New Capabilities of the Mark VI Web Version of the DOE/ORNL Heat Pump Design Model

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USNC/IIR Short Course on Simulation Tools

July 2004

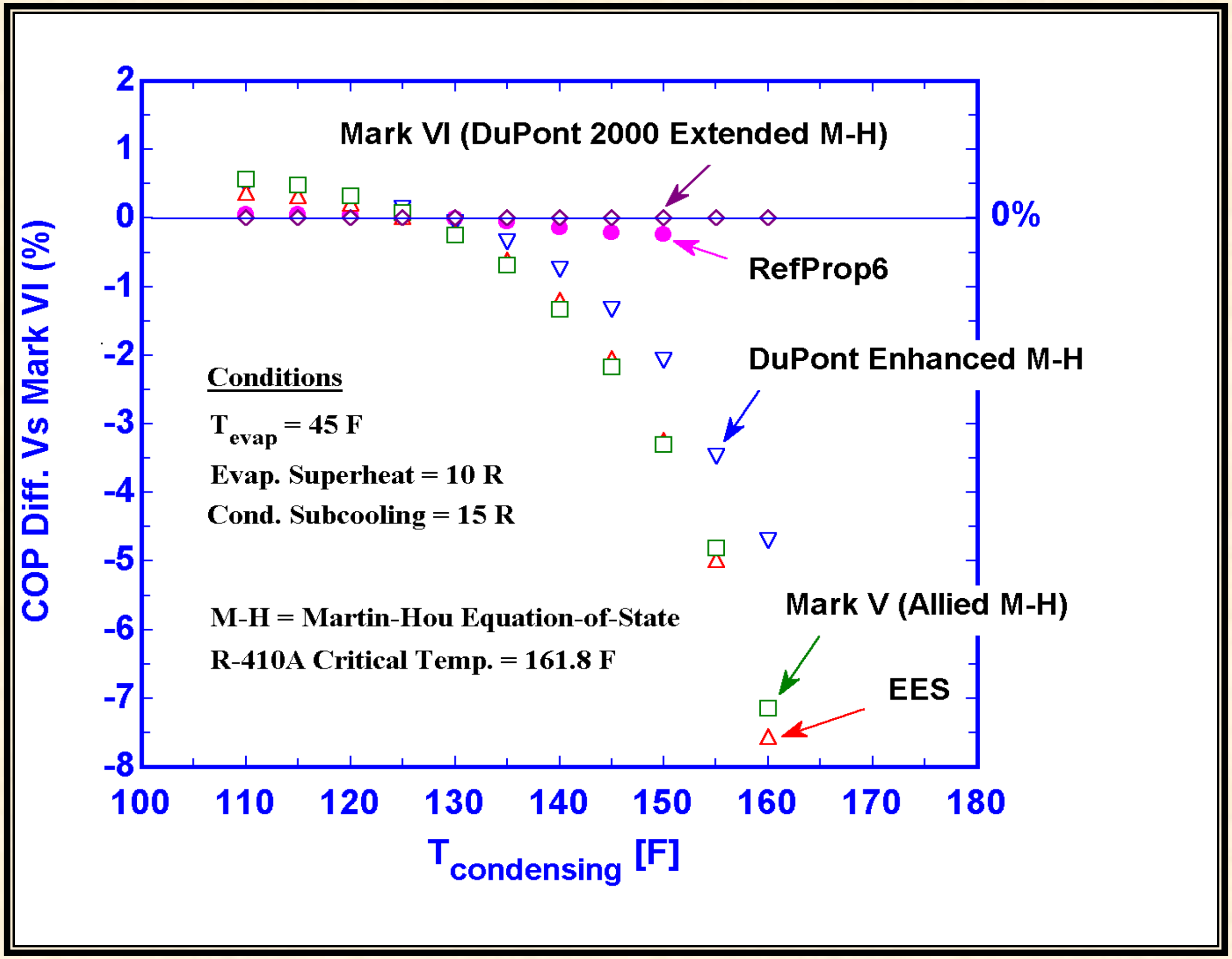
New Mark VI Web Model Features

- Improved HFC Properties and HT Correl’s
- Condenser Circuit Merging Capability
- Improved Airflow Calculation Options
  - Fixed flow for manuf. performance tables or
  - Mass flow varying with fan inlet conditions
    - Better airflow and fan power predict. with amb
- More Air-Side Surface Choices

Mark VI Model Improvements

- More HFC-Capable
  - New Properties for HFC Mixtures
    - Improved Near-Critical and Transport Props
  - HFC-Suitable Two-Phase H.T. Coefficients
    - Evaporating and Condensing
  - HFC-Suitable Flow Controls
    - Cap- and Short- Tube Correlations for R-410A

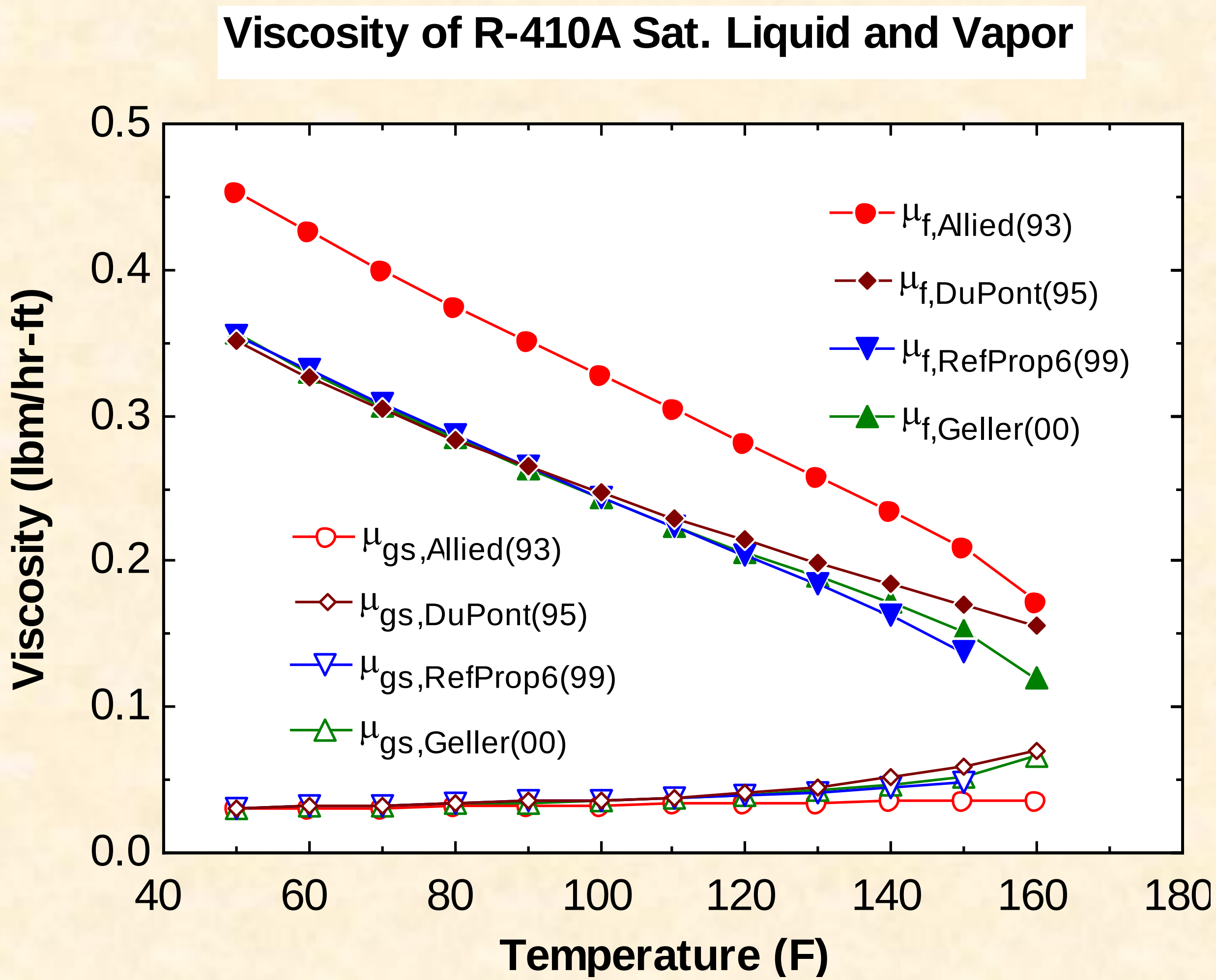
Cooling COP Comparisons for R-410A Over a Range of Condensing Temps With Different Property Representations



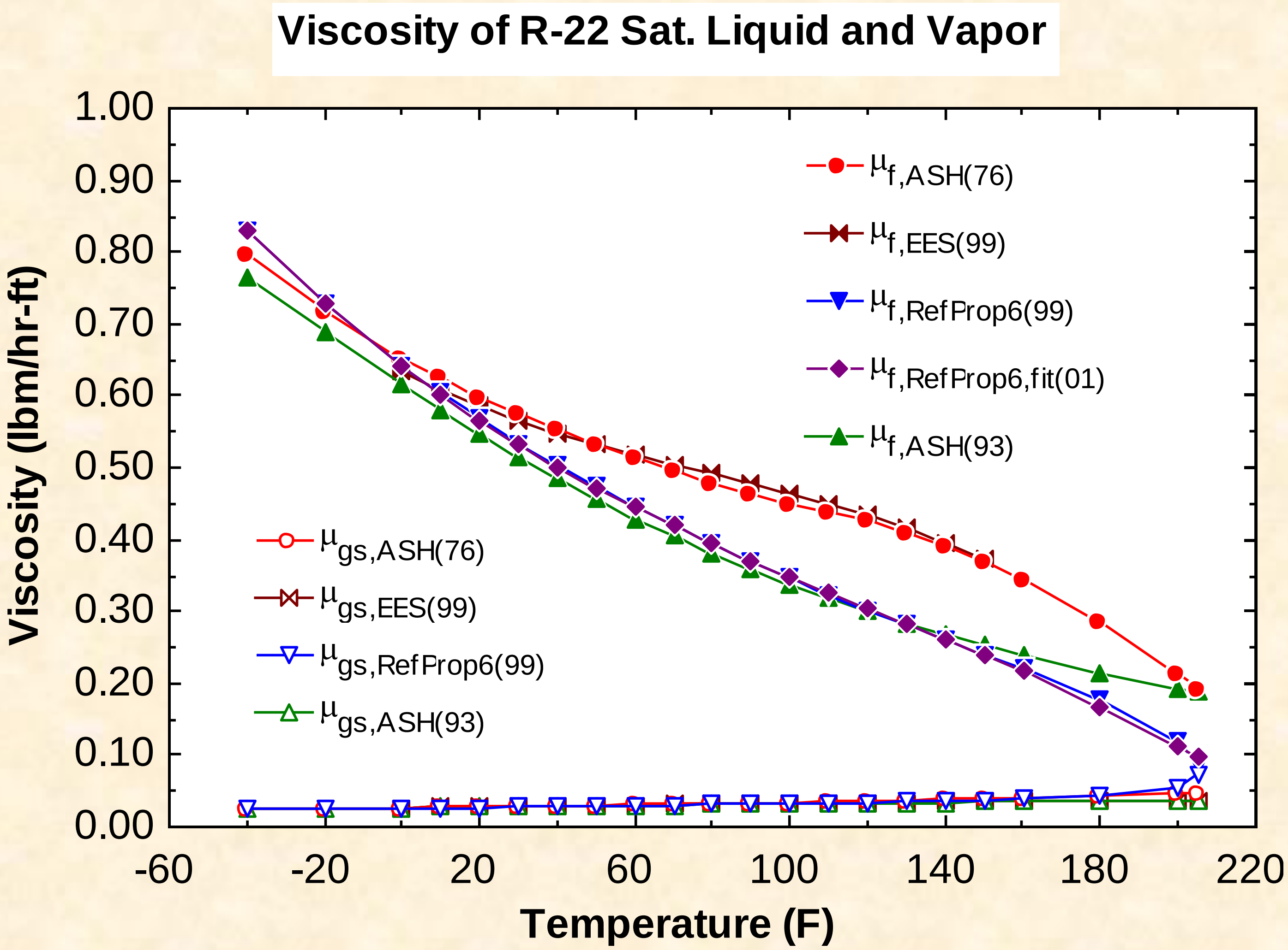
Mark VI Model Improvements

- **Improved Transport Properties**
  - Updated Correlations for HFC Mixtures
    - From Allied (93) to Geller (2000)
    - For viscosity, thermal conductivity
  - Updated Liquid Viscosity Correlation for R-22
    - From ASHRAE (76) to curve fit to RefProp6 (01)

Improved R-410A Transport Properties
- - Viscosity - -



Improved R-22 Transport Properties
- - Liquid Viscosity - -



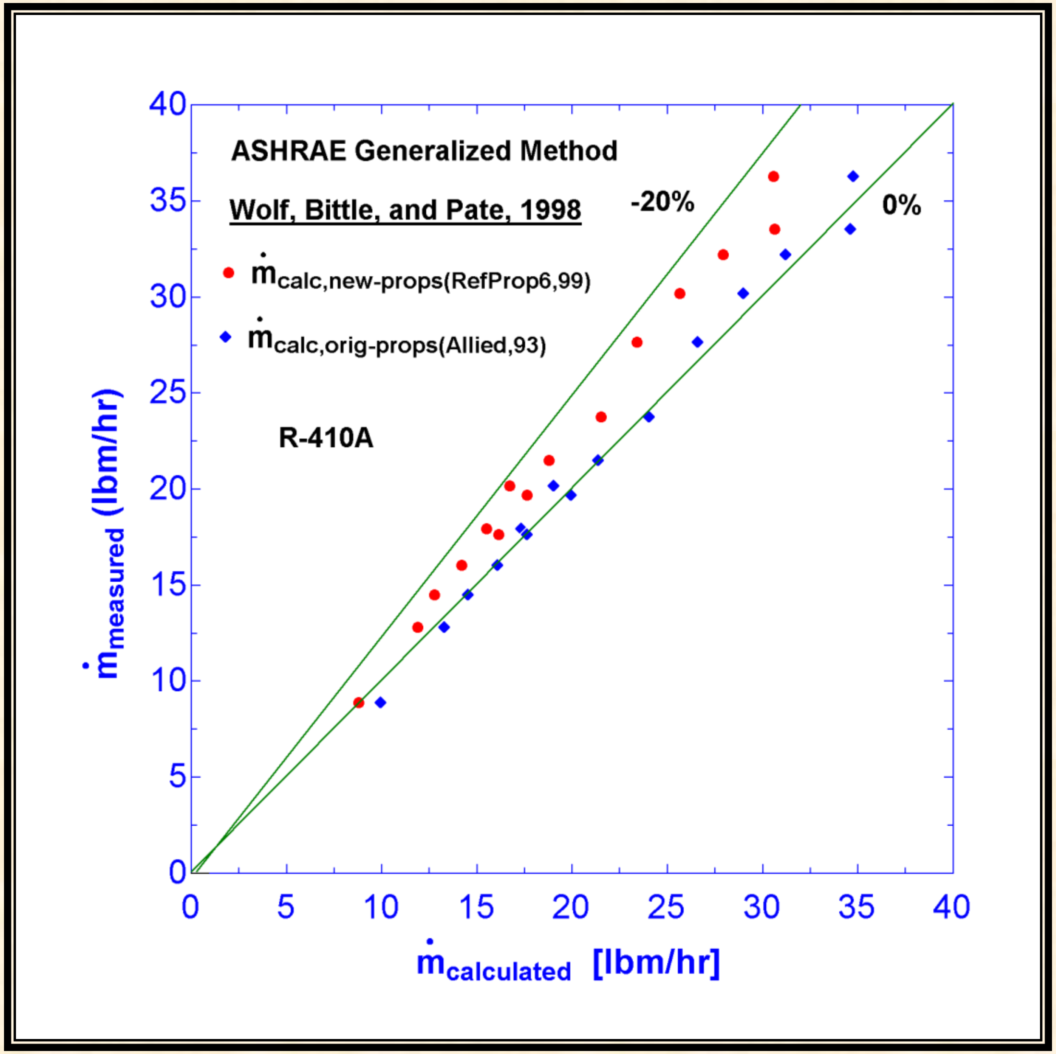
Mark VI Model Improvements

- **HFC-Suitable Two-Phase H.T. Coefs.**
  - Condensing --Dobson/Chato (1994)
  - Evaporating -- Bivens/Yokozeki (1994)
    Dryout point set at 0.90, interpolate to vapor values at x=1
  - For R-410A, 25% lower condensing and 35% lower evaporating h.t. coefs than previous R-22 based correlations

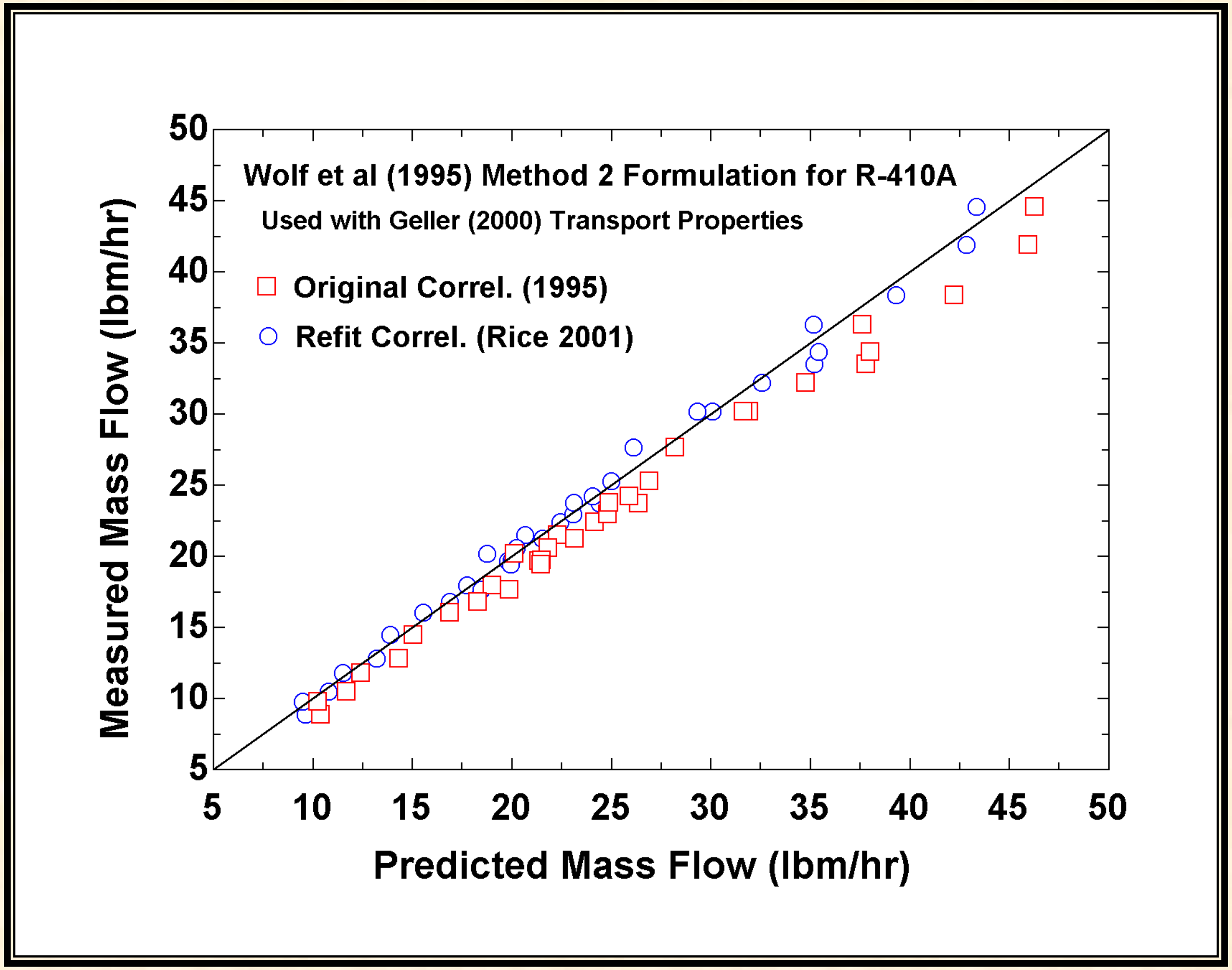
Mark VI Model Improvements

- HFC-Suitable Flow Control Correlations
  - Using Refrigerant-Specific for Best Accuracy
    - R-410A Specific Cap-Tube Correlation (Rice 2001)
      - refit of Wolf et al (1995) R-410A-Specific Correlation
      - used instead of ASHRAE generalized cap-tube correlation (Wolf et al 1998)
        - latter found to be flawed due to viscosity property changes (see plot which follows)
    - R-410A Short-Tube Orifice Correlation (Payne 1999)

Capillary Tube Mass Flow Predictions with Generalized ASHRAE Model Using Different Transport Property Correlations



Cap Tube Mass Flow Predictions with Revised R-410A Specific Correlation (Rice 2001)



New HX Model Features: Refrigerant-Side

- More HX Configurations
  - Circuit Branching
    - Merging in Condenser Subcooled Region
      - Often done in AC Condensers
      - Region- not geometric-based merging
  - Circuit Arrangements
    - 1- to N-Row Crossflow,
    - 2-to-N-Row Condenser CrossCounterflow

New HX Model Features: Air-Side

- Improved Airflow Calculation Options
  - Fixed flow for manuf. performance tables or
  - Mass flow varying with fan inlet conditions
- More Air-Side Surface Choices
  - User-specified fin geometry patterns
    - default fin geometries built-in
  - Extra fin area calculated explicitly
  - Automated comparison of fin types
- Samples of New Web Pages Follow
  - Additions highlighted

New Mark VI Indoor Coil Page

Indoor Unit Data

Inlet Air Conditions

Temperature: DB, °F 80	**Humidity**: (●) WB, °F 67 -or- ( ) RH, % 52

Blower Performance

Airflow Rate: Standard, cfm 1000. ☐ Ref. Fan Temp, °F	**Power**: ( ) Nominal, W 293.0 (●) Per unit flow, W/Mcfm 365	-or- **Efficiency**: ( ) Combined blower & motor 0.30

Air Handler and Duct Sizing Parameters

☐ Filter and Heater Sizes	(●) External ΔP, in. water 0.15 -or- ( ) Duct branch diameter, in. 6.0

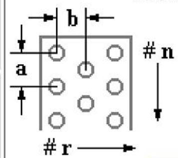
Heat Exchanger Configuration

Tubes
(●) Smooth ( ) Rifled
(●) Cu ( ) Al
OD (expanded), in. 0.3325
Wall, mils 12

Fins
(●) Al ( ) Cu
Pitch, fins/in. 13.0
Thickness, mils 10

Fin Type:
( ) Smooth ( ) Corrugated (●) Slit/Lanced
( ) Louvered ( ) Convex-Louvered ( ) Smooth Wavy

☑ Fin Pattern Geometry



Frontal area (finned face area) of coil, ft^2	3.802
Tube spacing, **a**, in.	1.00
Tube spacing, **b**, in.	0.625
Number of rows, **r**	4
Number of tubes, **n**	27
Number of equivalent, parallel circuits	
two-phase	4
liquid	2

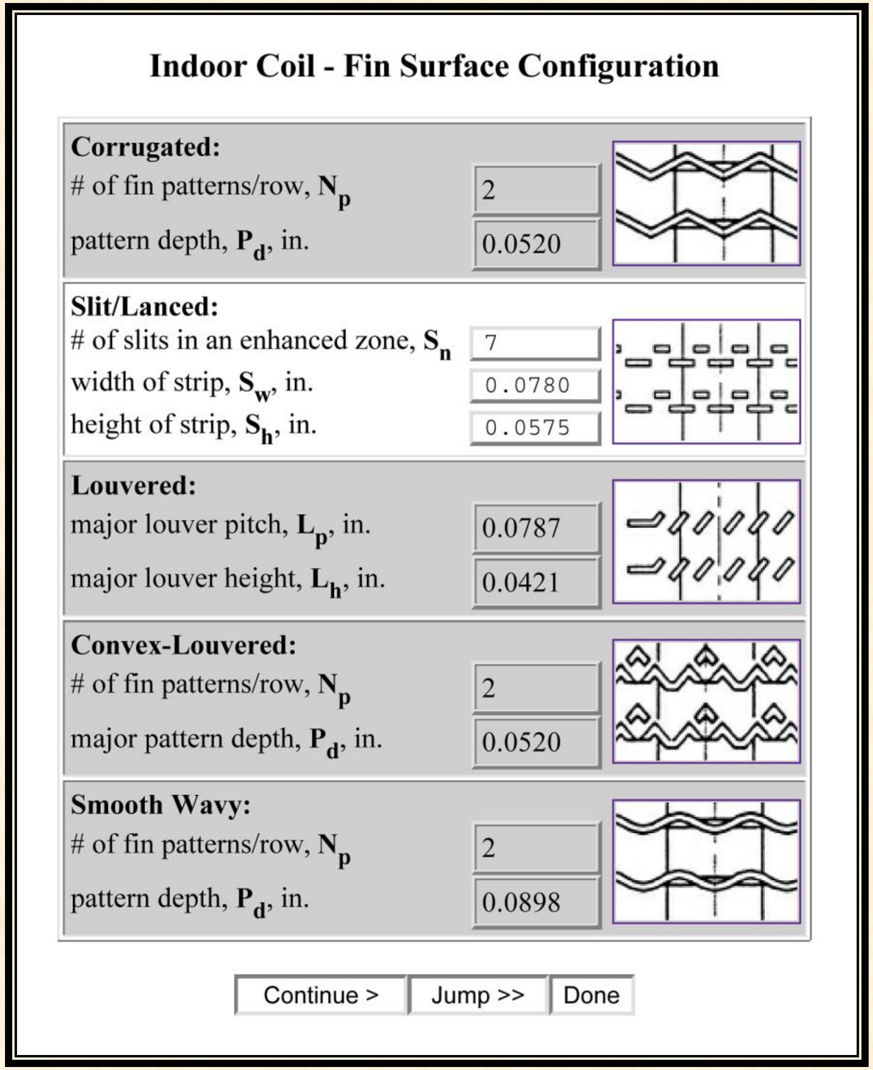
Refrigerant Flow Configuration:
(●) Cross ( ) Cross-Counter ( ) Cross-Parallel

Correction Multipliers

Refrigerant-Side:	Coil heat transfer 1.0	Coil surface area 1.0	Coil ΔP 1.0	
Air-Side:	Coil heat transfer 1.0	Coil surface area 1.0	Coil ΔP 1.0	System ΔP 1.0

Continue > | Jump >> | Done

Available Fin Pattern Geometry Selections



Indoor Coil - Fin Surface Configuration

Corrugated:	
# of fin patterns/row, N_p	2
pattern depth, P_d, in.	0.0520
Slit/Lanced:	
# of slits in an enhanced zone, S_n	7
width of strip, S_w, in.	0.0780
height of strip, S_h, in.	0.0575
Louvered:	
major louver pitch, L_p, in.	0.0787
major louver height, L_h, in.	0.0421
Convex-Louvered:	
# of fin patterns/row, N_p	2
major pattern depth, P_d, in.	0.0520
Smooth Wavy:	
# of fin patterns/row, N_p	2
pattern depth, P_d, in.	0.0898

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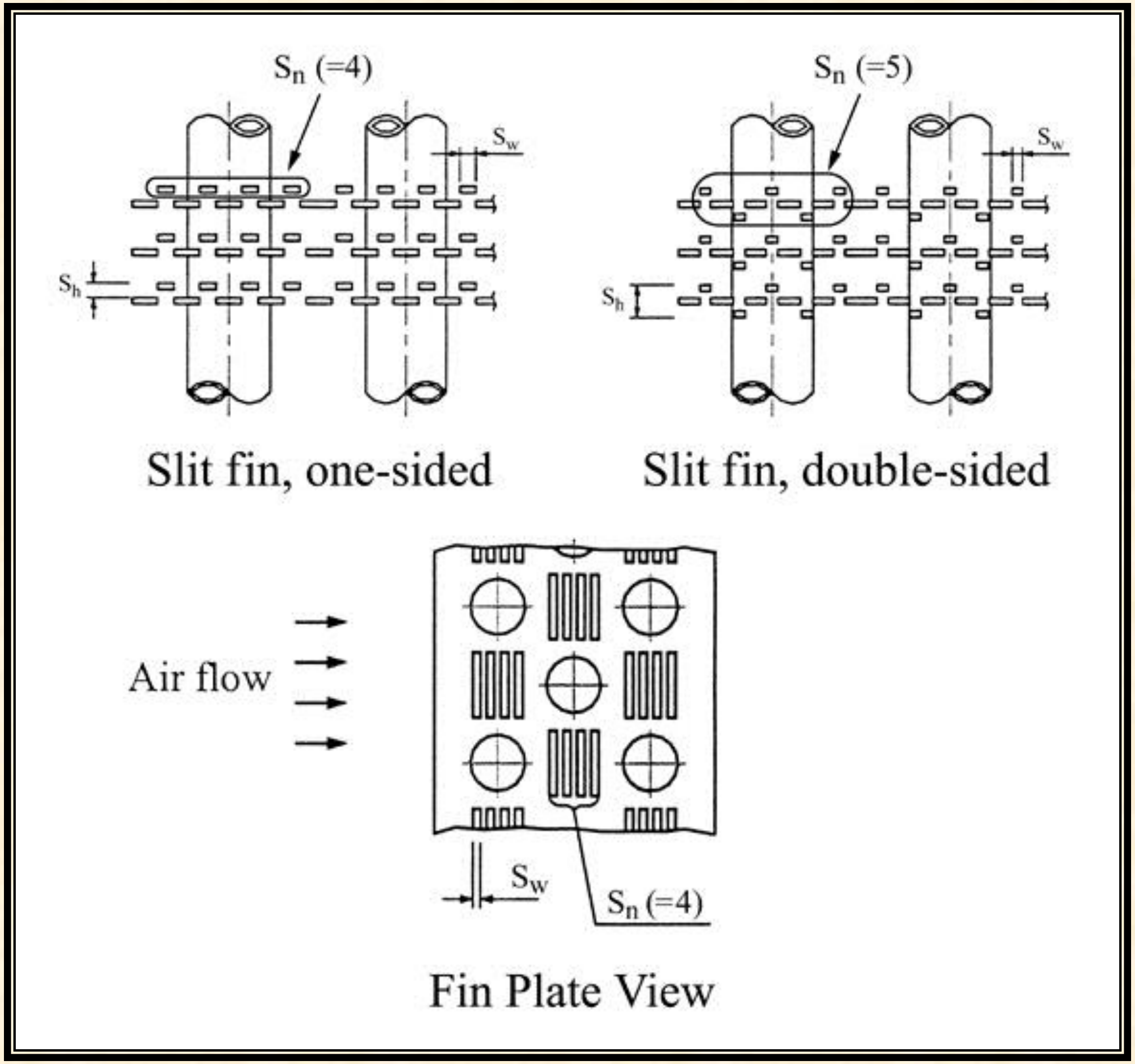
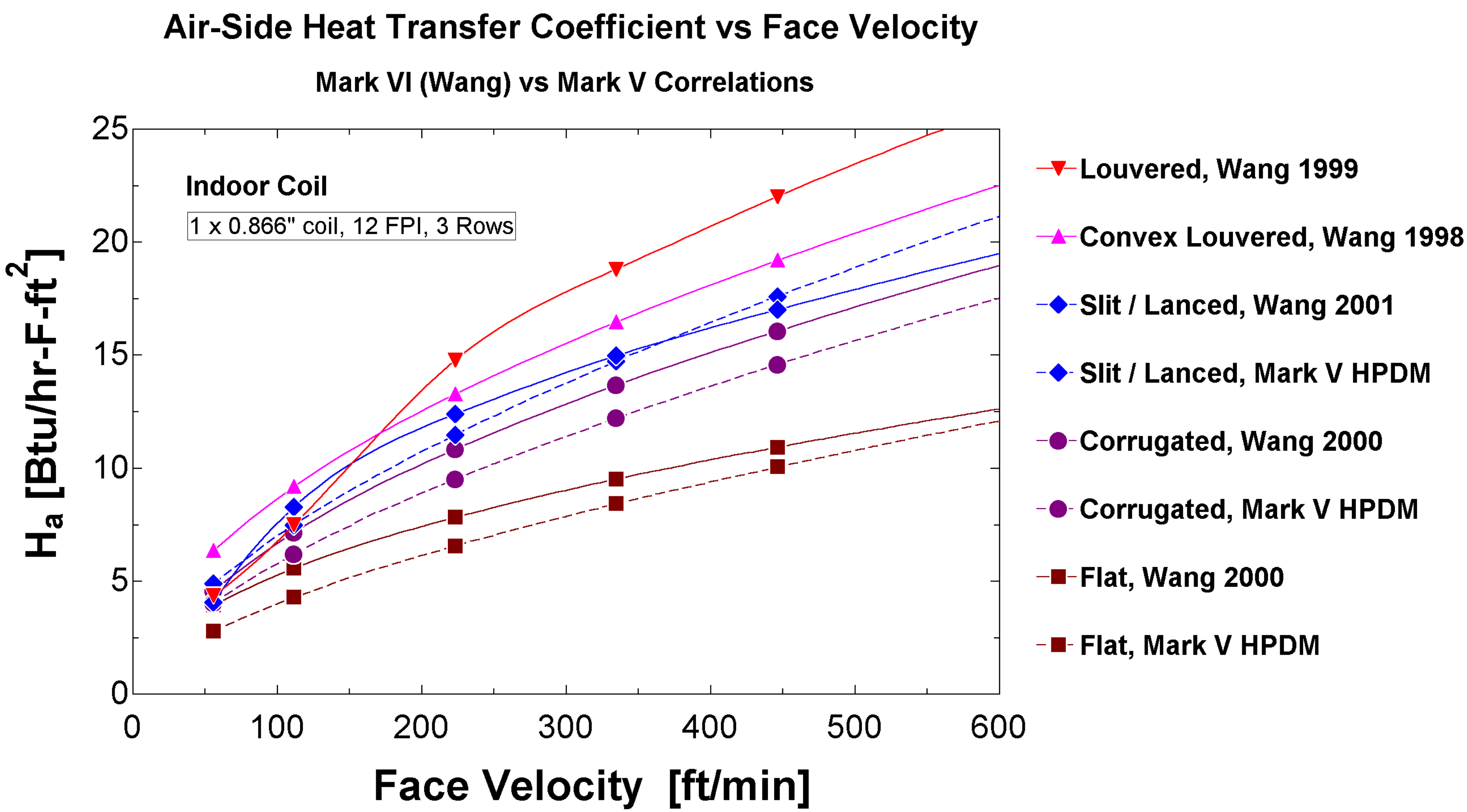
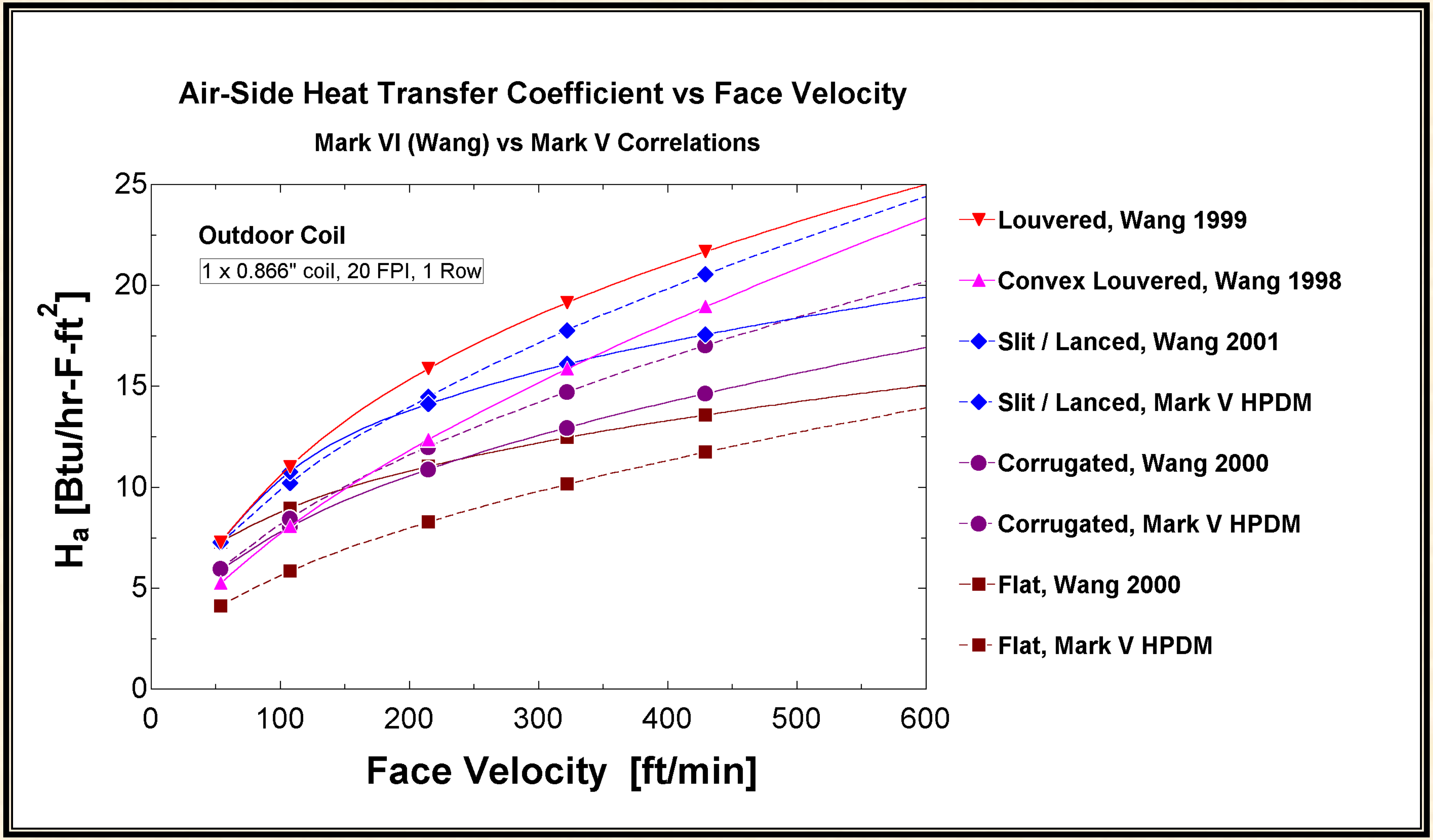
Online Fin Geometry Diagrams
Slit-Fin Pattern



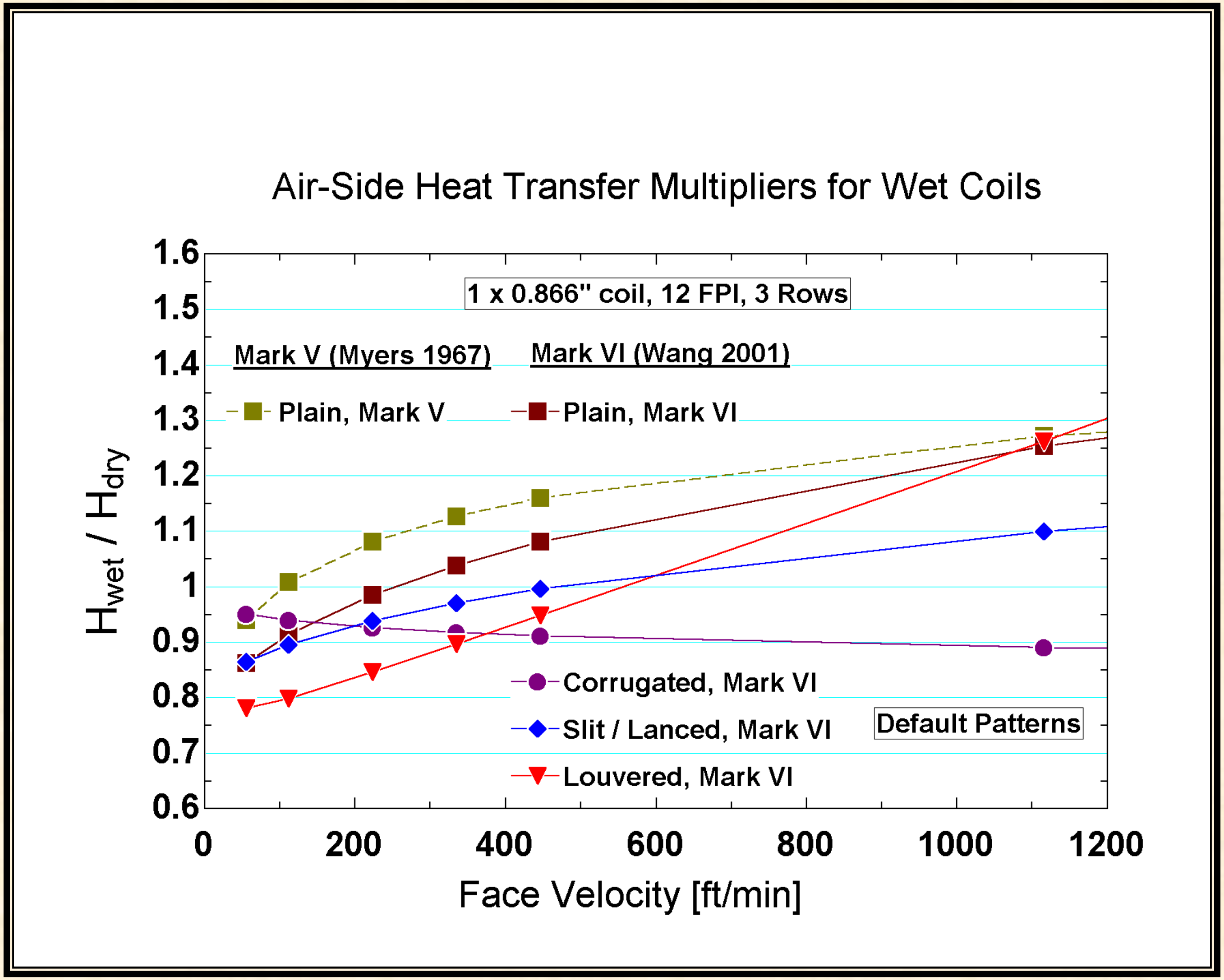
New Air-Side Surface Capabilities
Indoor Coil



New Air-Side Surface Capabilities
Outdoor Coil



Improved Dry vs Wet Coil Corrections



Improved Airflow and Fan Power Calculation Options

- Now Based on Standard Airflow (scfm)
  - Rather than on inlet airflow (acfm) at rating conditions
- Two Options for Specifying Airflow
  - Fixed flow for manuf. performance tables
    - needs only required scfm (fixes air massflow)
  - Mass flow varying with fan inlet conditions
    - better models cooling- vs heating-mode airflow and fan power changes
    - needs scfm at reference fan inlet temperature
    - mass flows and fan powers can vary up to 10% for indoor to > 20% for outdoor units

Results for Common HP Data Set

- Cooling Design Case
  - Run with Given SH and SC Conditions
  - Untuned and Tuned
    - Indoor HX tuning only
      - heat transfer mults. of 0.70
      - refr. pressure drop mult. of 2
- Heating Rating Case
  - Run with Calculated Cooling Mode Refr. Charge
    - and Specified Short-Tube Orifice Size
  - Untuned and with AC tuned Indoor HX
- Tuning Significantly Improved Agreement
  - In Performance Results and in Sat. Temps

Cooling Mode Comparisons to Test Data

ARI DESIGN COOLING CONDITIONS (Indoor 80/67F DB/WB, Outdoor 95F)					
MEASURES	Test Data	Untuned HPDM	Indoor HX Tuned*	Untuned HPDM	Indoor HX Tuned
				(% DIFF)	(% DIFF)
NET CAPACITY (Btu/hr)	34600	36660	34800	***5.95***	***0.58***
TOTAL POWER (W)	3301.5	3300.7	3276	***-0.02***	***-0.77***
EER (Btu/W-hr)	10.48	11.11	10.63	***6.01***	***1.43***
COMPRESSOR POWER (W)	2652.1	2654.4	2630.6	*0.09*	*-0.81*
OD FAN POWER (W)	187.4	184.9	185.2	-1.33	-1.17
SHR	0.76	0.777	0.766	2.24	0.79
				(DELTA-T)	(DELTA-T)
SAT. SUCTION (F)	46.5	49.4	46.4	***2.9***	***-0.1***
SAT. DISCHARGE (F)	117.7	119.2	118.1	***1.5***	***0.4***
SUPPLY TEMP (F)	60.3	58.9	60.2	-1.4	-0.1
* Tuned in AC Mode Only					

Heating Mode Comparisons to Test Data

ARI DESIGN HEATING CONDITIONS (Indoor 70F DB, Outdoor 47/43F DB/WB)					
MEASURES	**Test Data**	**Untuned HPDM**	**Indoor HX Tuned***	**Untuned HPDM**	**Indoor HX Tuned**
				(% DIFF)	**(% DIFF)**
NET CAPACITY (Btu/hr)	36700	37360	36760	***1.80***	***0.16***
TOTAL POWER (W)	3163.6	2959.4	3108.3	***-6.45***	***-1.75***
COP	3.4	3.7	3.47	***8.82***	***2.06***
COMPRESSOR POWER (W)	2510.7	2286.3	2434.8	***-8.94***	***-3.02***
OD FAN POWER (W)	203	216.7	216.6	6.75	6.70
				(DELTA-T)	**(DELTA-T)**
SAT. SUCTION (F)	32	30.4	30.7	-1.6	-1.3
SAT. DISCHARGE (F)	111.7	105.5	111.7	***-6.2***	***0***
SUPPLY TEMP (F)	98.8	98.9	98.4	0.1	-0.4

(HPDM results for specified short tube orifice size and refrigerant charge calculated from cooling mode)

*** Tuned in AC Mode Only**

Further Model Improvement and Testing -- ASHRAE 1173-TRP

- Objective
  - Wide-Range Testing of Public AC Models
    - Mild to Extreme Ambients
      - Low to High Indoor Humidity
    - Low to High Charge
    - Low to High Airflow
  - For HFC R-22 Alternatives
  - With Best Available H.T. and Charge Models
- ORNL & Purdue Public Models
  - To Be Improved/Tested/Validated

Mark 7 HPDM Development

- HFC Gliding Mixture Capable Version
  - For R-22 drop-in refrigerant analysis
  - With R-407C, R-404A, R-507 mixtures
- Converted to NIST RefProp 7.1
  - For Thermo Properties
- Further Updating of Refr-Side Correls Underway
  - HT and PD, Smooth and Micro-fin
- Modif. Of HX Routines to Handle Glide
- Planned Release Near End of 04

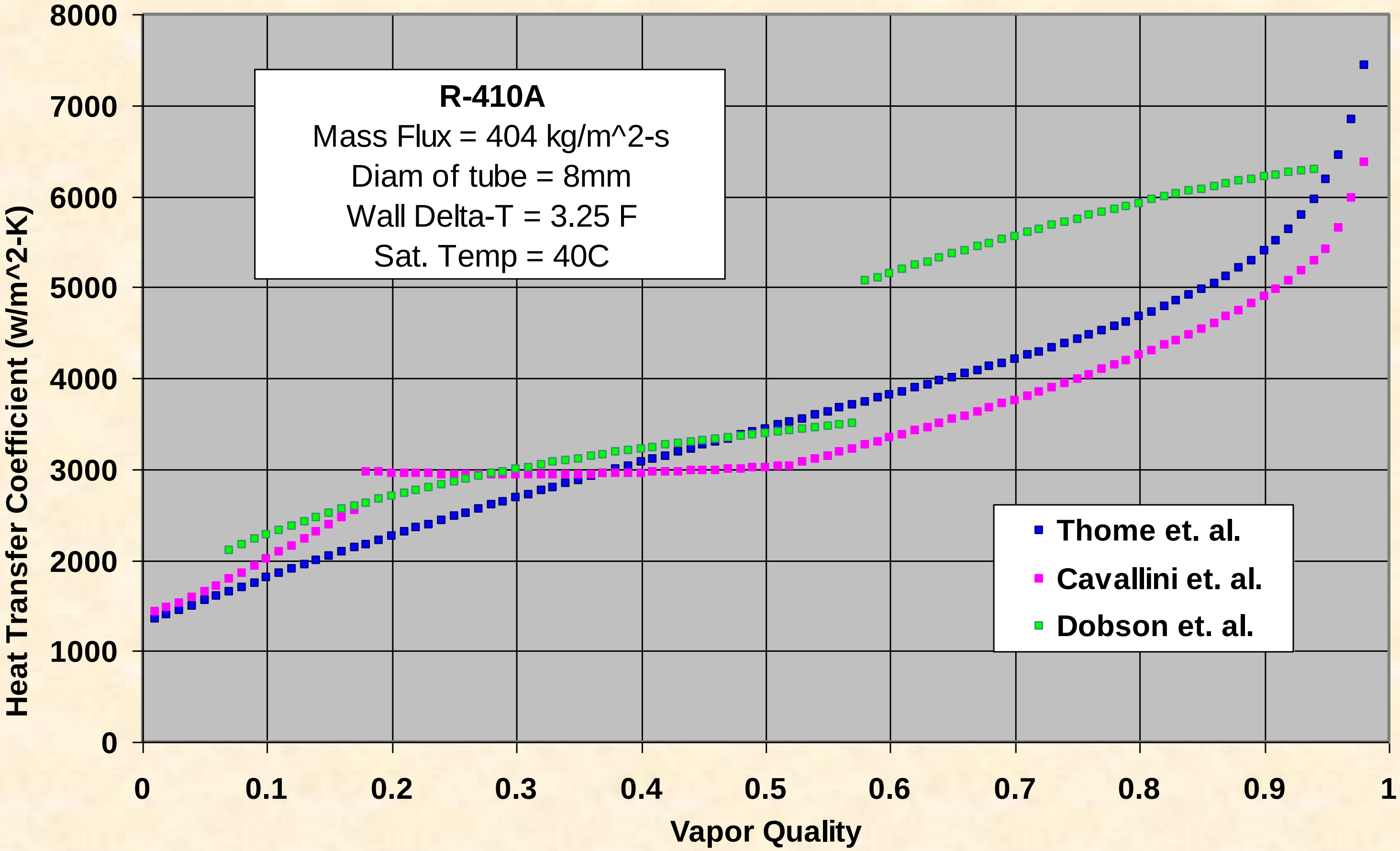
Refrigerant Property Changes - Mark 7

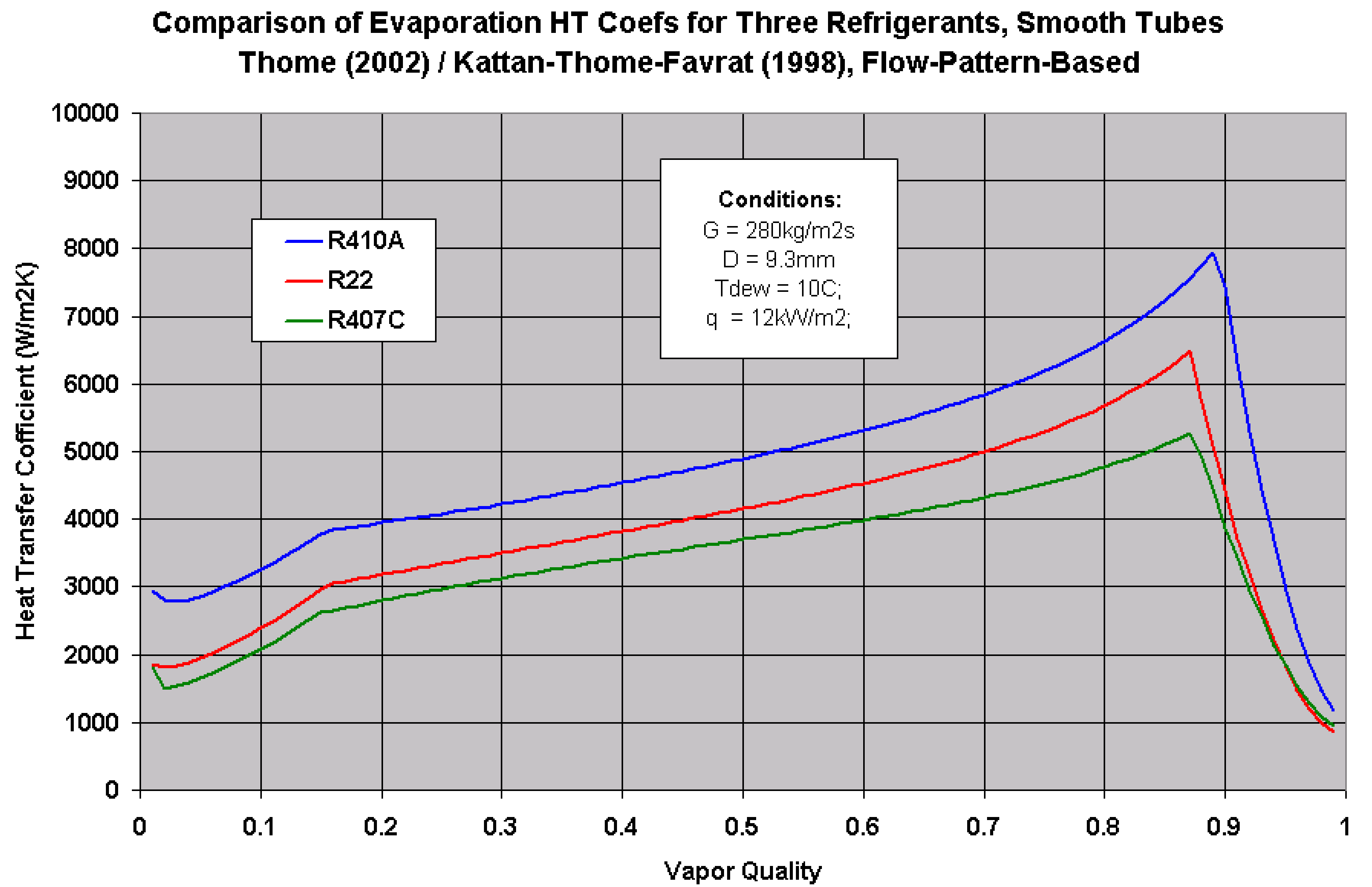
- **Thermo Properties**
  - **Converted to NIST REFPROP 7.1**
    - Capable of either pseudo-pure or full mixture calls
  - **Pseudo-pure representation for leading HFC mixtures**
    - Developed by NIST for use in cycle analysis
    - Fast execution in Mark 7 development model
      - 1 sec for pseudo, 2 sec for pure calls
      - vs 38 sec for full R-410A, 110 sec for full R-407C

Improved HT Correlations

- **New Condensing Correlations**
  - **Thome and Cavallini (2003)**
    - **handles multiple flow regimes**
  - **Improvement over Dobson/Chato (ACRC, 1995)**
- **New Evaporating Correlations**
  - Thome and Kattan (1998)
- **New Pressure Drop Correlations**
  - Kedzierski and Choi (2001)

Comparison of Condensing HT Correlations, Thome Correlation Better over Flow Regime Transitions

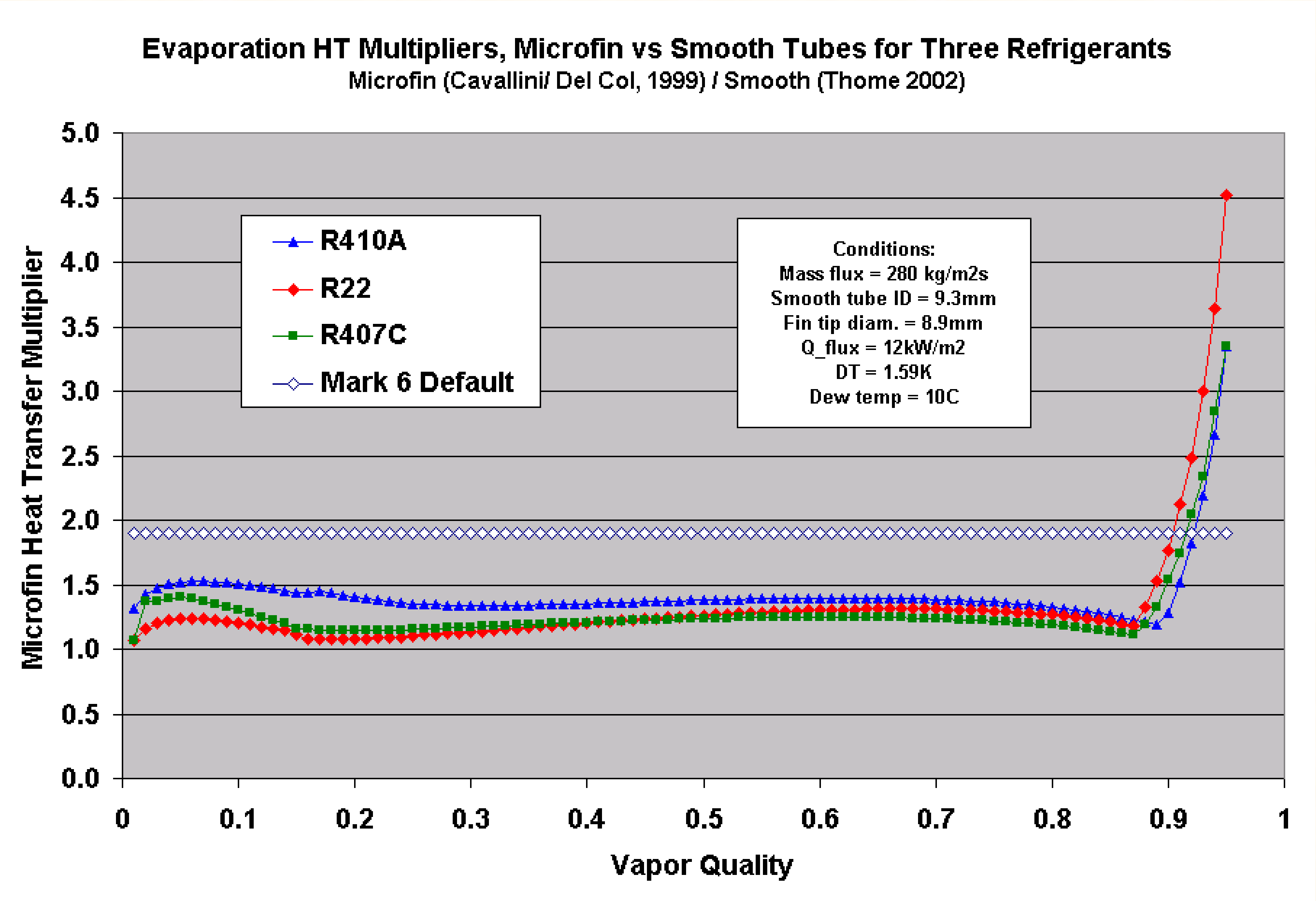


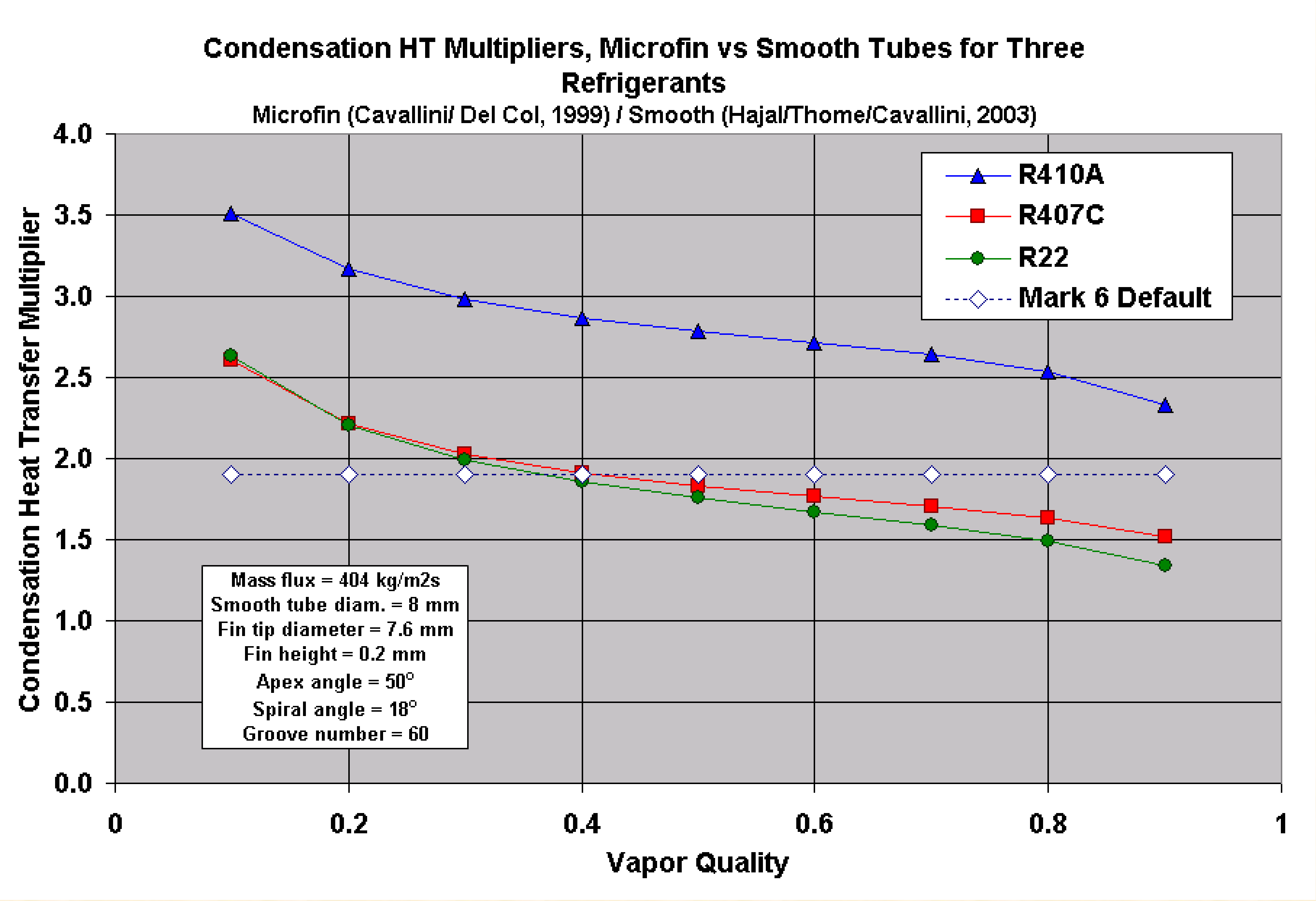


Comparison of Evaporation HT Coefs for Three Refrigerants, Smooth Tubes
Thome (2002) / Kattan-Thome-Favrat (1998), Flow-Pattern-Based
Heat Transfer Cofficient (W/m2K)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Vapor Quality
R410A
R22
R407C
Conditions:
G = 280kg/m2s
D = 9.3mm
Tdew = 10C;
q = 12kW/m2;

Micro-fin HT Correlations Tested and Compared with Smooth-Tube Results

- Evaporating
  - Cavallini (1999)
- Condensing
  - Cavallini (2000)
- For R-410A, R-407C, and R-22
  - at representative AC conditions


Evaporation HT Multipliers, Microfin vs Smooth Tubes for Three Refrigerants
Microfin (Cavallini/ Del Col, 1999) / Smooth (Thome 2002)
R410A
R22
R407C
Mark 6 Default
Conditions:
Mass flux = 280 kg/m2s
Smooth tube ID = 9.3mm
Fin tip diam. = 8.9mm
Q_flux = 12kW/m2
DT = 1.59K
Dew temp = 10C
Microfin Heat Transfer Multiplier
Vapor Quality
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1



Condensation HT Multipliers, Microfin vs Smooth Tubes for Three Refrigerants
Microfin (Cavallini/ Del Col, 1999) / Smooth (Hajal/Thome/Cavallini, 2003)
Condensation Heat Transfer Multiplier
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
0.2
0.4
0.6
0.8
1
Vapor Quality
R410A
R407C
R22
Mark 6 Default
Mass flux = 404 kg/m2s
Smooth tube diam. = 8 mm
Fin tip diameter = 7.6 mm
Fin height = 0.2 mm
Apex angle = 50°
Spiral angle = 18°
Groove number = 60