Longitudinal Heat Conduction in Finned-Tube Evaporators

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Seminar 1
Advances in Air-to-Refrigerant Heat Exchangers
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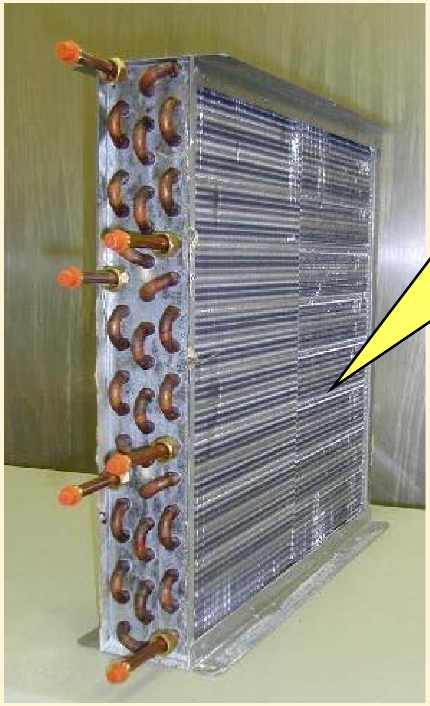
Source publications
Payne, W.V, Domanski, P., 2003, “Potential Benefits of Smart Refrigerant Distributors”, ARTI-21CR/605-200-50-1, http://www.bfrl.nist.gov/863/HVAC/pubs/index.htm
Domanski, P.A., **Choi**, J.M., **Payne**, W.V., 2007, “Longitudinal Heat Conduction in Finned-Tube Evaporators”, 22nd IIR Int. Congress of Refrigeration, Aug. 21-26, 2007, Beijing, China, http://www.bfrl.nist.gov/863/HVAC/pubs/index.htm

Background



Questions:

How significant are longitudinal heat conduction effects?

Can they be neglected?

OUTLINE

- Literature Review
- Experimental Setup and Test Program
- Experimental Results
- Discussion
- Conclusions

Literature Review

- Kays and London (1984)

Longitudinal tube heat conduction

Capacity degradation ↑ $\lambda = \frac{kA_w}{LC_{min}}$ ↑ $\frac{C_{min}}{C_{max}}$ ↑ NTU ↑ $(\varepsilon > 0.9)$

- Ranganayakulu et al. (1996)

Finite element simulation study; longitudinal tube heat conduction

$$\tau = \frac{\varepsilon_{NC} - \varepsilon_{WC}}{\varepsilon_{NC}} = f(\varepsilon_{NC},\ \lambda,\ \frac{C_{min}}{C_{max}}, \mathrm{NTU}) \qquad (\varepsilon > 0.8)$$

- Heun and Crawford (1994)

Analytical study; multipass, cross-counterflow, single-depth-row hx, fin conduction

Capacity degradation ↑ Fin conductance ↑ $\frac{A_a h_a}{\dot{m} c_{pa}}$ ↑

Literature Review (cont.)

- Romero-Mendez et al. (1997)

  Analytical study; single-row finned-tube heat exchanger; fin conduction

  Capacity degradation as high as 20 %

- Asinari et al. (2004)

  Hybrid finite-volume and finite-element study, CO_2 microchannel gas cooler

  Longitudinal conduction in fins, transverse and longitudinal conduction in tubes give negligible effect on the total heat flow

  Capacity degradation is negligible (1.1 %)

- Park and Hrnjak (2007)

  Experimental and simulation study; CO_2 microchannel gas cooler

  Capacity improvement 1.9 % - 3.9 % by cutting some fins.

  The authors emphasize the importance of circuitry design

- Other papers by Prasad, Shah, Chiou, Chinese researchers

Heat Exchangers Tested

Common design features:

- 3 depth rows with 18 tubes per row
- 9.5 mm outside diameter
- 457 mm long round copper tubes
- 25.4 mm tube spacing in a row
- 3 parallel refrigerant circuits
- 0.1 mm thick aluminum fins

HX-wavy, HX-slit, HX-slit-cut

HX-slit-cut

Design differences:

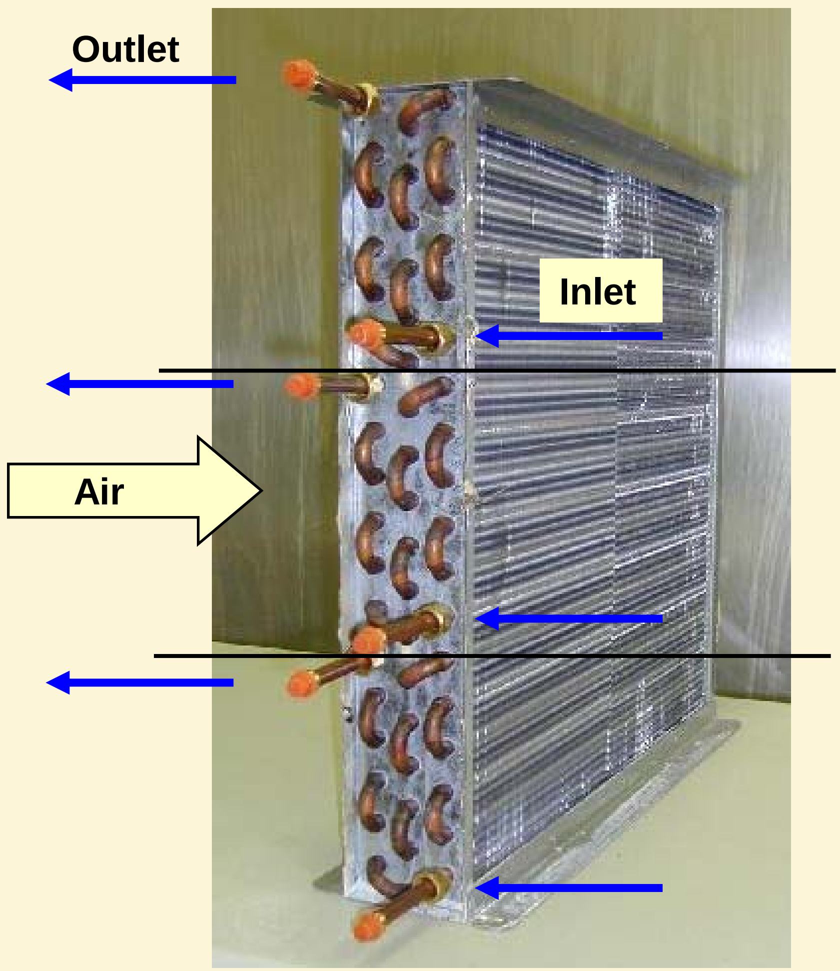
HX-wavy: used wavy fins

HX-slit: used slit fins

HX-slit-cut: depth rows separated by a cut in fins; slit fins

Three Refrigerant Circuits

Cross-counter flow configuration



Test Conditions

Air:

Dry bulb: **26.7** °C ± 0.3 °C

Dew point: **15.8** ± 0.3 °C

Refrigerant

Condenser exit

T_{sat} : **48.9** °C ±1.4 °C

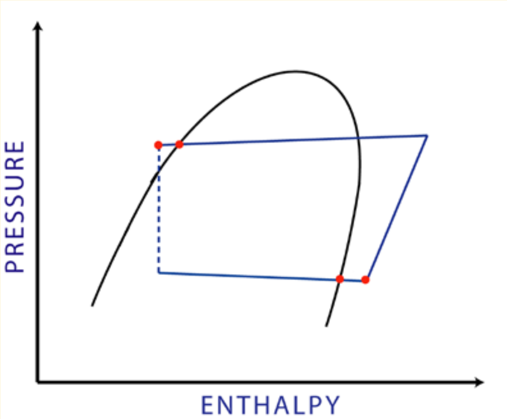
$T_{subcooling}$: **8.3** °C ±1.4 °C

Evaporator exit

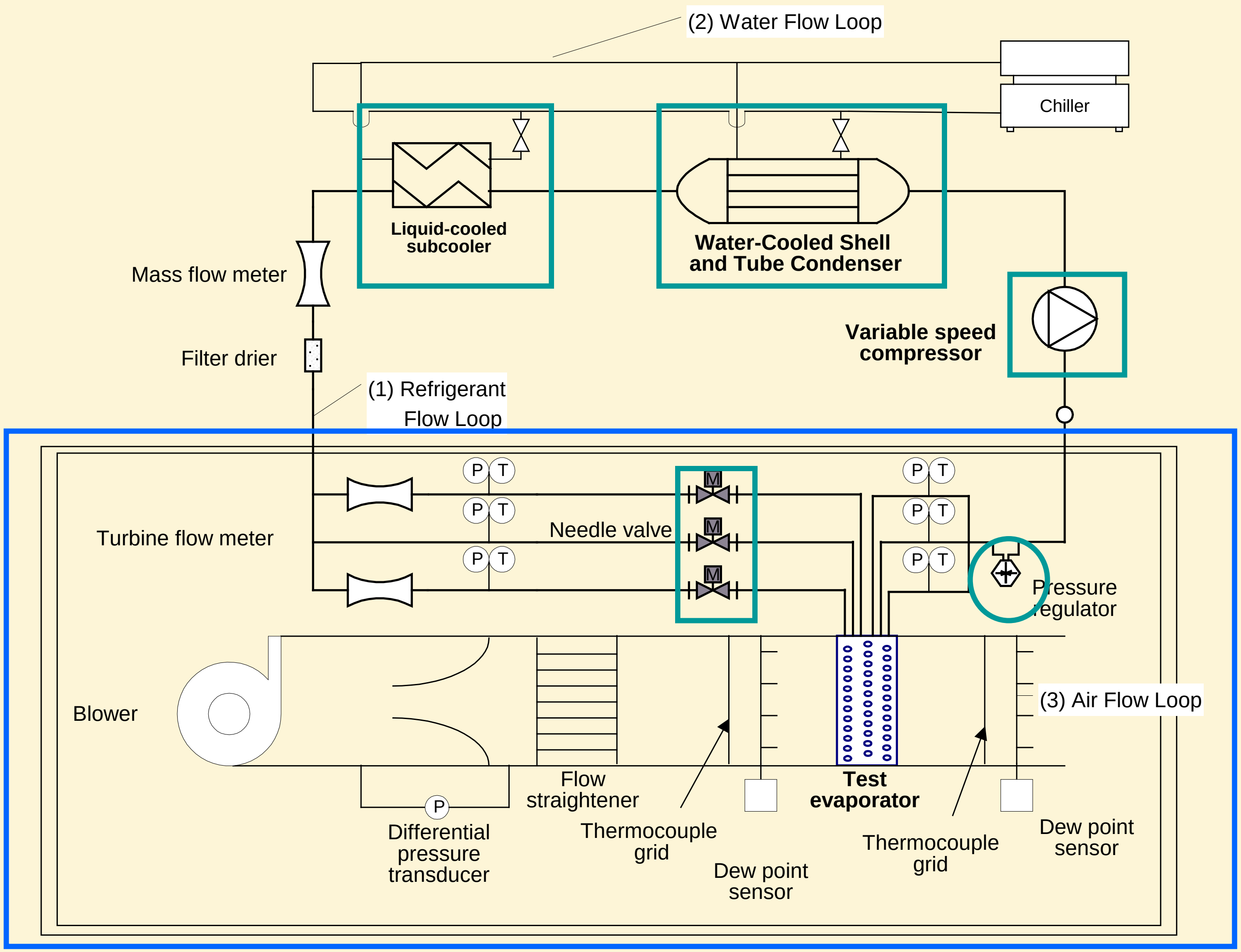
T_{sat} : **7.2** °C ±0.3 °C

$T_{superheat}$: **5.6** °C or **16.7** °C ±1.4 °C

Test	Air Volumetric Flowrate (m³/h)		Overall Exit Superheat (°C)		
			Superheat in Individual Three Circuits (°C)		
	1300	**1700**	**5.6**	**16.7**	**5.6**
			5.6/5.6/5.6	16.7/16.7/16.7	**?/**16.7/16.7
1	x		x		
2	x			x	
3	x				x
4		x	x		
5		x		x	



Experimental Setup



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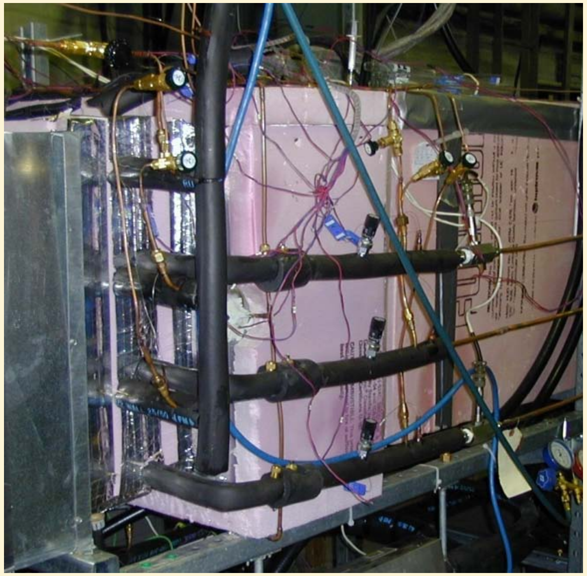
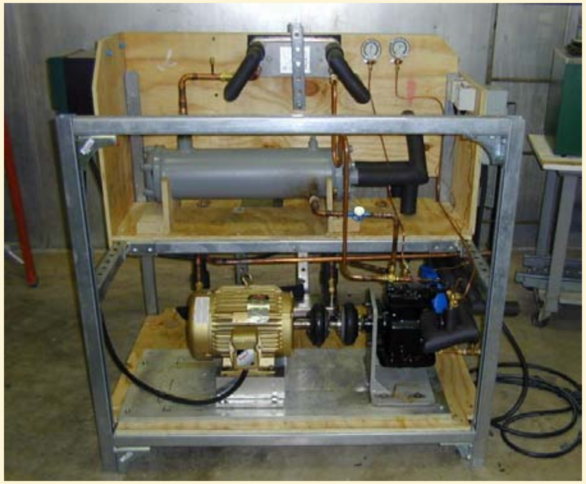




Measurement Uncertainties

(95 % confidence level)

Evaporator capacities: within ± 5 %

All air-side and refrigerant-side capacities were within 5 %.

Return bend temperatures: ± 0.5 ºC

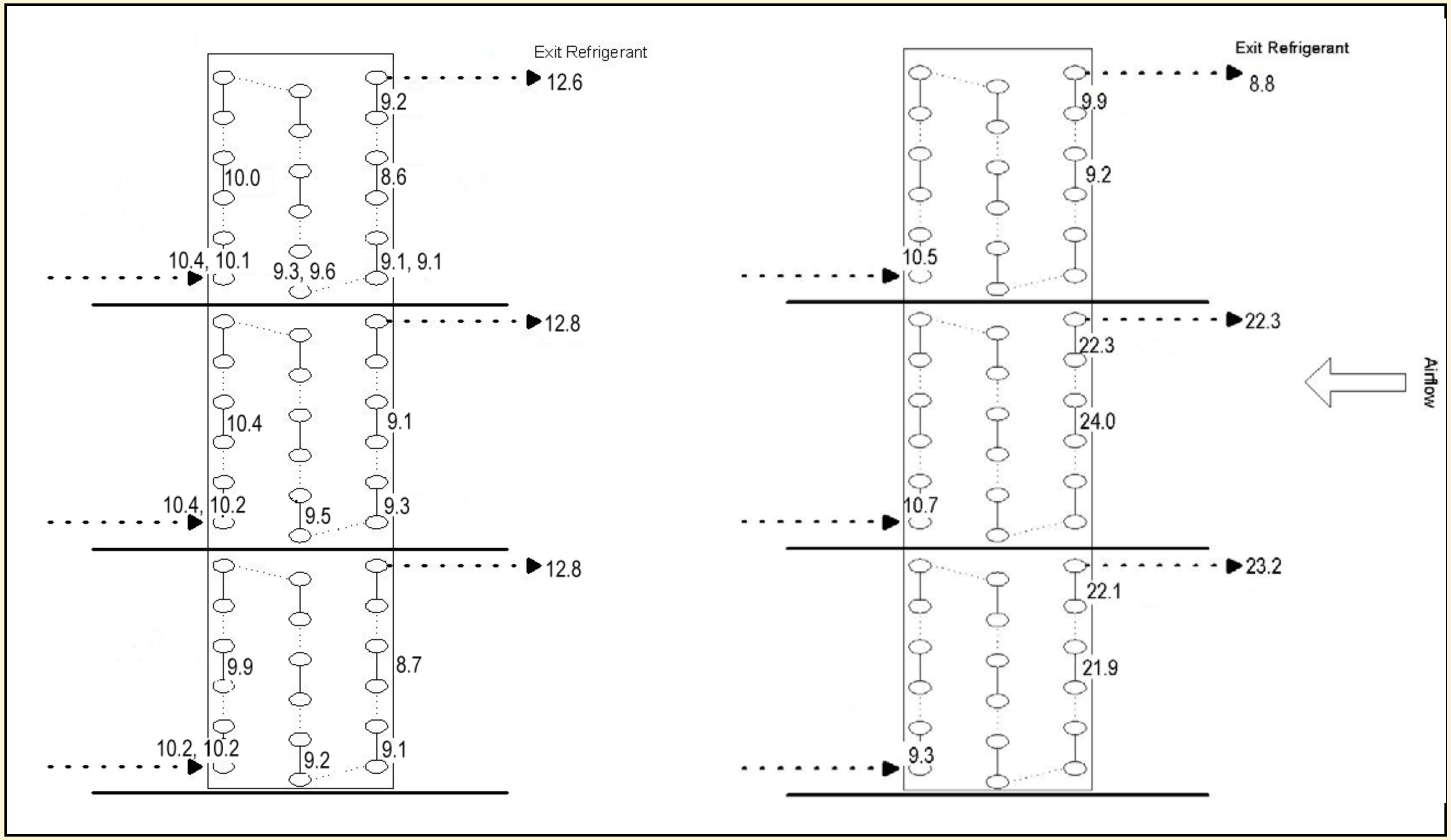
Thermocouples were

- calibrated with the data acquisition system
- placed on return bends using a conductive paste and copper tape, attached with plastic “zip” ties
- thermally isolated from air using a foam insulating tape.

Return Bend Temperatures

HX-wavy, overall superheat 5.6 ˚C

Individual superheats: 5.6/5.6/5.6 ˚C **Individual superheats: ?/16.7/16.7 ˚C**

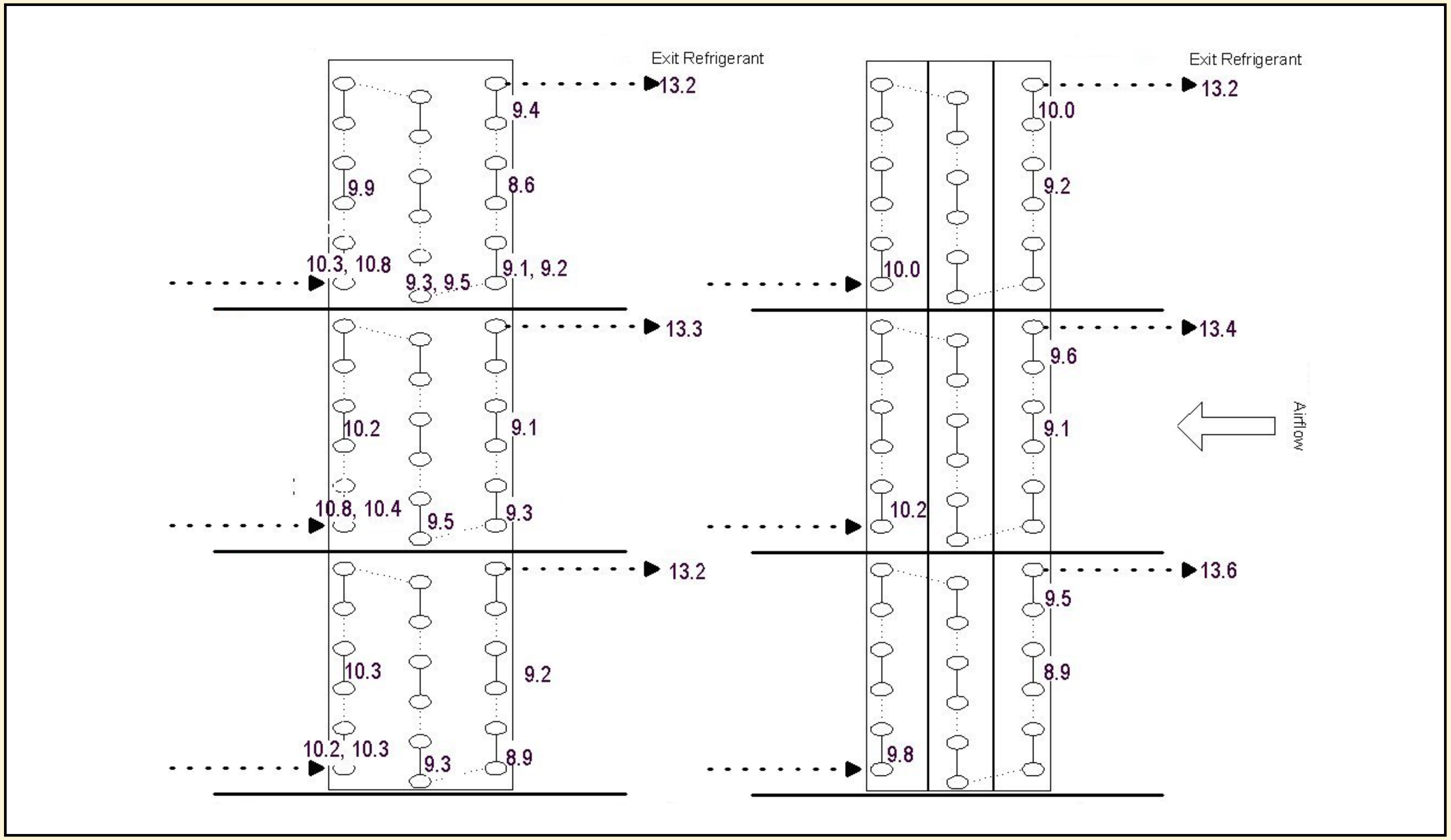


Test 1 Test 3

Return Bend Temperatures

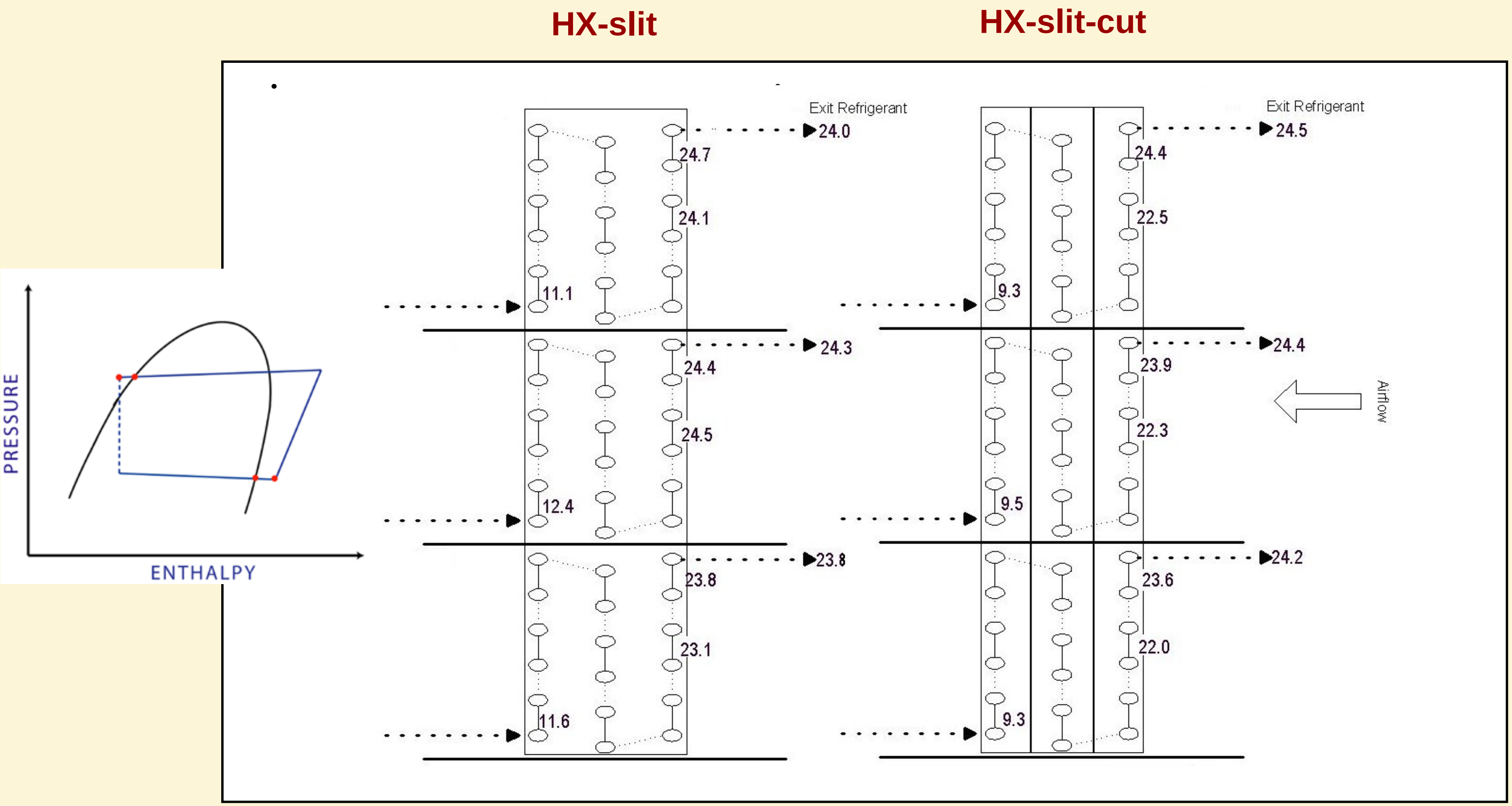
Uniform superheat: 5.6 °C,   Test 1

- **HX-slit**
- **HX-slit-cut**

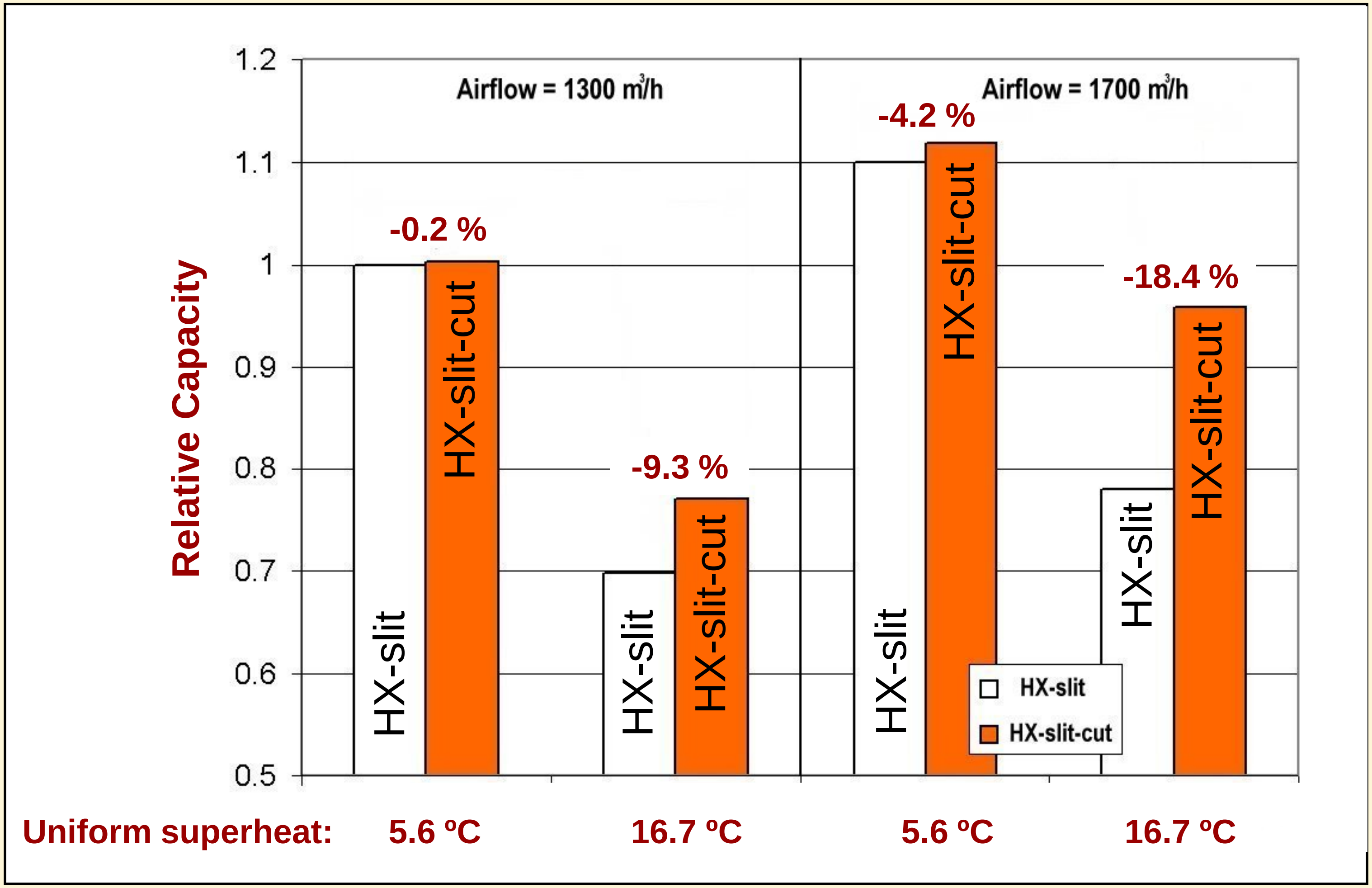


Return Bend Temperatures

Uniform superheat: 16.7 °C, Test 2

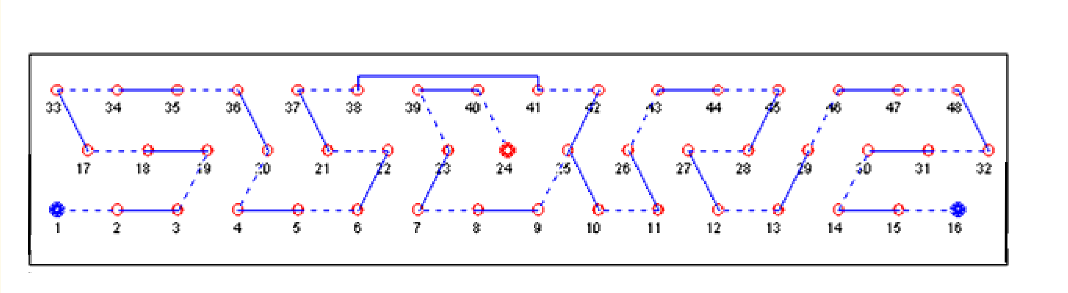


Capacity: HX-slit and HX-slit-cut



Discussion

What is the contribution of the tube longitudinal conduction to capacity degradation?



4.9 kW evaporator

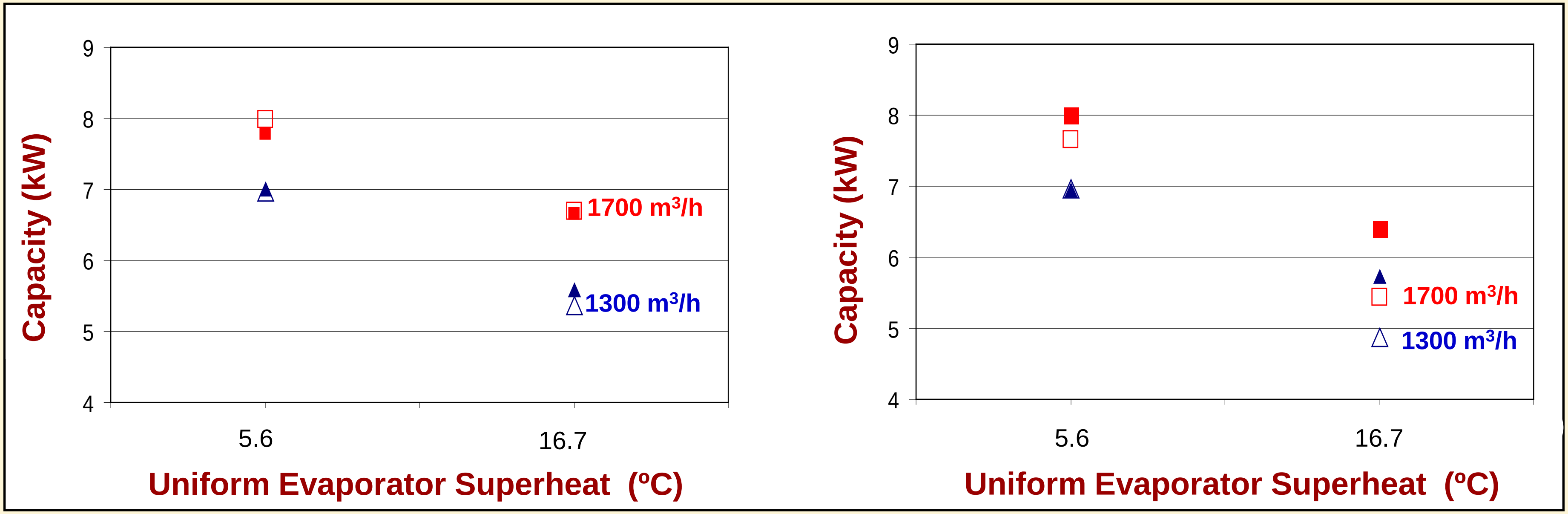
Evaluated tube # 15 using charts by Ranganayakulu et al. (1996):

$$\lambda = \frac{kA_w}{LC_{min}} = 0.0011 \qquad \frac{C_{min}}{C_{max}} = 0.411 \qquad NTU = 0.368$$

$$\tau = \frac{\varepsilon_{NC} - \varepsilon_{WC}}{\varepsilon_{NC}} = 0.0005 \qquad \varepsilon_{NC} = 0.29$$

Capacity: Tests versus Simulations

EVAP-COND **does not** account for longitudinal heat conduction



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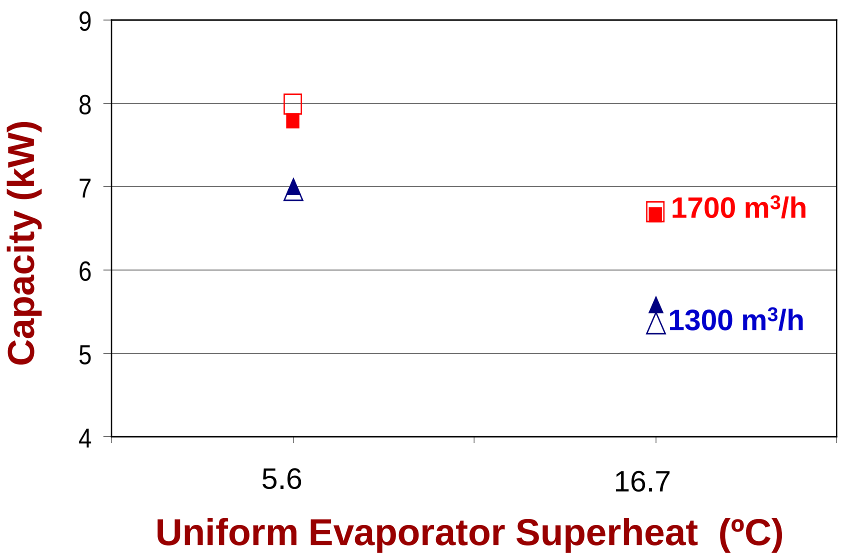
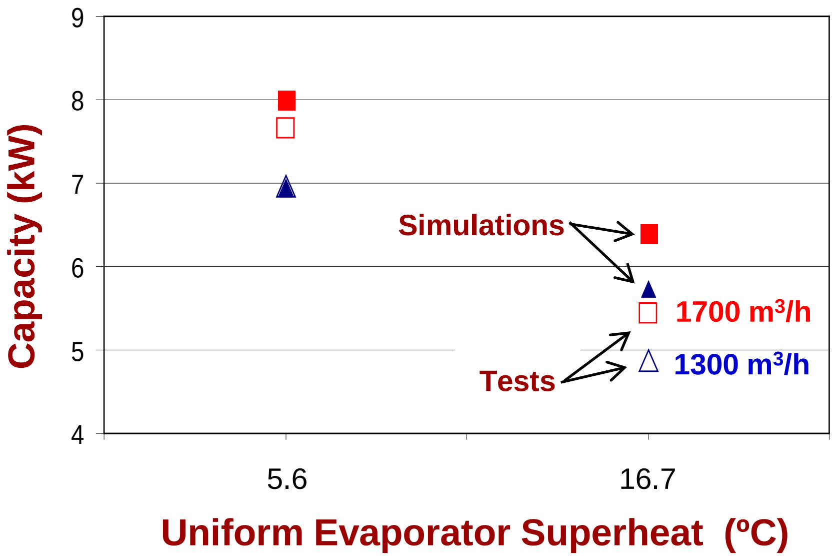
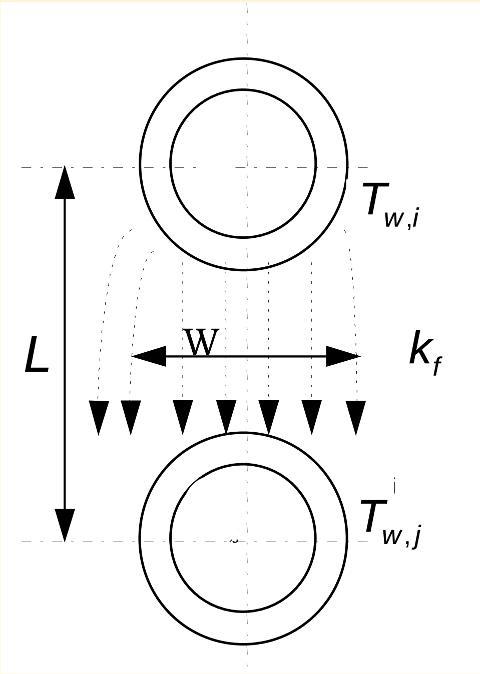
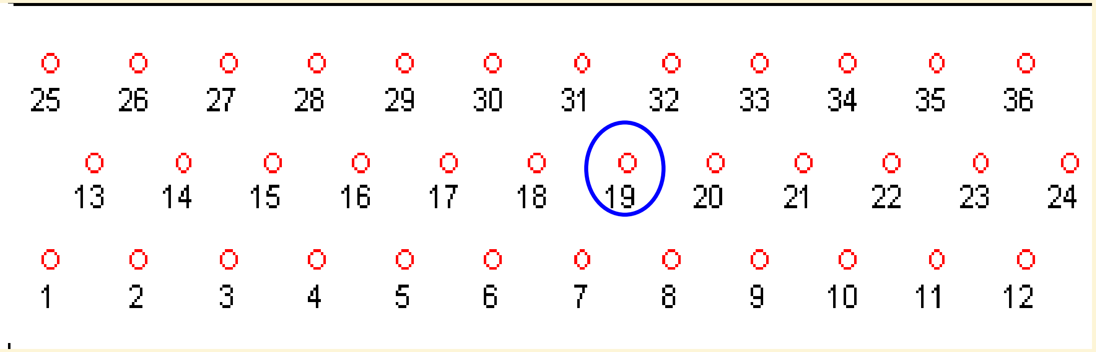




Tube-to-Tube Heat Transfer



$$(Q_{fin})_{i,j} \approx \frac{W t_f k_f}{L}\left(T_{w,i} - T_{w,j}\right)$$



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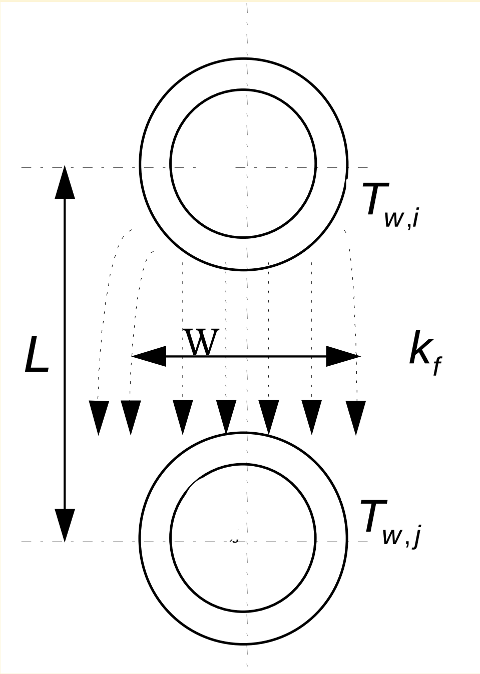

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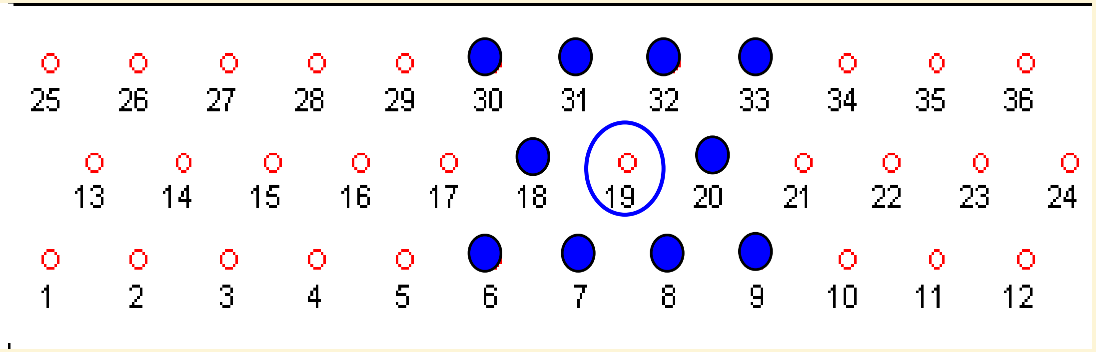

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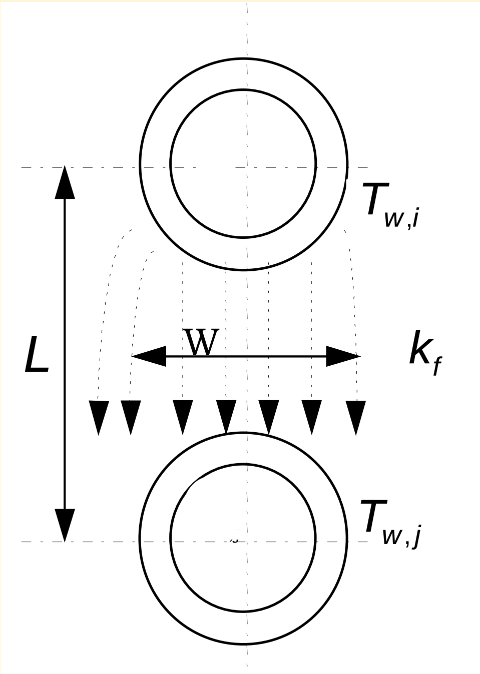

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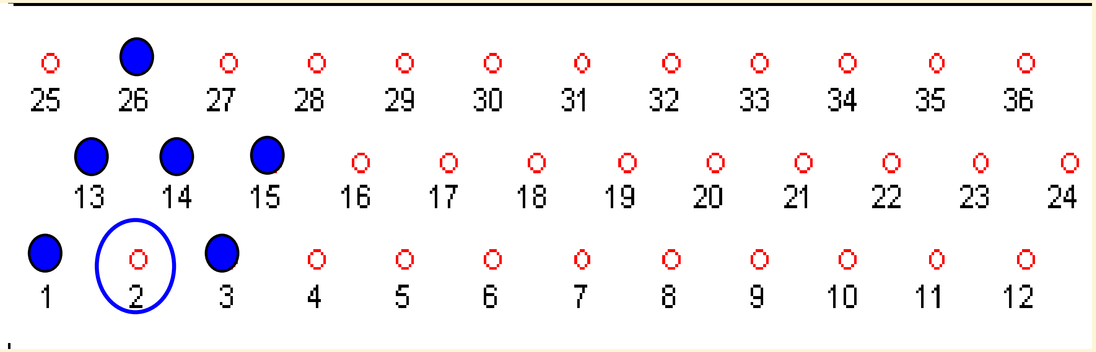
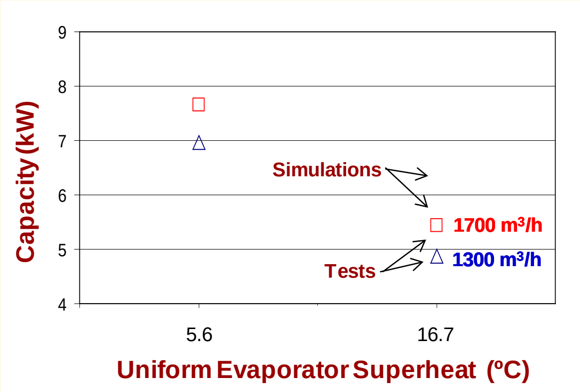
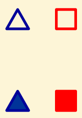


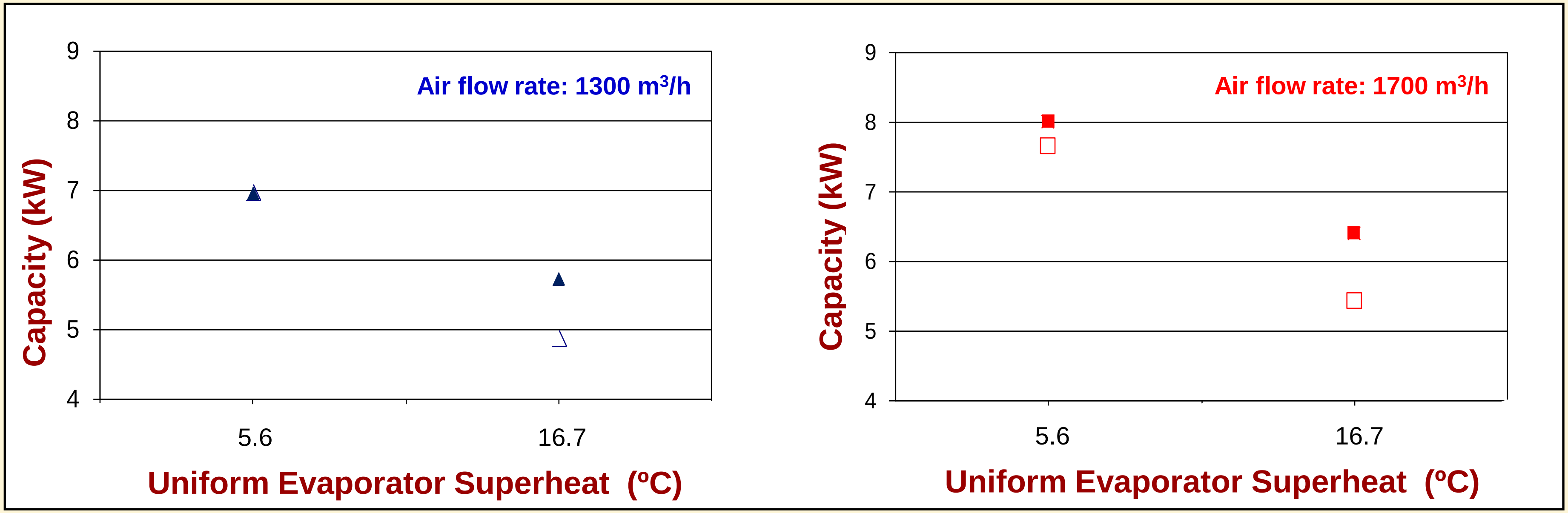
Capacity: Tests versus Simulations





Experiment

Simulations <u>without</u> internal heat transfer



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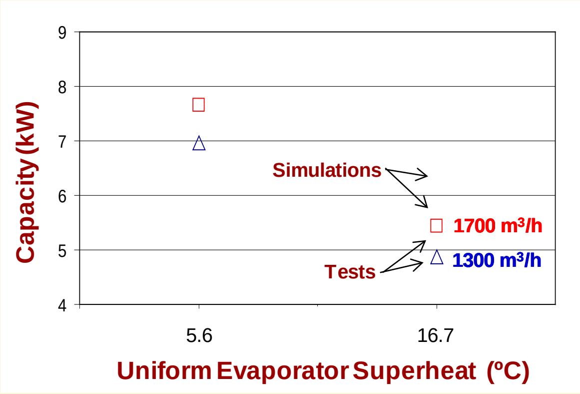
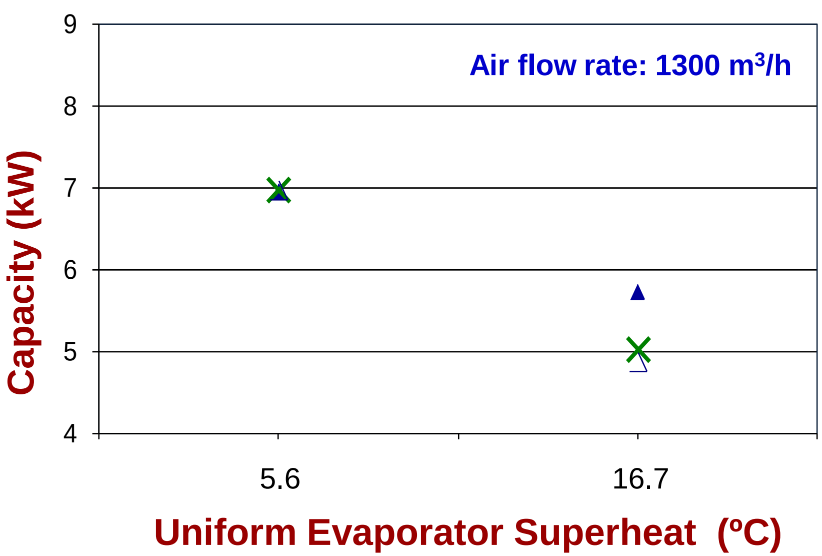
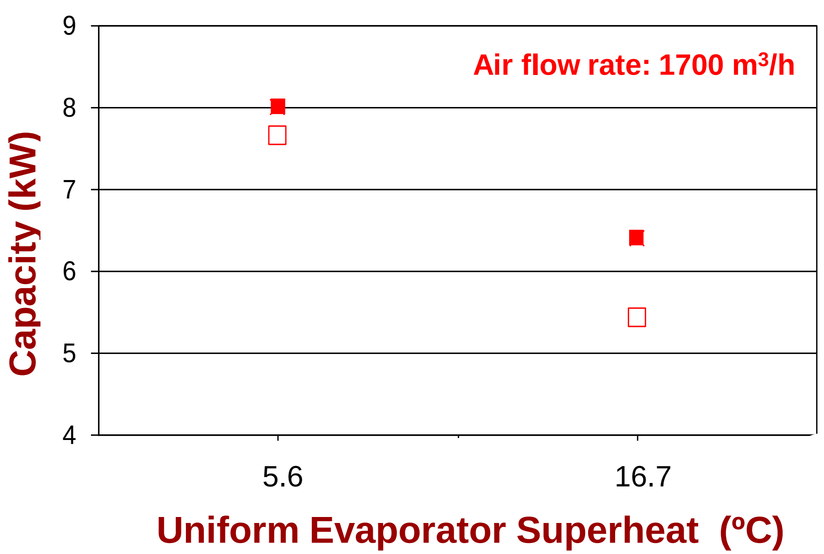


△ □ Experiment

▲ ■ Simulations <u>without</u> internal heat transfer

✕ Simulations <u>with</u> internal heat transfer





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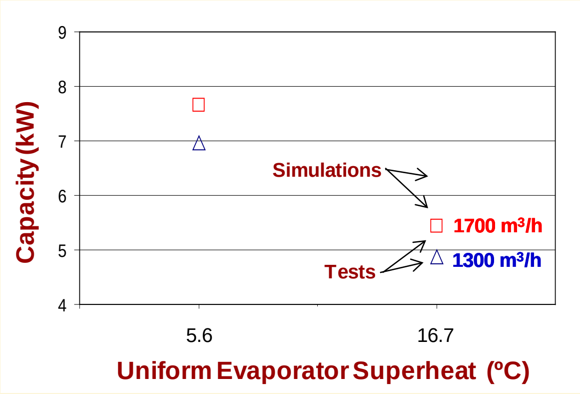

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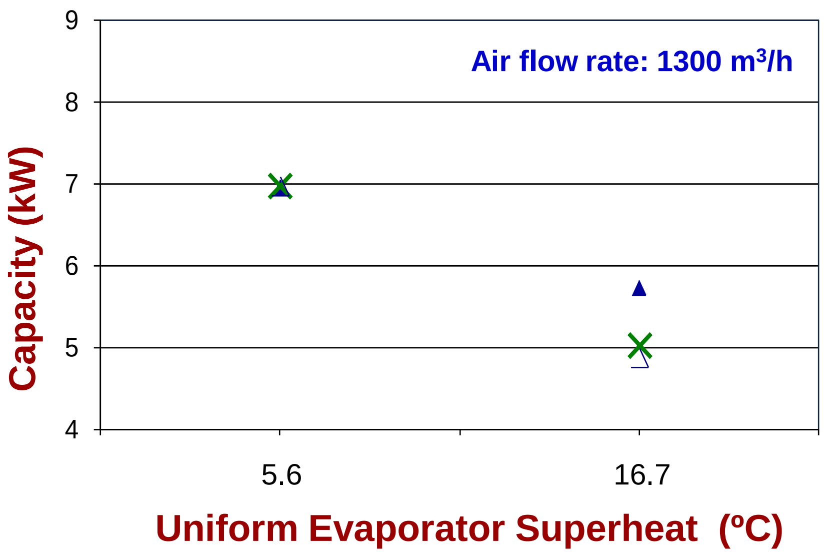

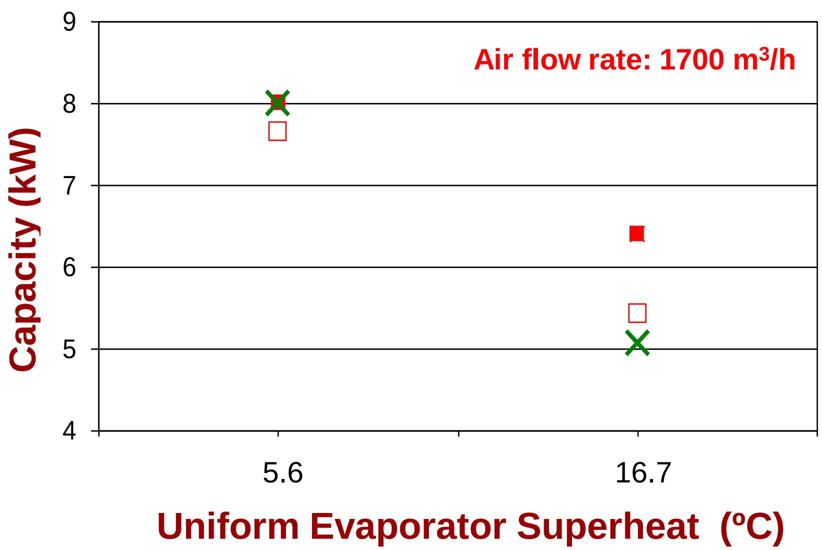

Conclusions

- Capacity measurements on HX-slit and HX-slit-cut evaporators are

  - very similar for 5.6 °C refrigerant exit superheat
  - different by as much as 18.4 % for 16.7 °C refrigerant exit superheat

- Air flow rate affects the difference in capacity between the HX-slit and HX-slit-cut

- Capacity measurements, pattern of measured return bend temperatures, and theoretical analysis indicate tube-to-tube heat transfer as the cause of capacity degradation

- It is desirable to account for tube-to-tube heat transfer in heat exchangers in which large differences in tube temperatures exist