Pressure (MPa)	8.69
Temperature (K)	647

AM Tube Designs

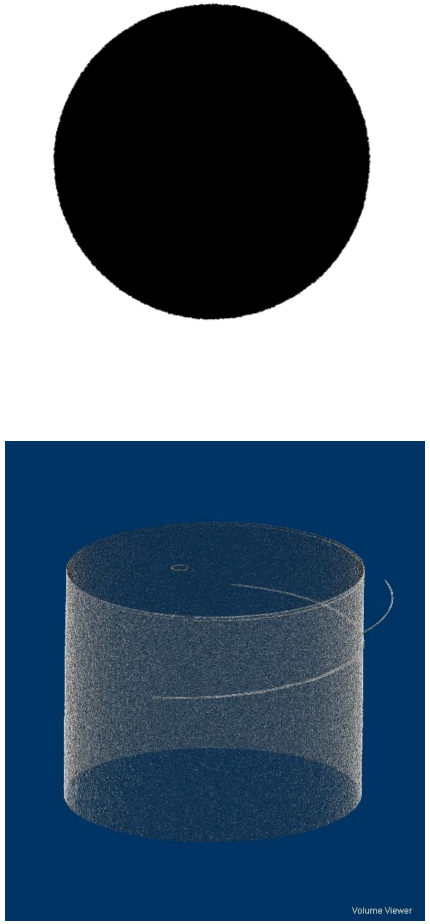
Design	A	B
Tube ID (inch)	0.275	0.275
A/A_0	1.65	1.65
Ellipse Major Diameter (inch)	0.0295	0.0197
Aspect Ratio (Major/Minor)	1	1
Pin Length (inch)	0.0689	0.0689
Pins per Axial Length (#/inch)	152	229
Pin Angle From Tube Wall	30°	30°


Design A: Baseline

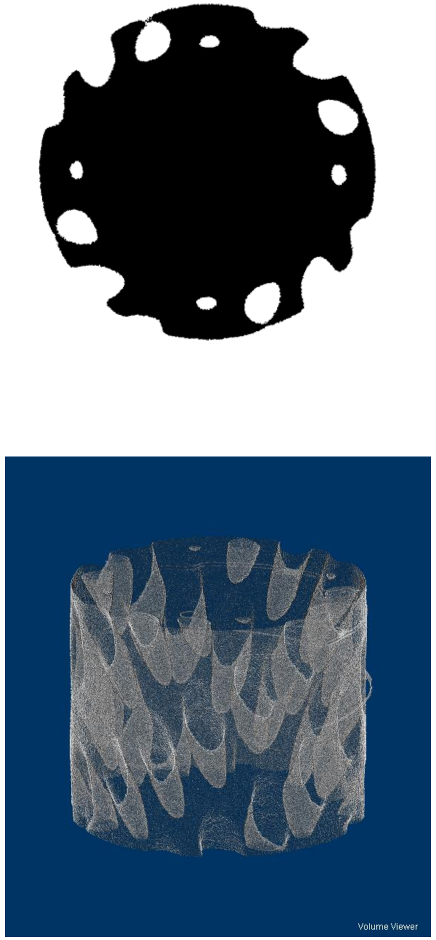

Design B: Smaller Pin Diameter

AM Tube CT Scans

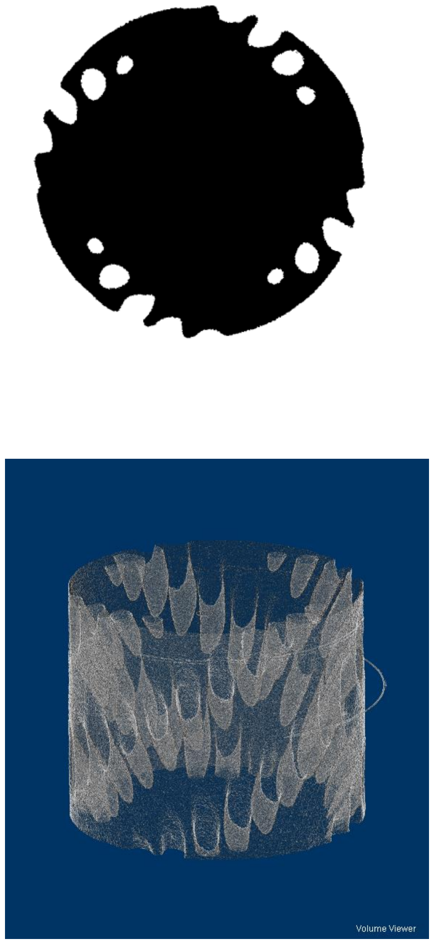
Baseline



Tube Design A



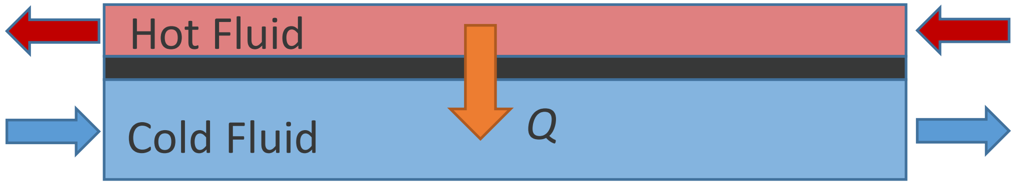
Tube Design B



7 mm

Experimental Approach – Wilson Technique

(Good if HTC's on both surfaces are very high)



$R_h = \frac{1}{h_h A_h}$

R_w

$R_c = \frac{1}{h_c A_c}$

$$R_{ov} = R_c + [R_w + R_h]$$

R_c, R_w, and R_h are not known.

R_{ov} can be calculated from $LMTD$ and Q.

$$Q = UA\,(LMTD)$$

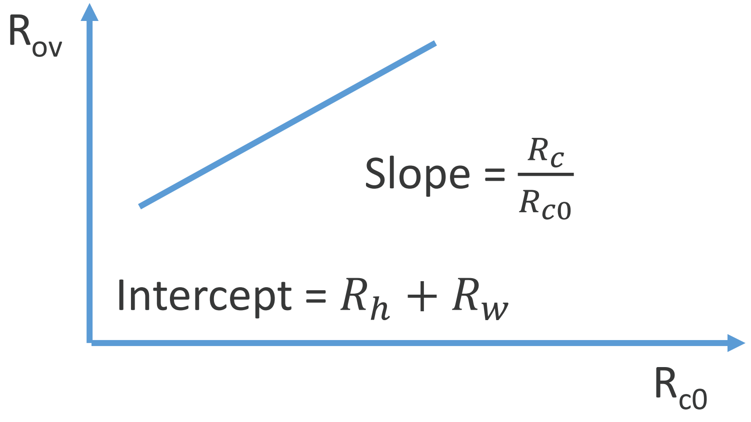
$$R_{ov} = \frac{1}{UA} = \frac{LMTD}{Q}$$

R_c is varied by changing cold side mass flow.

R_w and R_h are held constant by controlling hot side mass flow and average temperature.

Experimental Approach – Wilson Technique

(Good if HTC's on both surfaces are very high)



Plot $R_{ov} = LMTD/Q$ as a function of R_{c0}.

R_{c0} is cold side resistance calculated using Dittus-Boelter Correlation.

$$Nu_0 = 0.023 Re_D^{0.8} Pr^{0.4}$$

$$R_{c0} = \frac{1}{\left(\frac{k}{D}\right) 0.023 Re_D^{0.8} Pr^{0.4} A_0} \qquad Re_D = G\,D/\mu$$

$$R_{ov} = \left(\frac{R_c}{R_{c0}}\right) R_{c0} + [R_w + R_h]$$

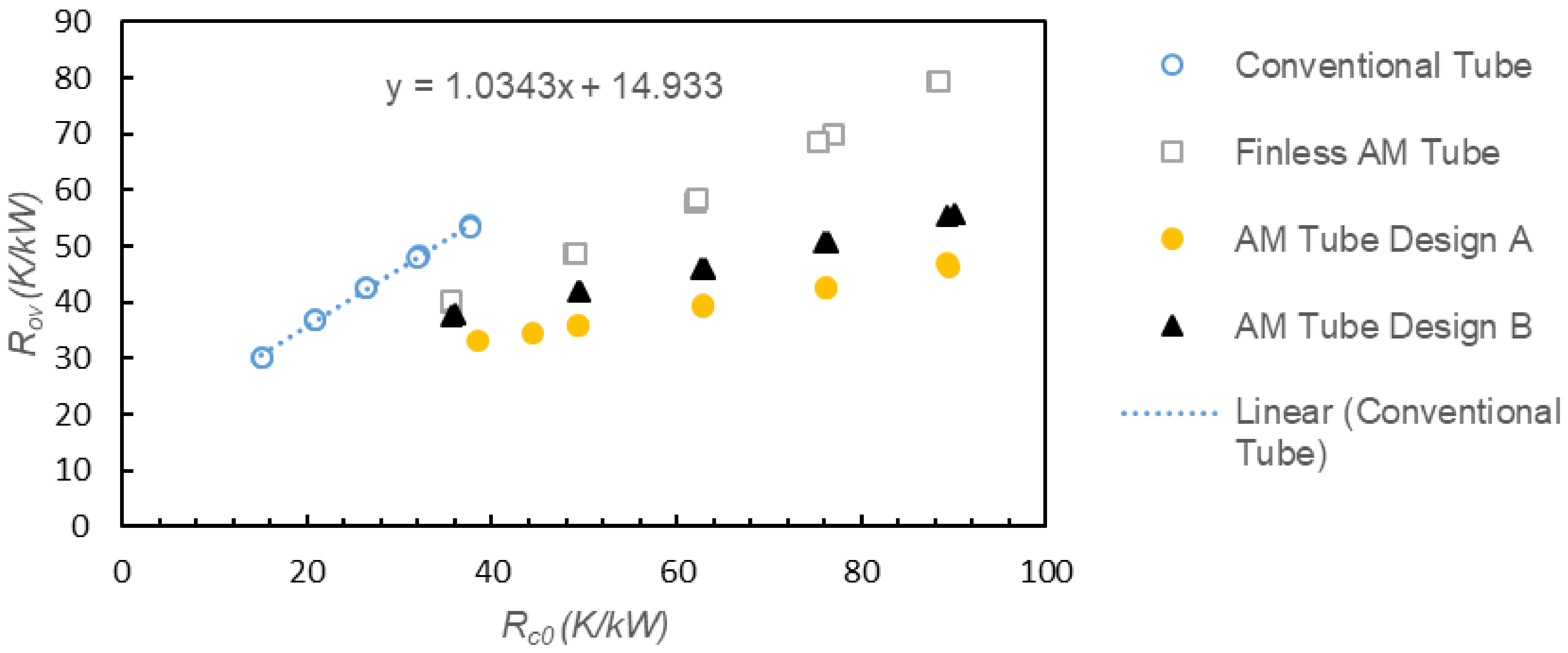
Slope = $\frac{R_c}{R_{c0}} = \frac{h_0 A_0}{hA}$

If Slope < 1,
$hA > h_0 A_0$

If Slope > 1,
$hA < h_0 A_0$

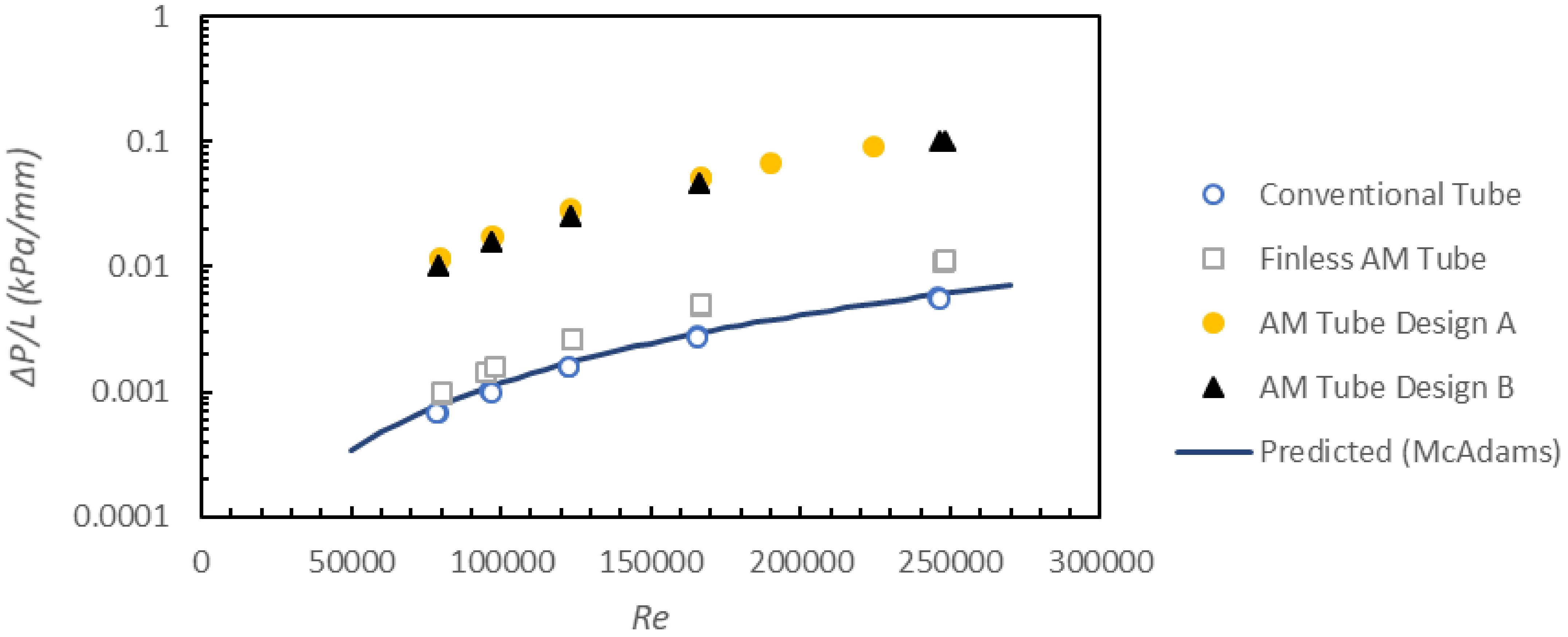
$$\frac{Nu}{Nu_0} = \frac{R_{c0}}{R_c} \frac{A_0}{A}$$

Heat Transfer Measurement: Wilson Plot



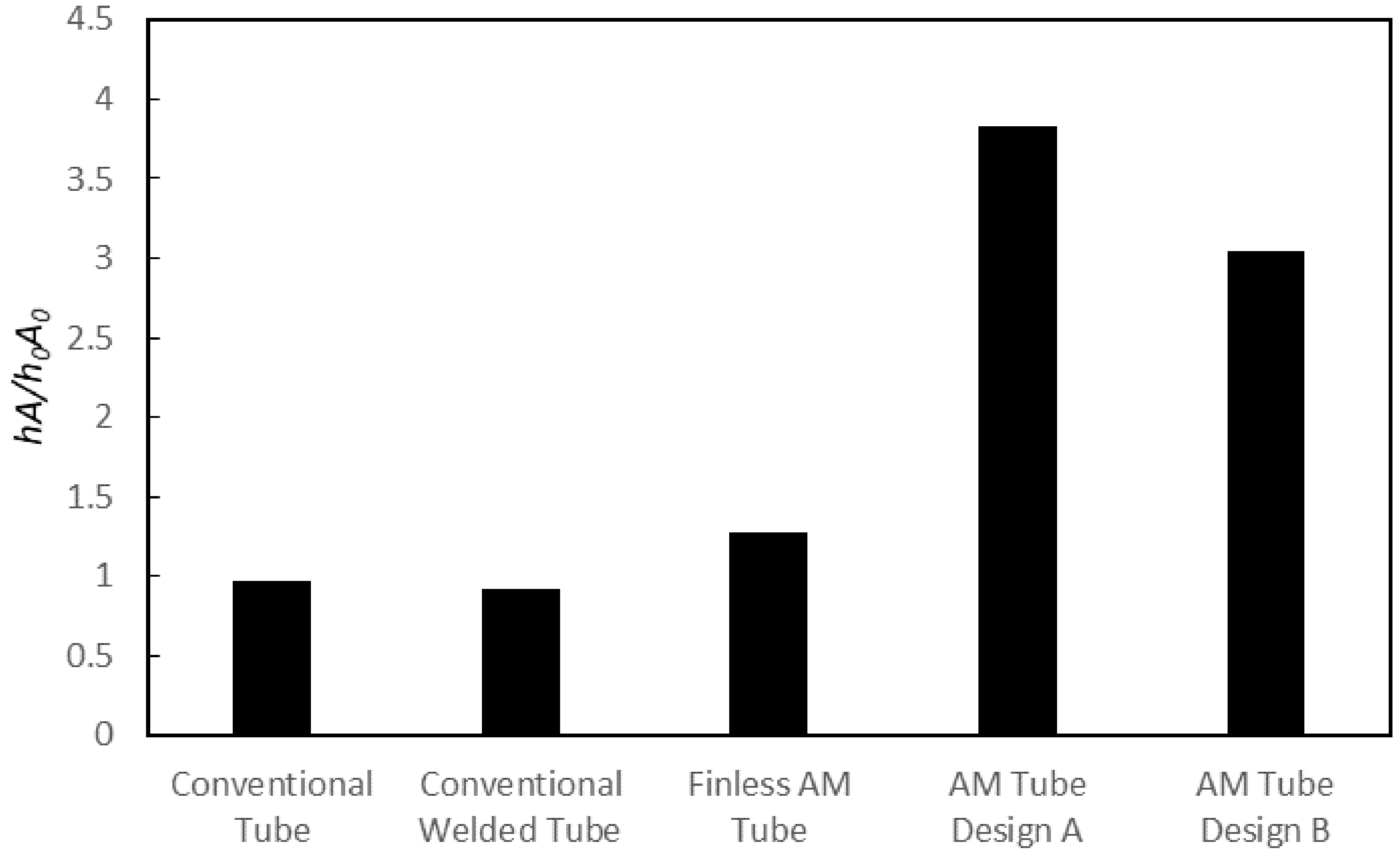
Data points were acquired at smooth tube Re ranging from 50,000 to 250,000.

Pressure Drop Measurement



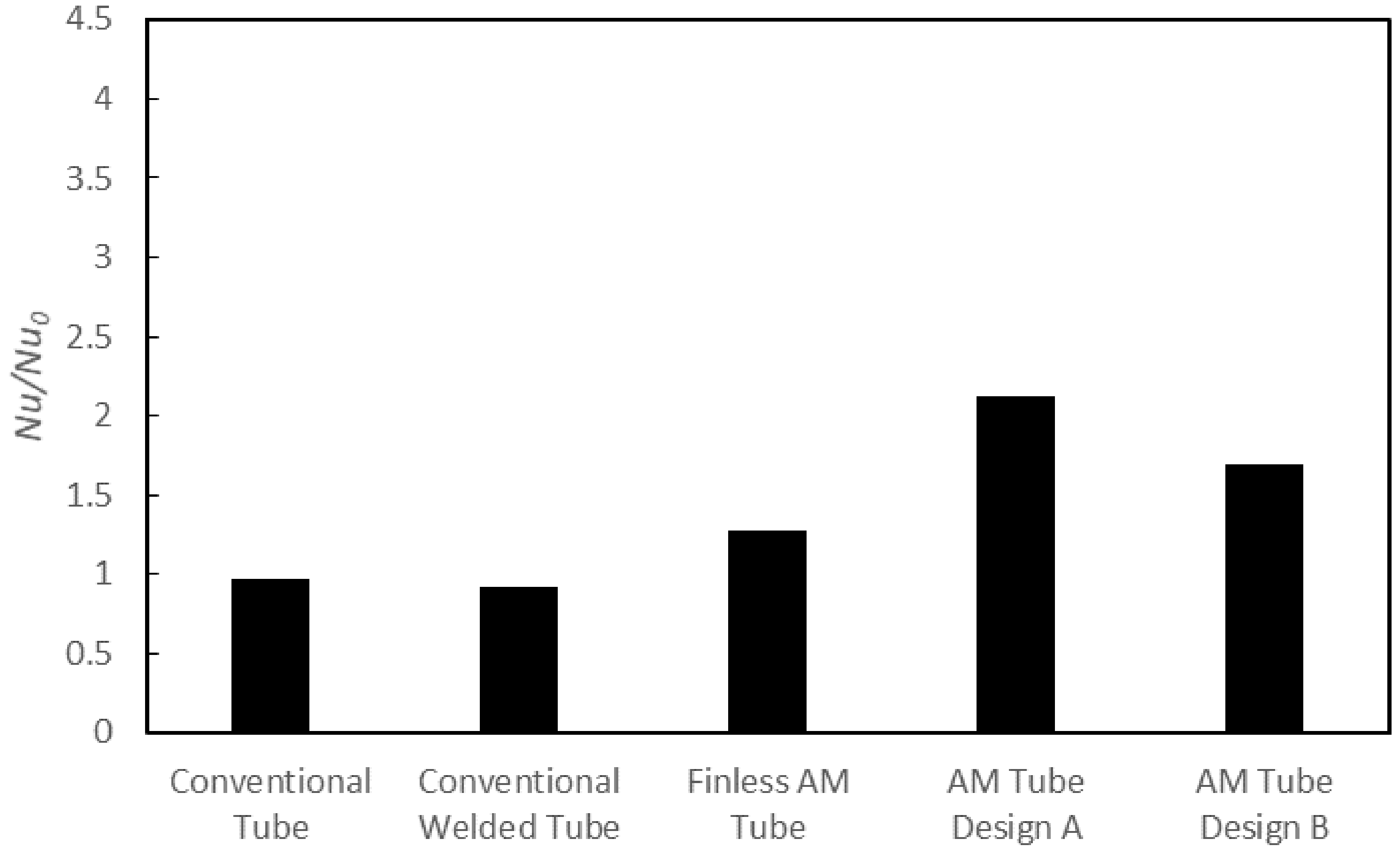
Data points were acquired at smooth tube Re ranging from 50,000 to 250,000.

Heat Transfer: hA/h_0A_0



Data points were acquired at smooth tube Re ranging from 50,000 to 250,000.

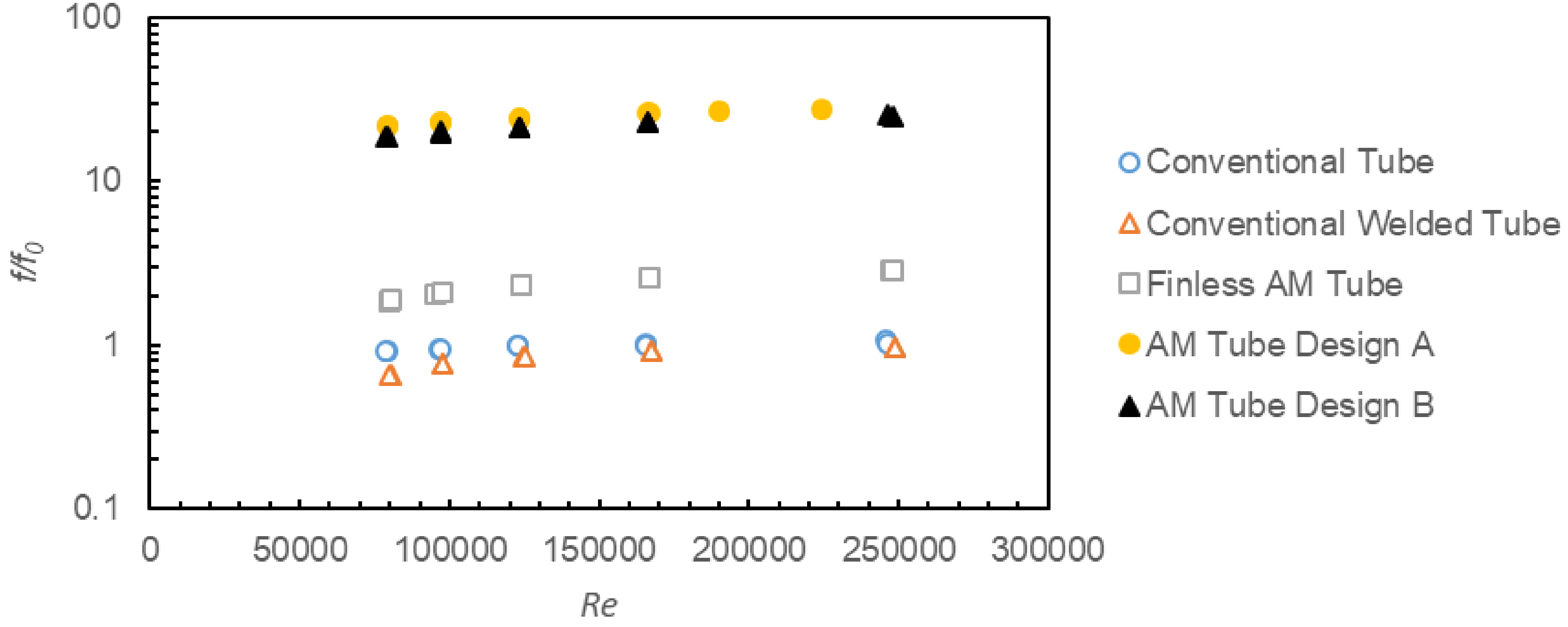
Heat Transfer: Nu/Nu_0



$$\frac{Nu}{Nu_0} = \frac{\mathrm{R_{c0}}}{R_c}\frac{A_0}{A}$$

Data points were acquired at smooth tube Re ranging from 50,000 to 250,000.

Friction Factor



Measured Friction Factor:

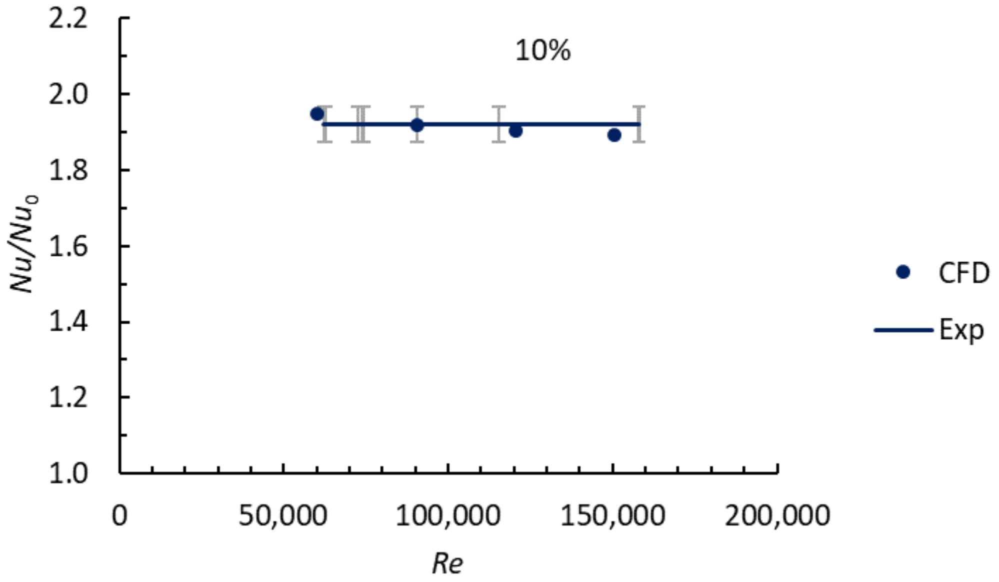
$$f = \frac{\pi^2}{8} \frac{\Delta P \, \rho \, D^5}{L \, \dot{m}^2}$$

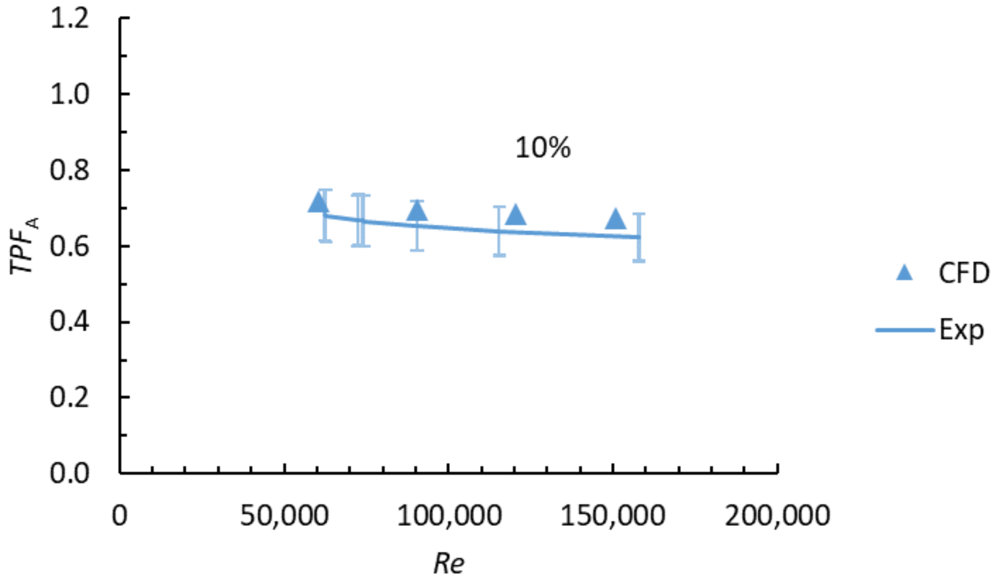
McAdams Correlation:

$$f_0 = 0.184 Re_D^{-0.2}$$

30k < Re_D < 2000k

CFD Validation of Tube Design B





$$TPF_A = \frac{Nu/Nu_0}{(f/f_0)^{\frac{1}{3}}}$$

Conclusions

The Wilson plot technique was utilized to measure the heat transfer coefficients in helical pin fin tubing.

- Results for a smooth tube agreed within 5% of the Dittus-Boelter correlation and within 7% of the McAdams correlation.
- Tube side conductance increased by 282% and the heat transfer coefficient increased by 112% for the best performing design.
- The average friction factor increased significantly

Acknowledgements

This work was supported in part by an appointment to the U.S. Department of Energy (DOE) Postgraduate Research Program at the National Energy Technology Laboratory (NETL). This appointment was administered by the Oak Ridge Institute for Science and Education (ORISE).

The effort at UT-Battelle, LLC, was conducted under Contract No. DE-AC05-00OR22725 with the U.S. Department of Energy for the project "Novel Recuperator Concepts for Supercritical CO2 based on Additive Manufacturing" and has been funded by the DOE Office of Energy Efficiency and Renewable Energy, Office of Fossil Energy and used resources at the Manufacturing Demonstration Facility (MDF), a DOE-EERE User Facility at Oak Ridge National Laboratory.

The effort at NETL was conducted under the sCO2 Field Work Proposal (FWP).

References

1. White, C.W., et al., *sCO2 Cycle as an Efficiency Improvement Opportunity for Air-fired Coal Combustion*, in *6th Int. sCO2 Power Cycle Symposium*. 2018: Pittsburgh, PA.

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