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Session 13 – Advancements in Compressor Design, Testing and Performance Modeling for New Efficiency Standards and Alternative Refrigerants

Analysis of the Performance Rating Standards of Positive Displacement Refrigerant Compressors

St. Louis, Missouri

Learning Objectives

1. Describe how the new, low-GWP alternative refrigerants affect the compressor design, performance characteristics, and operation.
2. Explain the purpose of compressor rating standards
3. Describe the proper use of the compressor performance maps
4. Derive from compressor performance maps the actual compressor performance at the real operating conditions in a system

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COMPRESSOR STANDARDS

- AHRI (Air-Conditioning Heating and Refrigeration Institute)
  - CAN/ANSI/AHRI 540 (E) - 2015, Performance Rating of Positive Displacement Refrigerant Compressors and Compressor Units
  - ANSI/AHRI 570 & 571 -2012: Performance Rating of Positive Displacement Carbon Dioxide Refrigerant Compressors and Compressor Units
  - ANSI/AHRI 510-2006: Performance Rating of Positive Displacement Ammonia Compressors and Compressor Units
- CEN (European Committee for Standardization)
  - EN 12900: Refrigerant Compressors – Rating conditions, tolerances and presentation of manufacturer's performance data
- SAC (Standardization Administration of China) [Partial List]
  - GB/T 29030-2012: Positive displacement CO2 refrigerant compressor(unit)
  - GB/T 27940-2011: Single-stage positive displacement refrigerant compressors parallel unit for commercial refrigeration application
  - GB/T 15765-2014: Hermetic motor-compressors for room conditioners
  - GB/T 29780-2013: Hermetic motor-compressors for household and similar application heat pump water heater
  - GB/T 18429-2001: Hermetic scroll refrigerant compressors
  - GB/T 10079-2001: Single-stage reciprocating refrigerant compressors
  - GB/T 19410-2008: Screw refrigerant compressors

COMPRESSOR STANDARD PURPOSE

- Primary Goals
  - Provide the industry the ability to accurately compare compressors
    - Consistent method of presenting data
  - Ensure published data from a compressor manufacturer is within a certain uncertainty
- Define Requirements Such as:
  - Testing (Use of ASHRAE 23.1, EN13771-1)
  - Rating Conditions
  - Minimum Data (What to publish)
  - Operation (Voltage limitation)
  - Marking (Nameplate information)
- The standards are not…
  - Designed to provide guidelines or suggestion with respect to system design or operating conditions
  - Mandatory or code

AHRI 540 Historical Rating Points

Historical Rating Points

Table E1. Historical Rating Conditions for Compressors Used in Commercial Refrigeration Applications (Based on 95°F, 35°C Ambient Temperature Surrounding the Compressor)[1]

Suction Dew Point Temperature		Compressor Type	Discharge Dew Point Temperatures		Return Gas Temperature[3]		Subcooling	
°F	°C		°F	°C	°F	°C	°F	°C
45	7.2	All	130	54.4	65	18	15	8.3
20	-6.7	All[2]	120	48.9	40/65[2,3]	4.4/18[2,3]	0	0
-10	-23	Hermetic	120	48.9	40	4.4	0	0
-25	-32	All[2]	105	40.6	40/65[2,3]	4.4/18[2,3]	0	0
-40	-40	All[2]	105	40.6	40/65[2,3]	4.4/18[2,3]	0	0

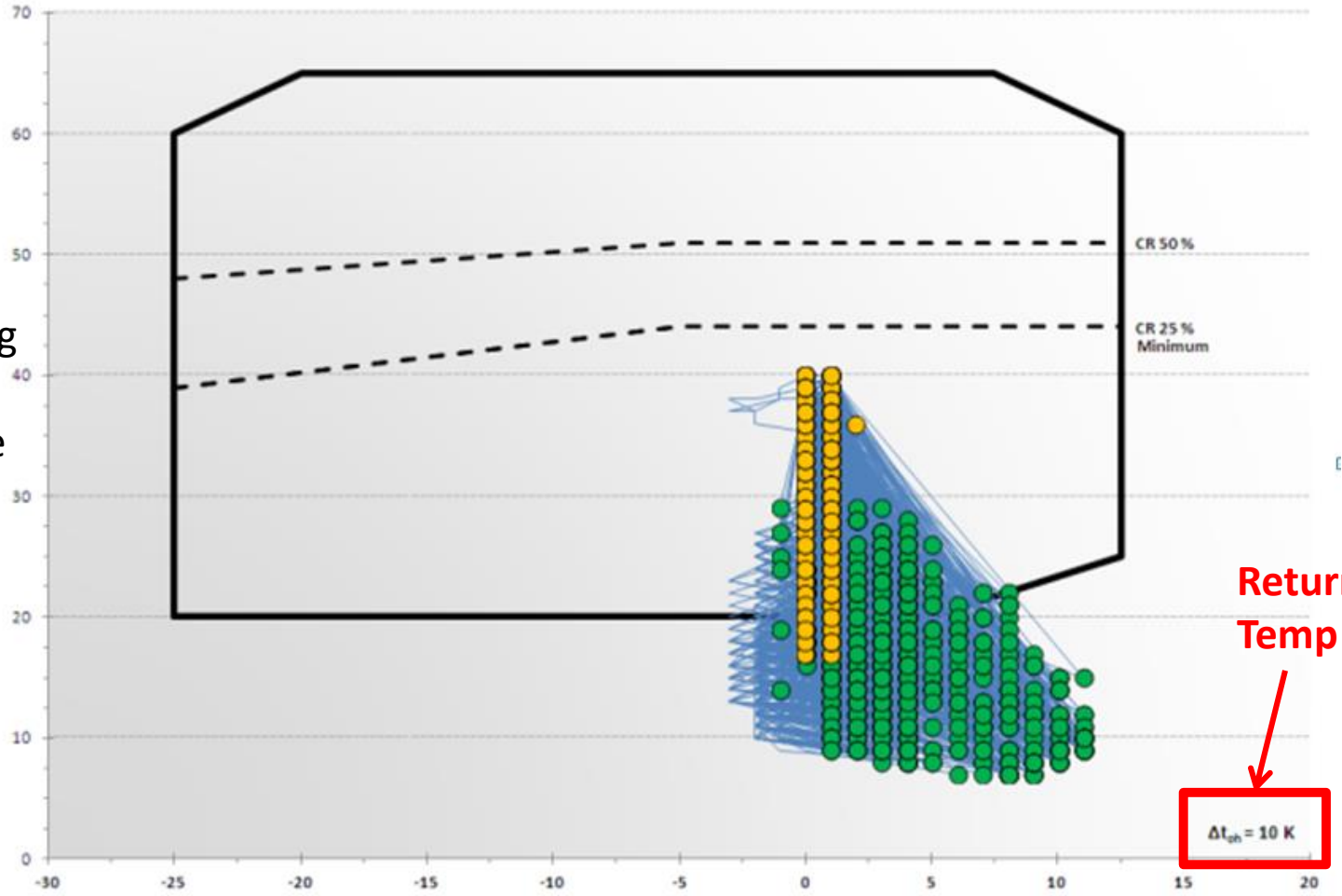
AHRI 540 Historical Rating Points

Historical Rating Points

Table E2. Historical Rating Conditions for Compressors Used In Air Conditioners and Heat Pumps (Based on 95°F, 35°C Ambient Temperature Surrounding the Compressor)[1,2]

Rating Test Point	Intended Use	Suction Dew Point Temperature		Discharge Dew Point Temperature		Return Gas Temperature	
		°F	°C	°F	°C	°F	°C
A	Air Source (Cooling)	45	7.2	130	54.4	65	18
B	Air Source (Cooling)	45	7.2	115	46.1	65	18
C	Air Source (Heating & Cooling)	45	7.2	100	37.8	65	18
D	Air Source (Heating)	30	-1.1	110	43.3	50	10
E	Air Source (Heating)	5	-15	95	35	25	-3.9
F	Air Source (Cooling)	45	7.2	80	27	65	18
G	Air Source (Heating)	35	1.7	90	32	55	13
H	Water Source (Cooling & Heating)	45	7.2	120	48.9	65	18

Compressor Operating Map



AHRI 540 Review

- Prior version required rating of individual points

AND

- Publish of coefficients for use with 10 term industry standard polynomial
  - t_S → Saturated suction temperature
  - t_D → Saturated discharge temperature
  - X → mass flow, power, amp draw and capacity

$$X = C_1 + C_2 \cdot (t_S) + C_3 \cdot t_D + C_4 \cdot (t_S^2) + C_5 \cdot (t_S \cdot t_D) + C_6 \cdot (t_D^2) + C_7 \cdot (t_S^3) + C_8 \cdot (t_D \cdot t_S^2) + C_9 \cdot (t_S \cdot t_D^2) + C_{10} \cdot (t_D^3)$$

- Uncertainty only applied to the individual rating points
- Industry focus
  - Higher Saturated Suction Temperatures
  - Additional Minimum Condensing Temperatures
    - IPLV
    - Average EER
  - Alternative Superheats

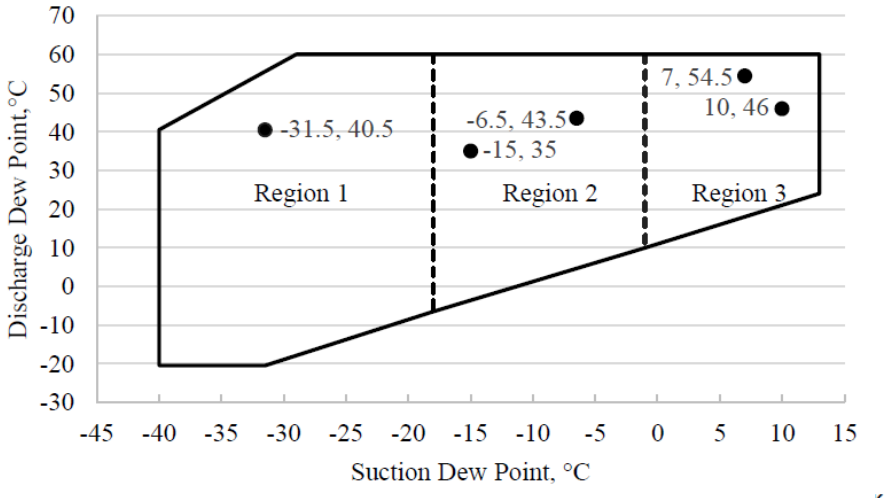
AHRI 540 Revision

- Compressor Manufacturers
  - Often rating compressors over an entire operating map due to customer needs
  - Selling to European market per EN 12900 (Operating map)
  - Struggling with designing for AHRI rating points vs. higher IPLV % running time
    - E.g.: Fixed volume compression type (screw / scrolls)
      - Vi (Volumetric index) can be matched towards target pressure ratio

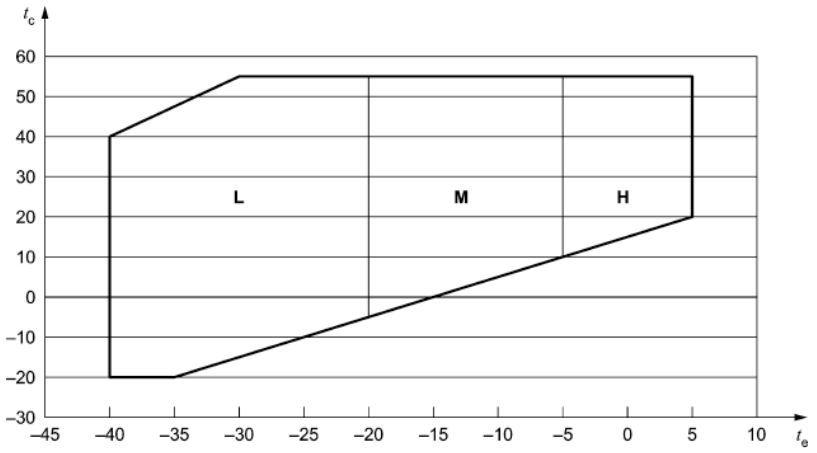
Move from individual points to rating of the compressor curves

AHRI 540 Harmonization with EN 12900

- Changed to rating of a map as opposed to specific points
- Tolerances → Uncertainties
  - Established over the map through regions
- Allows more meaning to published data over entire operating map
- Reference points still exist for “quick comparison”



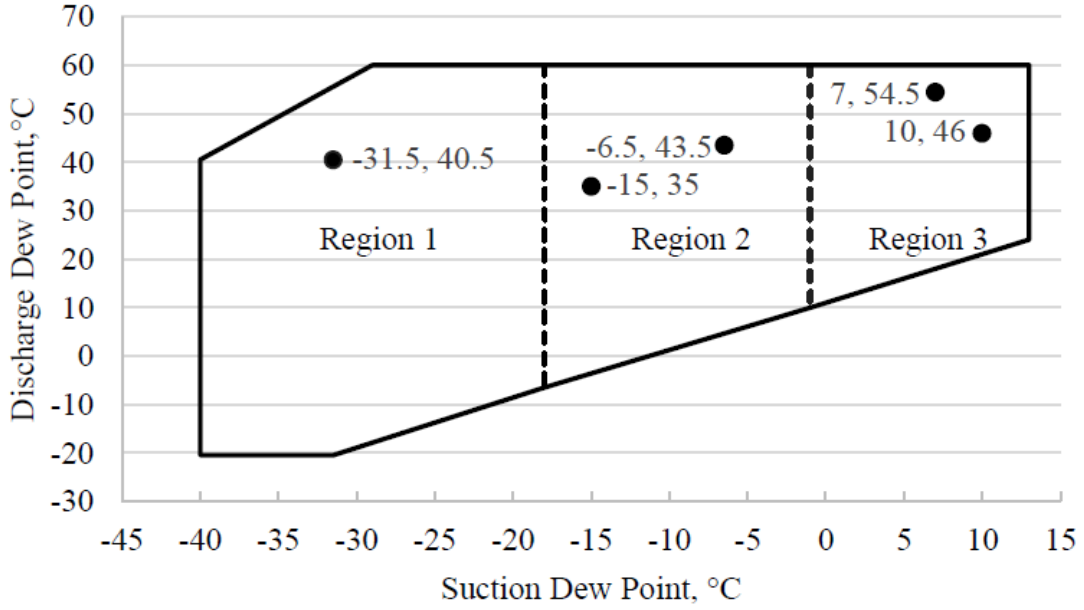
AHRI 540



EN 12900

Uncertainties

Table 3. Rating Uncertainty Limits for the Verification of Published Ratings			
Published Rating	Region 1	Region 2	Region 3
Minimum Refrigerant Mass Flow, lbm/hr, kg/s	90.0%	92.5%	95.0%
Minimum Refrigerating Capacity, Btu/h, W	90.0%	92.5%	95.0%
Maximum Power Input, W, W	110.0%	107.5%	105.0%



Uncertainties

- Principal Factors driving uncertainties (Partial List)
  - Production related effects
    - Manufacturing tolerances
  - Measurement related
    - Sensor/meter measurement tolerances
    - Variations in pressures
    - Oil circulation (impact on mass flow and heat exchange)
  - Data Processing
    - Variation in thermodynamic refrigerant properties
    - Creation of compressor curves
- Increased impact
  - Increases in pressure ratio
  - Decrease in compressor size
  - “Run in” performance
  - CO_2

Applying Performance Rating Out of Scope

- Use of Published Ratings for Batches of Equivalents
  - Appendix F of AHRI 540 (Informative)
  - Statistical information for understanding expected deviations for batch

Table F4. Acceptance Criteria for the Verification of Published Ratings Using a Sample Size of 3			
Published Rating	Region 1	Region 2	Region 3
Minimum Refrigerant Mass Flow, lbm/h, kg/s	94.5%	95.5%	97.0%
Minimum Refrigerating Capacity, Btu/h, W	94.5%	95.5%	97.0%
Maximum Power Input, W, W	105.5%	104.5%	103.0%

Applying Performance Rating Out of Scope

- Performance ratings established for specific superheat and/or return gas temperature
  - Appendix D of AHRI 540 (informative)
  - Superheat correction formulas
    - Based on suction densities
    - Correction factors should be provided by compressor manufacture for precise

$$\dot{m}_{corrected} = \{ 1 + F_v [(v_{rated} / v_{corrected}) - 1] \} \cdot \dot{m}_{rated} \quad \text{D1}$$

Where:

F_v	=	Volumetric efficiency correction factor – the correction factor will vary based on volumetric efficiency of the compression technology used, a value of one (1) can be used for an approximation. Contact the manufacturer for a more precise value.
$\dot{m}_{corrected}$	=	Refrigerant Mass Flow Rate at suction condition, lbm/h, kg/s
$\dot{m}_{rated}$	=	Refrigerant Mass Flow Rate at rated superheat, lbm/h, kg/s
$v_{corrected}$	=	Specific volume at suction condition, ft^3/lb, m^3/kg
v_{rated}	=	Specific volume at rated condition, ft^3/lb, m^3/kg

Zeotropic Refrigerants

- Industry is having an increased focus on refrigerants with glide
  - Due to search for Low GWP solutions
- Impact of the glide is in the heat exchangers
  - Actual system runs at higher suction pressure and high discharge pressure in comparison to the dew point
  - Actual system capacity would be higher
  - Efficiency less impacted (about same)
- Why are compressors ratings based on Dew Point?
  - No glide inside of a compressor
    - Low pressure compressed to higher pressure
  - Mass flow measured
  - Power measured
  - Capacity is calculated!

Zeotropic Refrigerants

- Predicting of glide calculation
  - Mid-point can be used as rough estimate
  - AHRI 540 Appendix C (informative)
    - Condensing pressure: Average of bubble point and dew point
    - Suction pressure: Average of TXV temperature and dew point
      - Subcooling will move this mid point
  - Actual saturated point could/should be obtained from heat exchanger manufacturer
- Compressors rated in accordance with a standard are still valid for zeotropic refrigerants due to rating of entire operating map

Capacity should be calculated by system manufacturer based on heat exchange knowledge

Future Compressor Standard Work

- Part load Performance standards
  - EN 12900 has simplistic solution
  - Dedicated standard AHRI 545 is underway (similar solution proposed)
- Specific to AHRI
  - Revisions of 510, 570
  - Possibly combine in to 540
- Vapor injection / Economized
- Centrifugal compressors

Conclusions

- Number of Refrigerants increasing due to search for low GWP solutions
- Efficiency standards increasing
- Compressor manufacturers required to provide accurate data for system guidance and manufacturer comparison
- Compressor performance standards provided to assist industry in decision making
- Industry must understand proper use of performance standards to allow for rating out of scope, use of zeoptropics and consideration of uncertainties

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Questions?

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