



Optimize to Exceed

Effective Design of Small-Diameter Copper Tube-Fin Heat Exchangers May 24th, 2017

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Speakers



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- M.S., Mechanical Engineering University of Maryland, College Park
- Joined OTS 2011



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- Joined OTS 2016



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U Copper Alliance™



Defend and grow markets for copper based on its superior technical performance and its contribution to a higher quality of life worldwide. Members include copper mining and fabricating companies.



- Introduction
 - Motivation
 - Background
- Heat Exchanger Modeling
 - Fundamentals
 - Introduction to CoilDesigner®
 - Demonstration: modeling a 5 mm heat exchanger
- Applications

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- Validation against experimental data
- Example of 5 mm design
- Conclusions and Q&A



Introduction

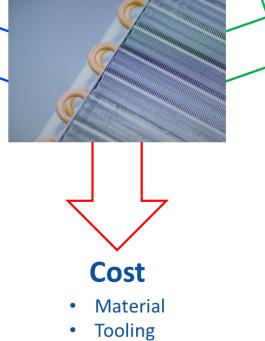
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Why Does Heat Exchanger Design Matter?

Energy Efficiency

- Energy consumed in buildings
 - COP
 - Billing Cost
 - Primary energy use
 - CO₂ emissions
- Partial load



• Size / Weight

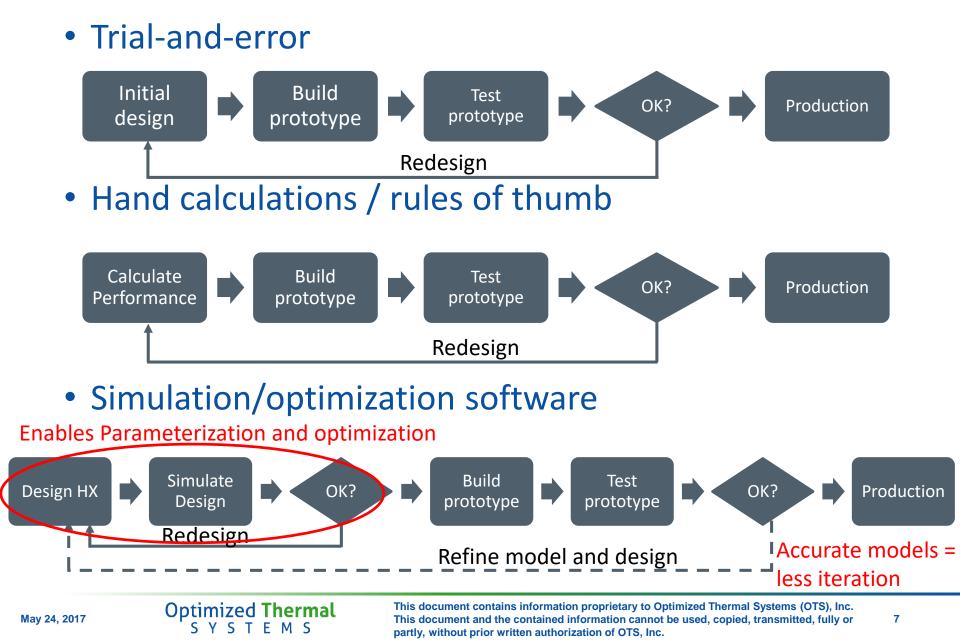
Environment and Safety

- Direct refrigerant emissions
- Footprints (e.g. CO₂, end-of-life equipment)

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Heat Exchanger Design Techniques





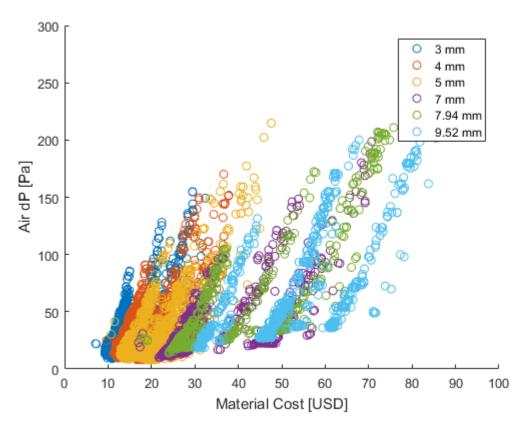


How Many Ways Are There To Design a Tube-Fin Heat Exchanger? At Least:

- 6 Tube diameters (5 mm, 1/4", 7 mm, 5/16", 3/8", 1/2")
- 6 fin types (flat, wavy-smooth, wavy-herringbone, slit, louver, wavy-louver)
- 10 Fin densities
- 10 tube lengths
- 10 vertical pitches
- 10 horizontal pitches
- 10 circuitries
- •••

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Already 3.6 million designs!



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Fundamentals

Heat exchanger modeling

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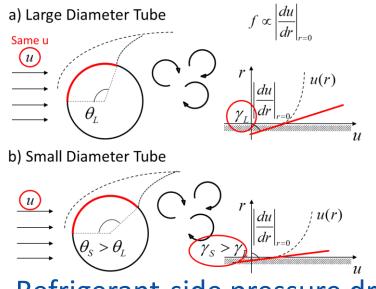
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Small Diameter Design Considerations



Accurate modeling tools

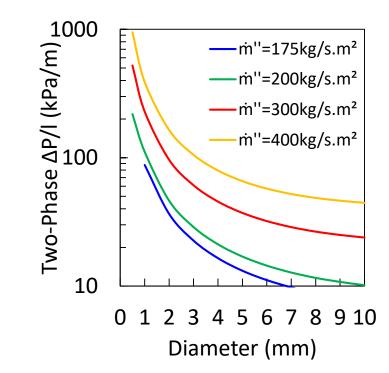
Air-side pressure drop



Refrigerant-side pressure drop

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Results Facults - Tabbed View Pic	ts 30 View Tube End Pi	ota				General
Denuite Cananal	W. Transpoorteou					Project File Name:
						C Sters Dennis Vocuments
	Value Units	Alt, Value Alt, Units	STVAUE STUNE	s Eng. Velve Eng. Units		9CA_SnalDane
Heat Loads						Descriptions
Total Heat Load	4901,6615 W		4901,5615 W	16725.1672 Btahr		
Sensible Heat Load	4911.5615 W		4901,5515 W	16725.1572 Bhahr		
Latert Heat Load	0.0000 W		1,000 W	6,000 Blahr	100.0 N	
Servible Heat Tatlo	1.0000 W		1.000 W	1,000 06444	NVV N	Update Description
Ref. Lipid Hestiad	-481,8631 W		-485,8625 W	-1644.5268 #tubr		Common Tanks
Ref. Two-phase Heatland	-4192,4947 W		-4192,4947 W	-14305.3891 884%r		Dill farameters.
Ref. Vapor Heatland	-227,2005 W		-227,2005 W	-775,2512 Btahr		Specify coll dimensi
Def Jibs Heatings Gen	4911.5615 W		4901,5615 W	16725.1672 Btahr		carrelations.
				and and and an	HeatLoad	Specify triat at an Specify triat at an
Charge/Condensate					Senable Load [#[01719/1572528whv] [0019/009whv]	Fluid Properties C
Refrigerant Charge	0.0862 kg		6.0062 kg	6.2901 Ben	[MM11 M1 M202 BM4] [MM14 COBM4]	
Refrigerant Liquid Charge	0.0322 kg		4.4322 kg	6.8713 Bro		Tube Connections
Refrigerant Two Phase Charge	0.0529 kp		8.8529 kg	6.1167 bn	HTC (Bullet #F)	Choose a Tube to
Refrigerent Vapor-Charge	0.0011 kg		9,0011 kg	6,8923 bm	0 200 400 600 800 1000 1200	Its connected tube
Condensate	0.0000 kg/s		8.8000 kg/s	6.0000 lbm/s		REMARK AT U.S.
					RV -	
tion flates					RTP	Available Tabes
Total Refrigerant Plave	0.0280 kg/s		4.8288 kg/s	6.8417 (bm/s		7.84-2
Air Mass Flow Rate	5.5189 kg/s		1.1189 kg/s	2.4667 Ibrils	R.	1.8e-3 1.8e-4
Air Flow Rate	0.9700 m³/e		0.9700 m3/a	34,2552 ft3/s	Ar-	Tube 5
Standard Air Flow Rate	0.9370 m//a		4.8370 m³/a	33.0987 ft/w		Tuber5 Tuber4 Tuber7
					0 2000 4000 6000	Tube 8 Tube 9
Pressure Drops					HTC (MMR)	
HX.Air Pressure Drop	37.6598 Pa	0.15119 in:H20	37.6598 Pa	0.0055 (p.si	Heat Transfer Coefficients	7.8e-11 7.8e-12
System Air-Side Resistance	0.0000 Pa	0.0 in H20	8.0000 Pa	6.8000 psi		
Total Air Side Precoure Drop	27.6598 Pa	0.15119 in H20	27,6598 Pa	6.0055 pei		Tube-14 Tube-15
Refrigerant Pressure Drop	69436.6018 Pa		69436.6018 Pa	\$0.0799 pai		7.8e-35 7.6e-17
Refrigerent Set. T Drop	L0879 K		1.0679 ×	1.8582 **	HX.Langth- 1583 80.83 38	
Outlet Canditions						Tube-19 Tube-20
Avg. Air Outlet Temperature	305.2697 K		345.2687 K	89.8154 19	Charge - 003 kg / 007 kp 005 kg / 012 km	1.8e-21 1.8e-22 ¥
Avg. Air Optiet Wethulb Temperature	293,7229 K		293,7229 K	69,0510 15		1.6e-22 *
Avg. Air Oublet lisebuib temperature Avg. Air för	291,7239 K		24,5458 %	24,0658 %	Hort, John Charles and During and State and St	Chould Command
Avo, Refrigerent Outlet Pressure	2001215.5942 Pa		2004205.3982 Pa	305,7004 pail		Lines II Command
Avo, Refrigerent Oxfet Temperature	308,0533 K		368,8532 K	94,5290 77		
Avg. Rehigerant Outlet Quality	-0.1145		-0.1149	-0.3146	0 20 40 60 80 100	
Avp. Refrigerant Sat. Delta	-5.0425 K		-5.0415 K	-16.2747 19	Refrietrat Place via Datibution	



Small Diameter Design Considerations



• Refrigerant Choice

Material Cost



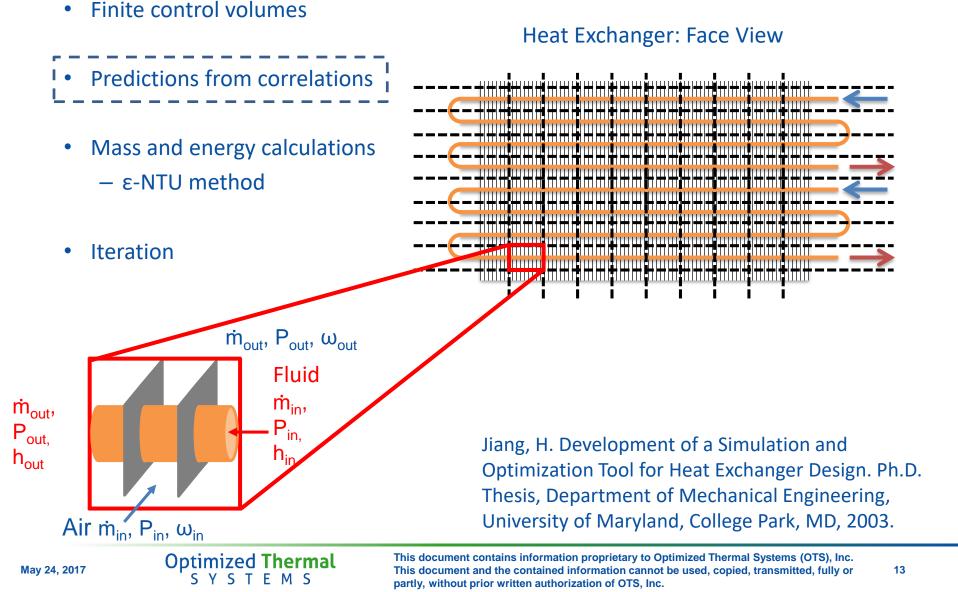


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Modeling Fundamentals

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Demonstration

Modeling in CoilDesigner®

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Example HX – Geometry Details



5 mm Condenser with Louver Fins

Parameter	Dimension
Tube configuration	1x24
Finned length	547 mm
Tube OD	5 mm
Tube pattern	19.05 x 16.5 mm
Fin thickness	0.1 mm
FPI	15
	and the second second



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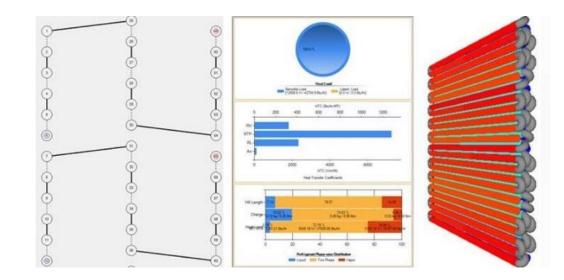
Example HX – Operating Conditions



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R-410A Testing

Tain	RH in	Air flowrate	Ref P in	Ref T in	Ref mdot
К	%	m3/s	Ра	К	kg/s
301	45	0.97	2,735,642	322	0.028



Input into CoilDesigner[®]....

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Example HX – Experimental Testing





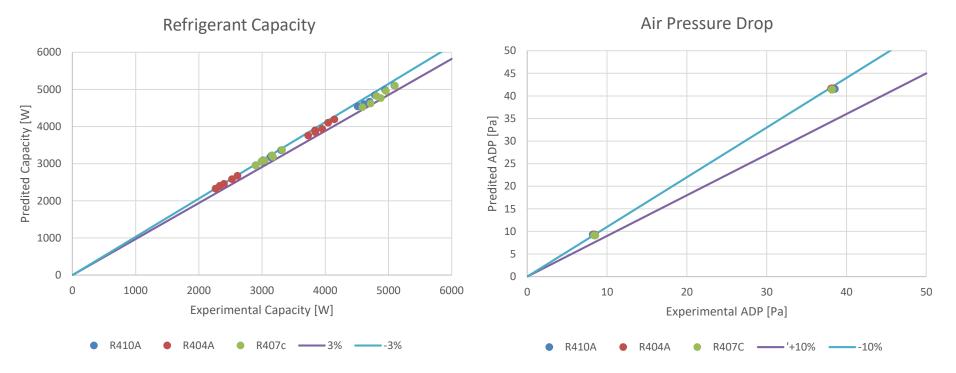
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Example HX – Experimental Results



ADP	Trefout	Prefout	RDP	Taout	Rhaout	Ref capacity	Subcooling coil out
Ра	K	Ра	Ра	K	%	W	К
38.4	310	2,652,371	83271	305	21	4702	6.5



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Applications

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Drop-In Replacement Condenser



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- Baseline design:
 - 3/8" OD tubes
 - 2x22 tubes in 1" equilateral stagger
 - 18 fins per inch
 - 700 x 559 x 44 mm
- Requirements:

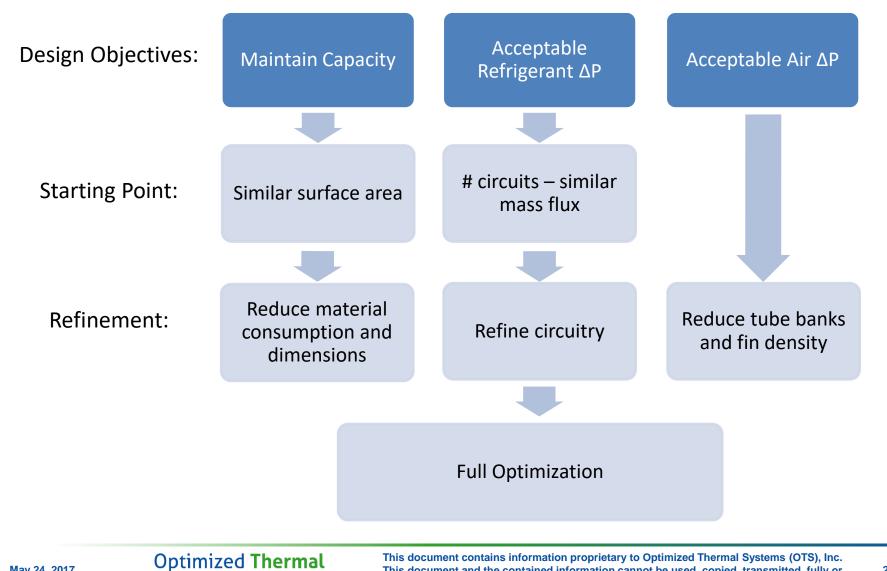
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- Maintain 4 kW capacity
- Do not increase air ΔP significantly beyond baseline: 27 Pa
- Do not increase refrigerant ΔP significantly beyond baseline 6.4 kPa

Replace 3/8" tube heat exchanger with 5 mm coil

Drop-In Replacement Condenser (2)





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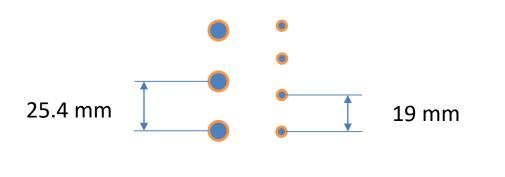
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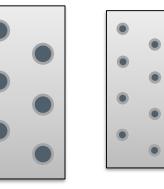
5 mm Layout



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- Baseline design has 2x22 tubes with 1" vertical spacing
- Typical 5 mm vertical spacing is 19.05 mm:
 - Keep even number: 28 tubes vertically
- Baseline fin density is 18 FPI
 - External heat transfer area is 22.6 m²
 - 2-row 5mm pattern requires 24 FPI to achieve equivalent surface area
 - 3-row 5mm pattern meets this surface area with 16 FPI





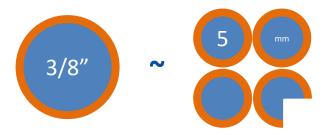
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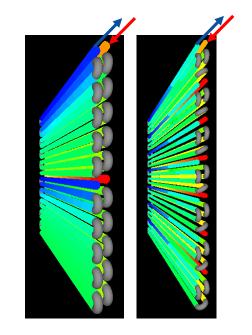
Circuiting



- In order to maintain acceptable refrigerant pressure drops, the mass flux through tubes should not increase significantly
- Baseline has 2 circuits, mass flux, $G = \frac{\dot{m}}{A} = \frac{0.02065 \left[\frac{kg}{s}\right]}{2*\frac{\pi}{4}(0.00886 [m])^2} = 167 \left[\frac{kg}{m^2 * s}\right]$
- With 5 mm tubes, ID = 4.6 mm;

# Circuits	Mass flux [kg/m²s]
6	207
7	177
8	155





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- 3-row, 16 FPI design has a 27 Pa pressure drop and improved performance
 - FPI could be reduced further to reduce costs and maintain capacity
- 2-row 24 FPI design has a 37 Pa air-side pressure drop: nearly a 40% increase
 - Consideration of fan curve, may allow for lower FPI design to operate at higher air flow rate and increased capacity
 - We can investigate designs that operate with equivalent fan power ($\propto Q\Delta P$)

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Summary of Candidate Designs



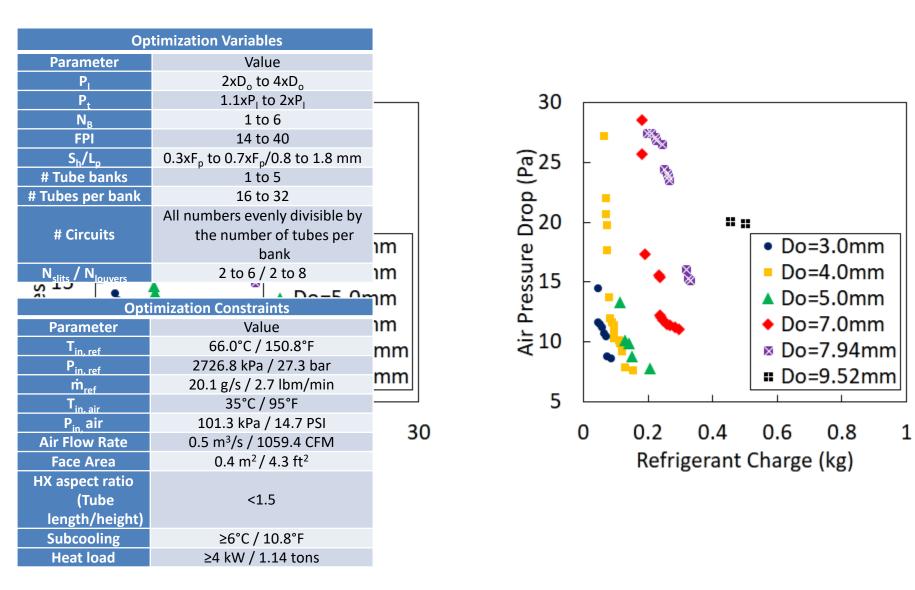
Design	16 FPI – 3 row, 7 circuits	16 FPI – 3 row, 14 circuits	24 FPI – 2 row	17 FPI – 2 row
Air Flow Rate	100%	100%	100%	110%
Air ∆P	100%	100%	135%	83%
Fan Power	101%	101%	135%	91%
Capacity	102%	100%	99%	97%
Refrigerant Pressure Drop	139%	23%	114%	118%
Tube Material	61%	61%	40%	40%
Fin Material	86%	86%	90%	61%
Apprx. Tube Internal Volume	52%	52%	34%	34%

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Heat Exchanger Optimization





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Summary

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5 mm HX: A Closer Look



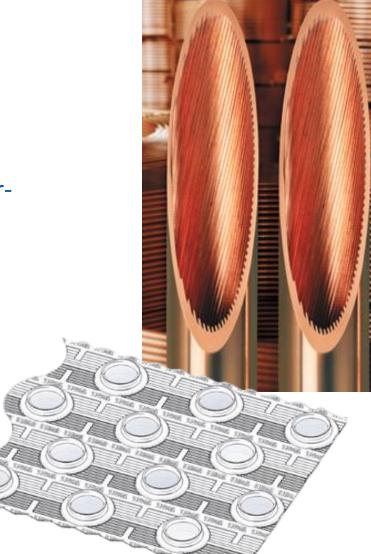
MicrogrooveTM tube:

- Less material consumption
- Internally-enhanced → increased refrigerant heat transfer
- Smaller diameter → increased airside heat transfer

External fins:

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- Customizable, with complex enhancements
- Higher fin densities
- Higher heat transfer



5 mm HX: Putting It All Together



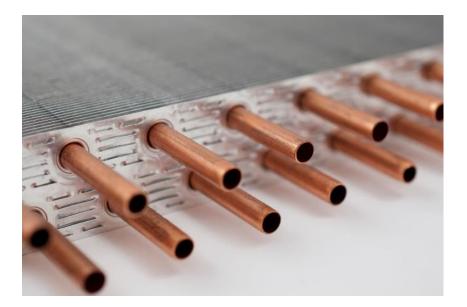
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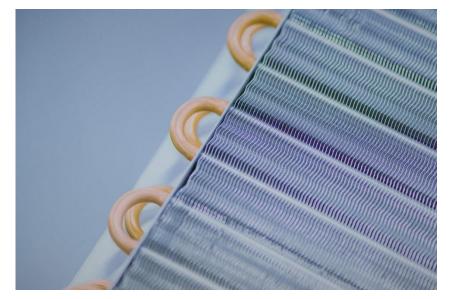
Manufacturing:

- Tube expansion with mechanical or pressure expansion
- Equipment available for tube insertion and fin stacking

Design:

- Select fin and tube arrangement for acceptable air pressure drop
- Design number of circuits to maintain refrigerant pressure drop
- Utilize simulation and optimization tools to maximize performance





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Next Steps



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- Provide your feedback! Complete the webinar surveys
- Q&A summary sheet to be provided with webinar download materials
- Don't forget to download a copy of the CoilDesigner[®] demo
- Want a sample heat exchanger?
 - Complete surveys for all three webinars
 - Examine, measure, test, share results

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Thank you

Q&A

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