Making Sense

Webinar Series

EMERSON™
Climate Technologies

Making Sense Webinars

Emerson and Our Partners Giving Insight on the Three Most Important Issues in Refrigeration

We're Making Sense of the promising role of **new refrigerants.**

The widespread deployment of sustainable, energy-efficient refrigeration solutions using natural refrigerants is fast approaching.

Emerson Climate Technologies invites you to interact with some of the refrigeration industry's most trusted and respected thought leaders on the emerging roles of low global warming potential and natural refrigerants. Don't miss our thought provoking presentation on promising alternative refrigerants, and be sure to visit with our experts throughout the event.

At AHR 2013, we're helping attendees MAKE SENSE of the issues that matter most.

Check our website at www.emersonclimate.com/makingsense for presentation schedules and topics. Bring this card with you to one of our presentations and you'll be entered for a chance to win an Apple iPad®

> See what makes sense at the AHR Expo, booth #1605.

We're Making Sense of **energy reduction** technologies.

Innovative energy reduction technologies are ushering in a new era of system and equipment optimization.

Emerson Climate Technologies invites you to network with the refrigeration industry's foremost innovators in energy reduction technologies. We will be hosting a presentation about how the improvements in equipment and systems technologies are being utilized in today's refrigeration applications. Our experts will be present throughout the event to answer any question you may have about these innovations – from the utilization of digital modulation and electronic expansion valves to the applications of scroll and variable speed technologies.

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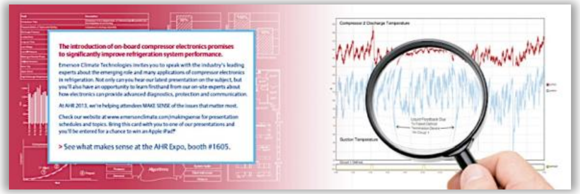
> See what makes sense at the AHR Expo, booth #1605.

We're Making Sense of the application of electronics to improve **operational visibility.**



The introduction of on-board compressor electronics promises to significantly improve refrigeration system performance.

Emerson Climate Technologies invites you to speak with the industry's leading experts about the emerging role and many applications of compressor electronics in refrigeration. Not only can you hear our latest presentation on the subject, but you'll also have an opportunity to learn firsthand from our on-site experts about how electronics can provide advanced diagnostics, protection and communication.

At AHR 2013, we're helping attendees MAKE SENSE of the issues that matter most.

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Making Sense of the promising role of new refrigerants.

Webinar Series

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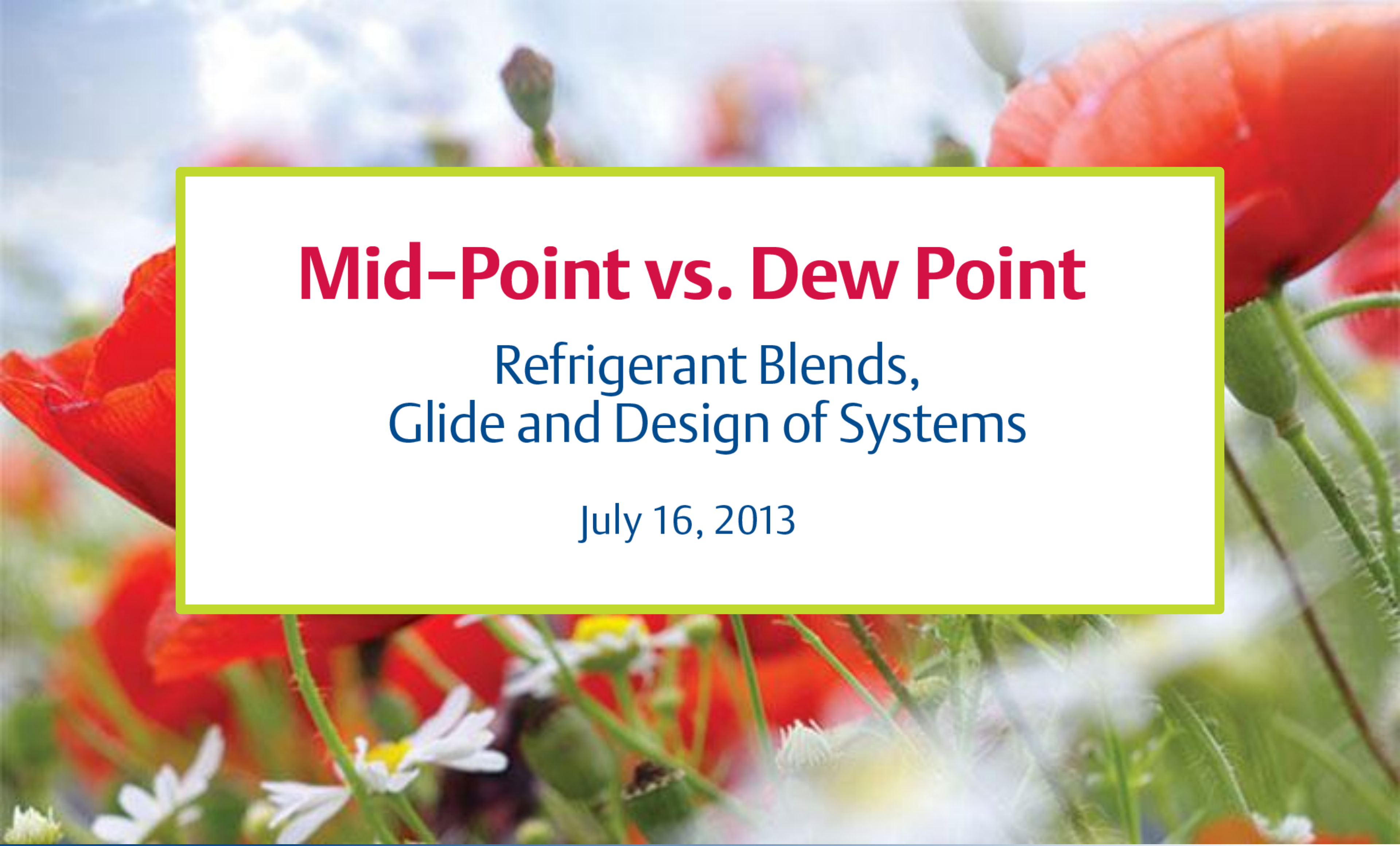

Mid-Point vs. Dew Point

Refrigerant Blends, Glide and Design of Systems

July 16, 2013

Presented By:

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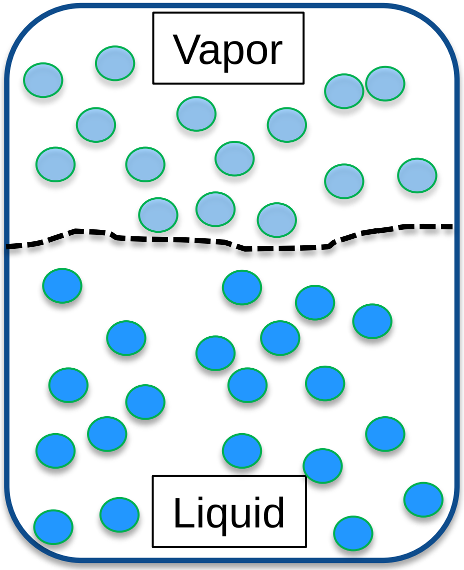
Agenda

- **Basics of Refrigerant Blends and “Glide”**
- **How Refrigerant Glide Affects System Components**
  - Heat Exchangers
  - Compressors Selection
- **Maintenance of Systems Using Refrigerants With Glide**
  - Setting Superheat, Sub-cooling
  - Charging Systems and Handling Leaks
- **Questions and Answers**

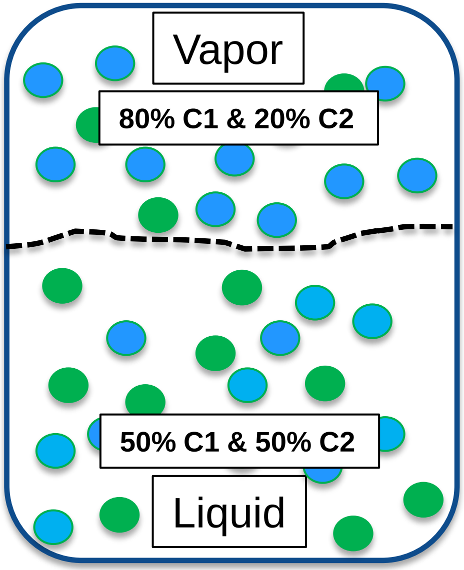
Refrigerants and Refrigerant Blends

- Refrigerants can be single component or a blend of several component chemicals
- ASHRAE classifies blends as Azeotropic (R500 Series) and Zeotropic (R400 Series)
- Single refrigerants and Azeotropic blends evaporate or condense at constant temperature in a constant pressure process
- For Zeotropic blends going through a constant pressure process, the temperature varies between dew (saturated vapor) and bubble (saturated liquid) points
  - The temperature variation (glide) can be relatively small like R410A, and R404A, which for practical purposes can be treated as single refrigerants or Azeotropes
  - However, many Zeotropes have larger temperature glide – subject of this webinar

What Is Glide?

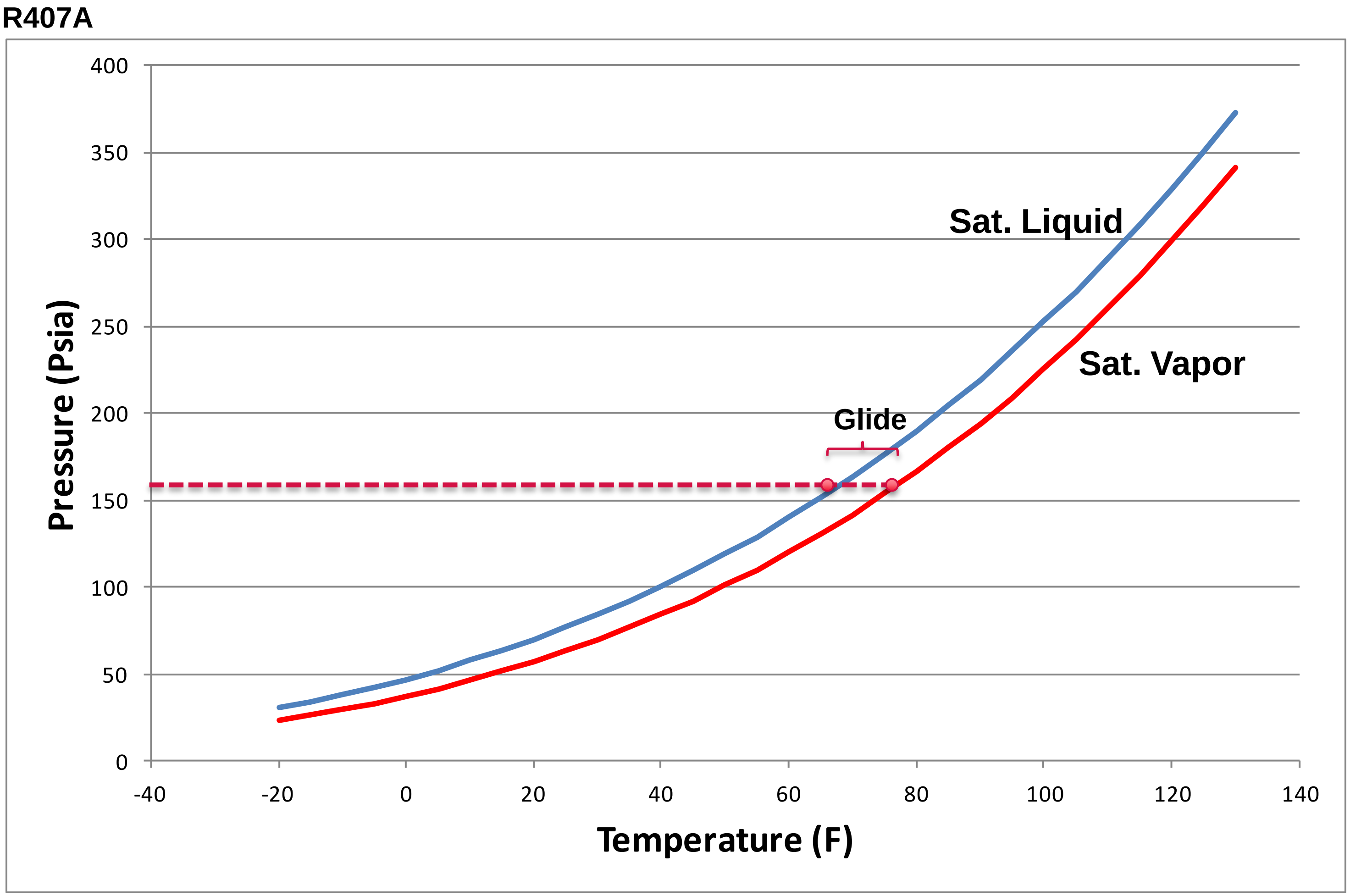


Single Component Refrigerant in Equilibrium

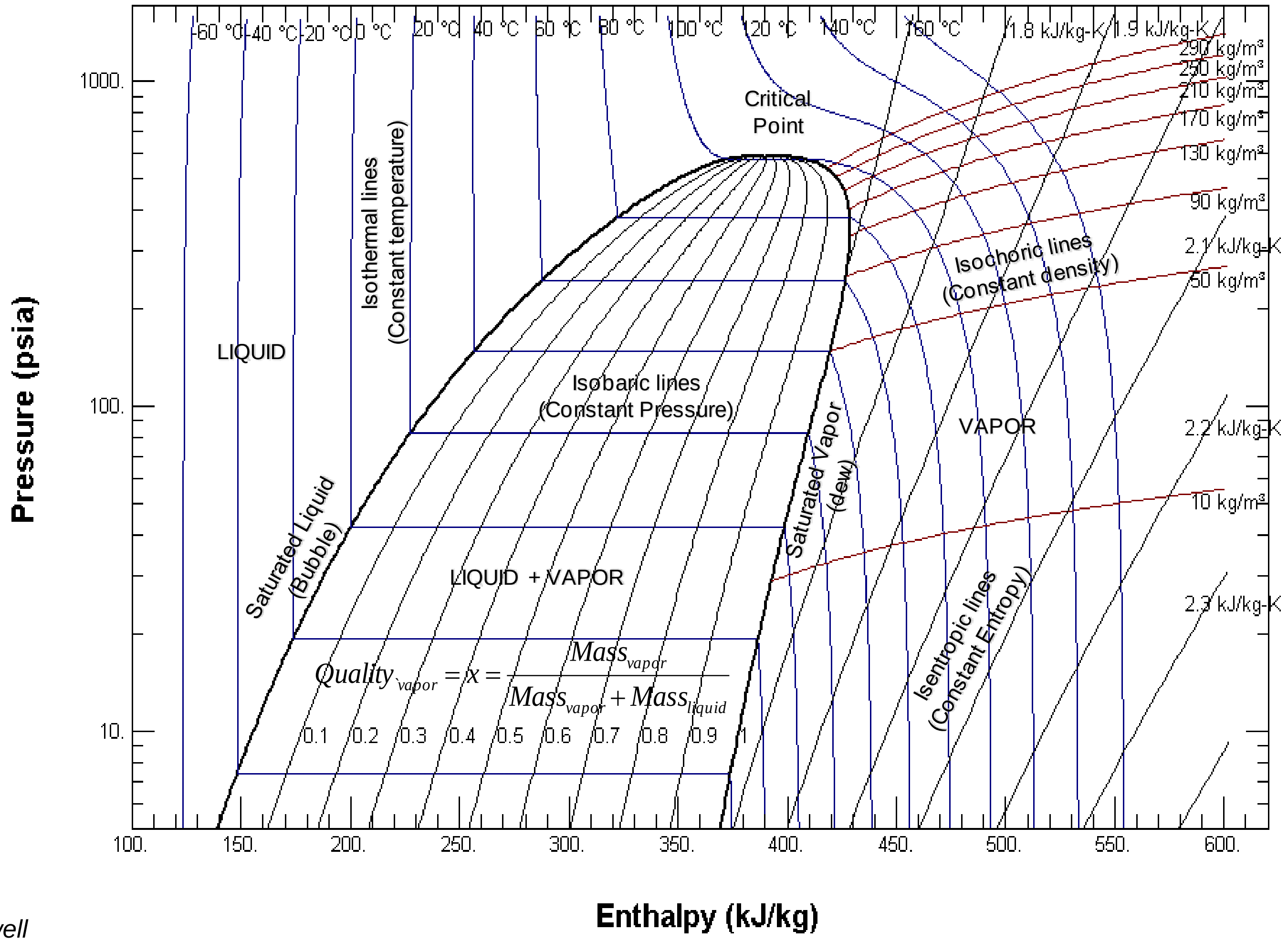


Two-Component Blend in Equilibrium

What Is Glide?

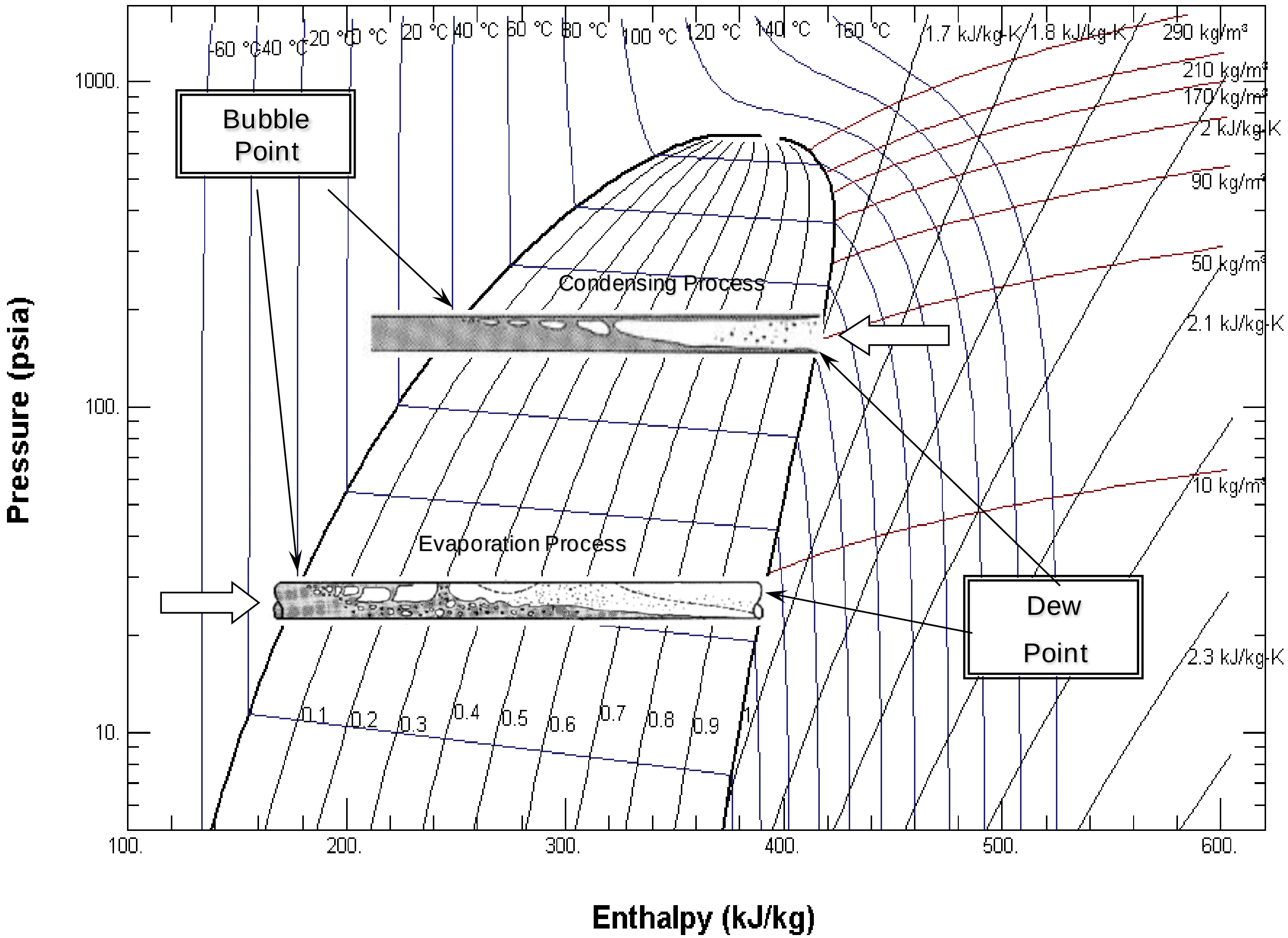


Mollier Diagram (p-h Chart): Single Refrigerant



Courtesy: Honeywell

Mollier Diagram (p-h Chart): Single Refrigerant



Courtesy: Honeywell

States Along the Vapor Line Are at Dew Point

> **"When the saturated vapor starts to cool, it will form dew drops…"**

States Along the Liquid Line Are at Bubble Point

> **"…saturated liquid will start to form bubbles when heated…"**

In Between the Two Is Your "Mid-Point"

MakingSense

Mid-Point vs. Dew Point and the Refrigeration Cycle

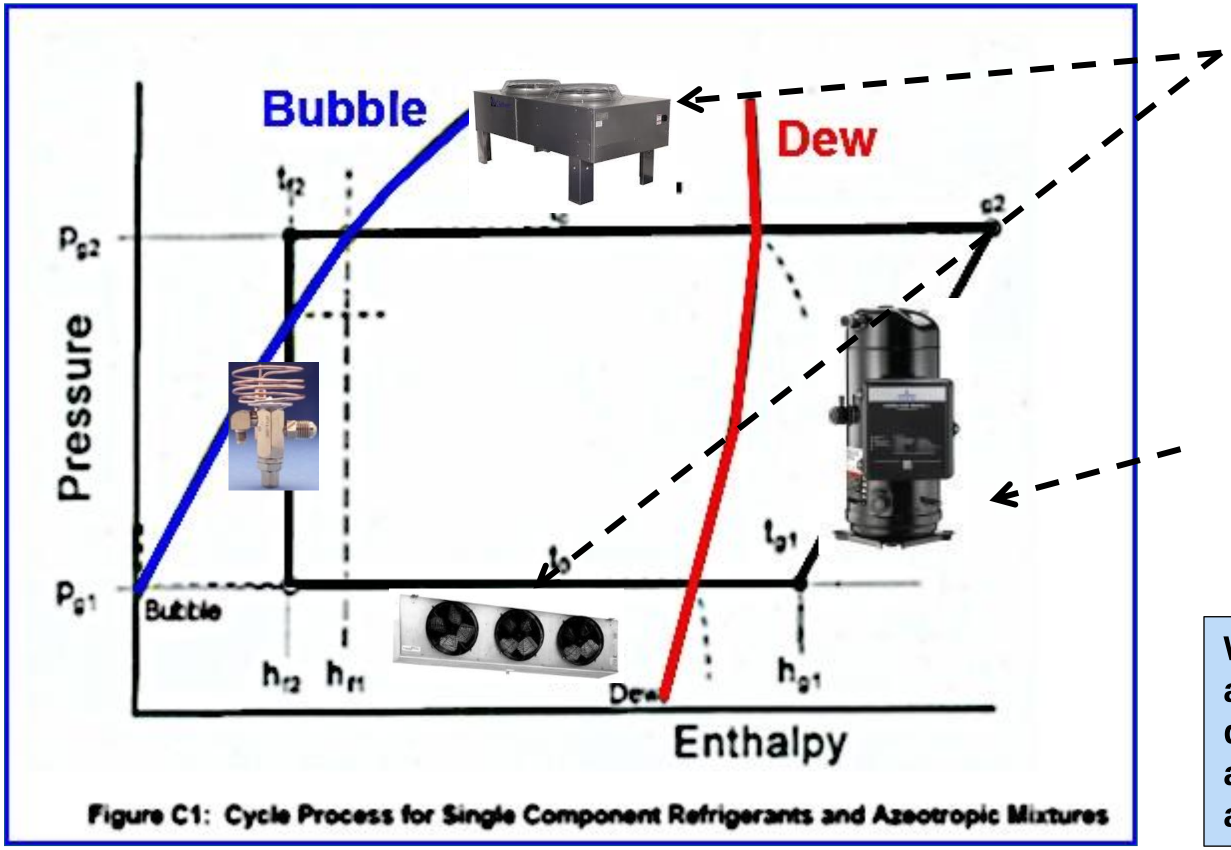


Figure C1: Cycle Process for Single Component Refrigerants and Azeotropic Mixtures

Assume Negligible Pressure Drop Effects

Heat Exchangers (Condenser & Evaporator) Operate at Mid-Point (or Bubble/Dew) Conditions

Compressors See Dew Point Conditions

When there is no glide and assuming little/no pressure drop, the temperature at mid-point = temperature at dew point

Mid-Point vs. Dew Point and the Refrigeration Cycle (Continued)

But When There Is Glide…

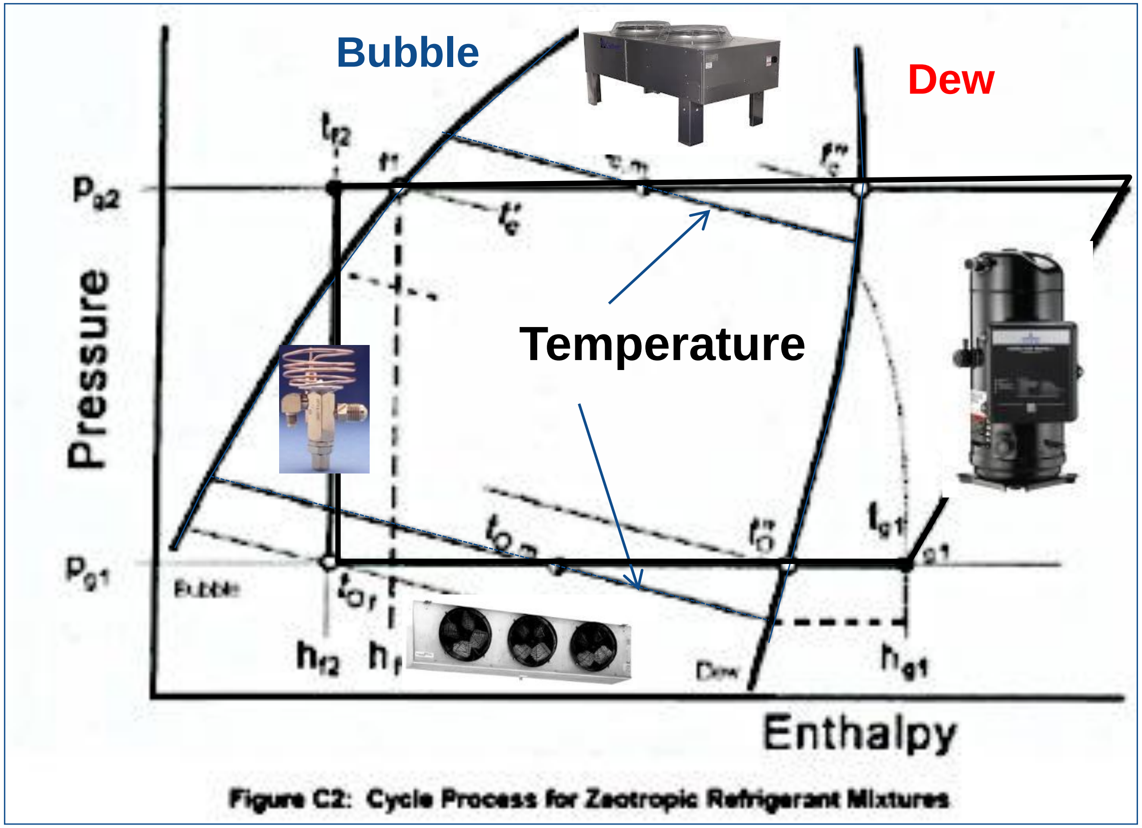


Figure C2: Cycle Process for Zeotropic Refrigerant Mixtures

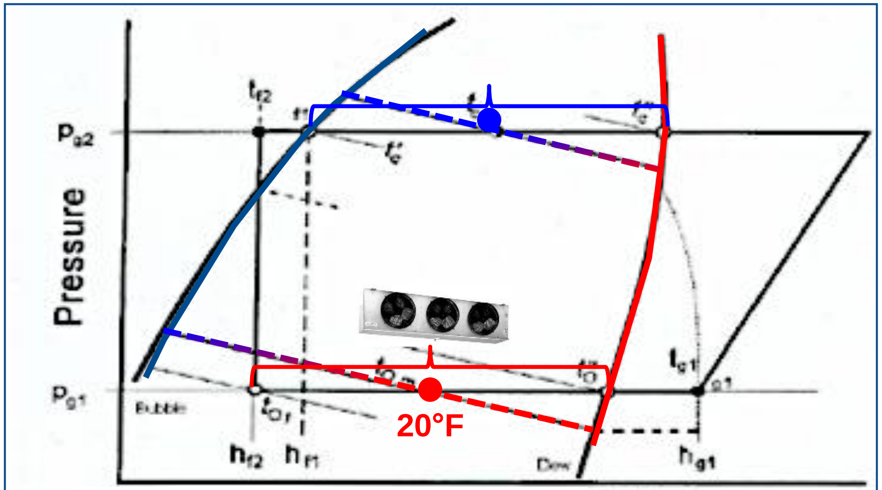
Assume Negligible Pressure Drop Effects

Per AHRI Standards, Compressors are Rated Based on Dew Point Pressure/ Temperatures

When there is glide and assuming little/no pressure drop, the temperature at mid-point ≠ temperature at dew point

Designing a System for Refrigerants With Glide: Heat Exchangers

- **Evaporator**
  - Average Temperature Across the Coil + Fan = Discharge Air Temperature
    - This is also recognized as the Mid-Point
    - Evaporator Mid-Point Temperature = Average of Evaporator Inlet and Outlet Temperatures (Dew Point)
      - Ideal Evaporator Inlet Temperature, $T_i = f\ (h_{liq}, P_{evap,dew})$
      - The inlet temperature is subject to system sub-cooling!

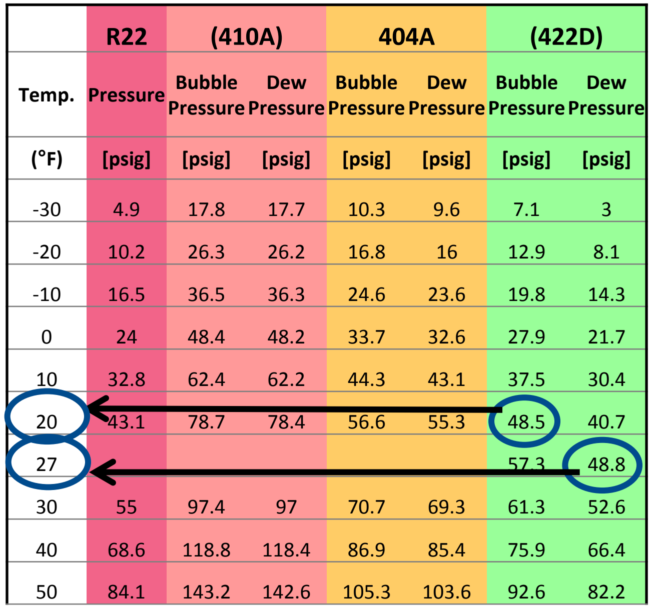


Refrig.	$T_{evap,in}$	$T_{evap,mid}$	$T_{evap,out}$
HCFC 22	20°F	20°F	20°F
HFC 407A	16.4°F	20°F	23.6°F

Assuming 110°F Condensing and No Sub-cooling

Average Evaporator Coil Temperature

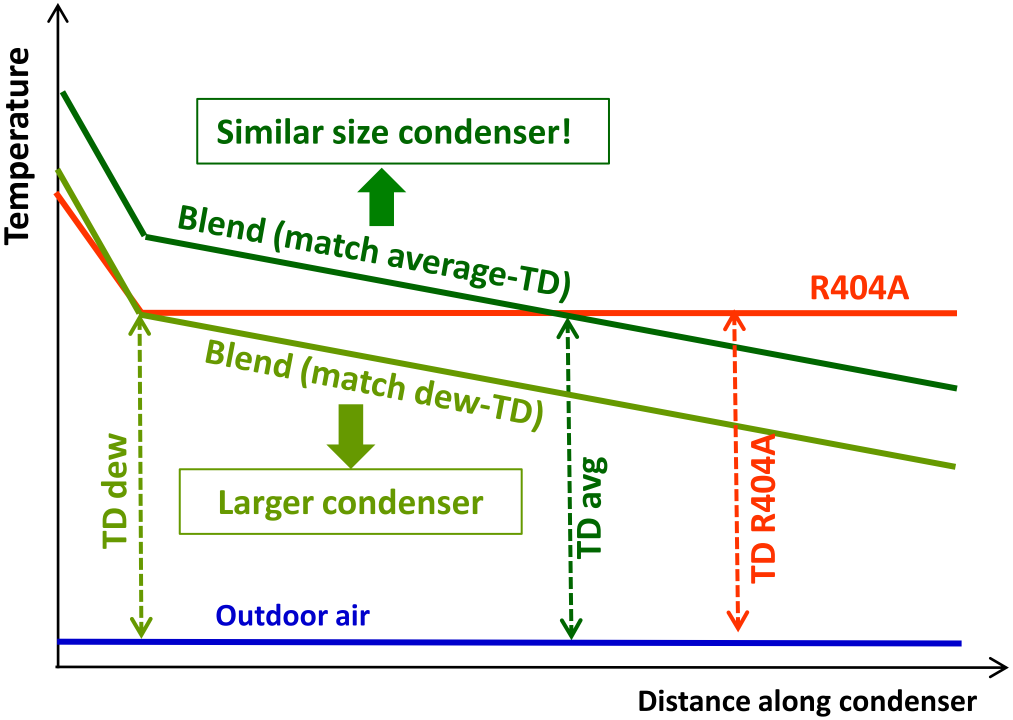
Pressure-Temperature Chart



	R22	(410A)		404A		(422D)	
Temp.	Pressure	Bubble Pressure	Dew Pressure	Bubble Pressure	Dew Pressure	Bubble Pressure	Dew Pressure
(°F)	[psig]	[psig]	[psig]	[psig]	[psig]	[psig]	[psig]
-30	4.9	17.8	17.7	10.3	9.6	7.1	3
-20	10.2	26.3	26.2	16.8	16	12.9	8.1
-10	16.5	36.5	36.3	24.6	23.6	19.8	14.3
0	24	48.4	48.2	33.7	32.6	27.9	21.7
10	32.8	62.4	62.2	44.3	43.1	37.5	30.4
20	43.1	78.7	78.4	56.6	55.3	48.5	40.7
27						57.3	48.8
30	55	97.4	97	70.7	69.3	61.3	52.6
40	68.6	118.8	118.4	86.9	85.4	75.9	66.4
50	84.1	143.2	142.6	105.3	103.6	92.6	82.2

- **For the Evaporator Coil:**
  - Using gauges, determine the pressure at the outlet of your evaporator
  - Find the corresponding Bubble Temperature using the "Bubble" column
  - Likewise, find the Dew Temperature using the Dew Column
  - Evaporating Temp. = (Bubble Temp + Dew Temp)/2
- **Example:** Find the average evaporator temperature of a system using R422D as the refrigerant when the gauge pressure at the evaporator outlet reads 48 psig.
  - Find ~48 psig in Bubble Column: 20°F
  - Find ~48 psig in Dew Column: 27°F
  - The Average Coil Temp = (27+20)/2 = 23.5°F
- **A more accurate estimate would account for inlet quality. So instead of average, multiply bubble by 0.40, dew by 0.60 and sum:**
  - Find ~48 psig in Bubble Column: 20°F
  - Find ~48 psig in Dew Column: 27°F
  - The Average Coil Temp = 0.40*(20) + 0.6*(27)= 24.2°F

Condenser Sizing



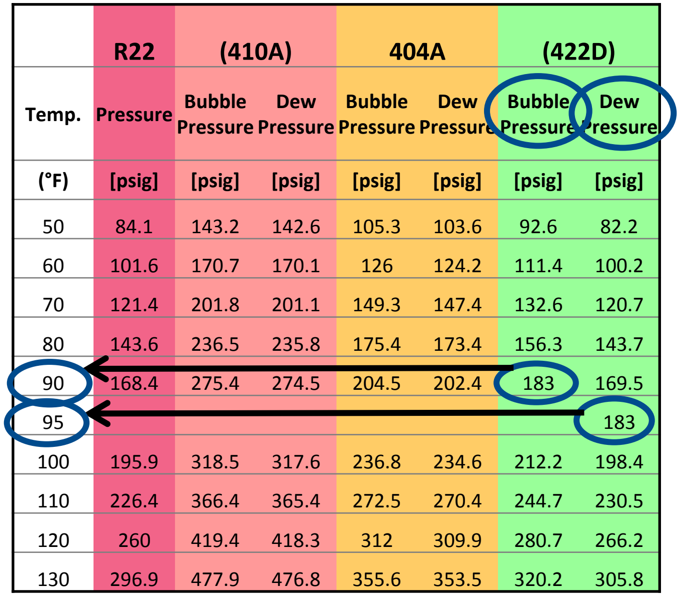
$$TD_{cond} = T_{\text{condensing}} - T_{ambient}$$

- **Catalogs typically use dew point for condensing temperature of blends**
- **With TD based on dew point, blends will show smaller capacity than single refrigerants**
- **This will lead to oversized condensers for blends**

Design Condensing Temperature Should Use Average of Bubble and Dew Points.

Average Condenser Coil Temperature

Pressure-Temperature Chart



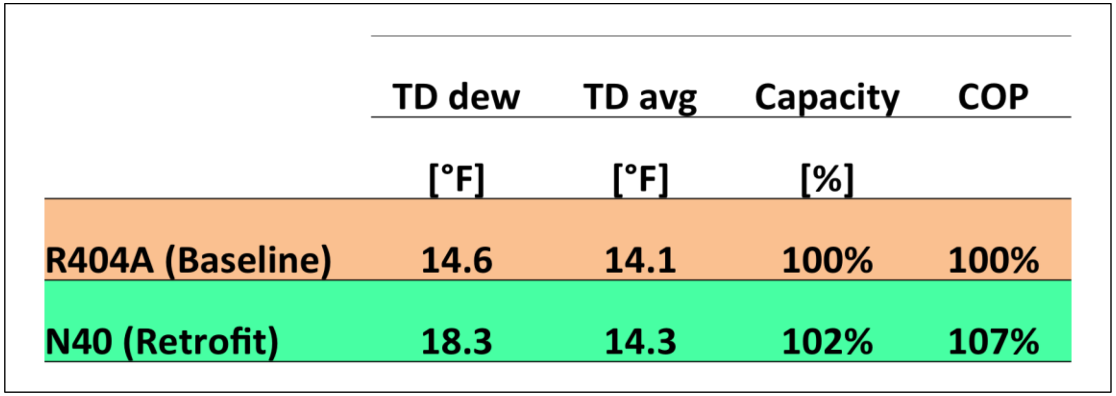
	R22	(410A)		404A		(422D)	
Temp.	Pressure	Bubble Pressure	Dew Pressure	Bubble Pressure	Dew Pressure	Bubble Pressure	Dew Pressure
(°F)	[psig]	[psig]	[psig]	[psig]	[psig]	[psig]	[psig]
50	84.1	143.2	142.6	105.3	103.6	92.6	82.2
60	101.6	170.7	170.1	126	124.2	111.4	100.2
70	121.4	201.8	201.1	149.3	147.4	132.6	120.7
80	143.6	236.5	235.8	175.4	173.4	156.3	143.7
90	168.4	275.4	274.5	204.5	202.4	183	169.5
95							183
100	195.9	318.5	317.6	236.8	234.6	212.2	198.4
110	226.4	366.4	365.4	272.5	270.4	244.7	230.5
120	260	419.4	418.3	312	309.9	280.7	266.2
130	296.9	477.9	476.8	355.6	353.5	320.2	305.8

- **The operating coil temperature for single component refrigerants is the corresponding temperature found in the P-T Chart.**
- **For blends, however, proceed as follows:**
  - Using gauges, determine the pressure at the outlet of your condenser. Inlet pressure may also be used.
  - Find the corresponding Bubble Temperature using the “Bubble” Column.
  - Likewise, find the Dew Temperature using the Dew Column.
  - Average Coil Temp. = (Bubble Temp + Dew Temp)/2
- **Example: Find the average condensing temperature of a system using R422D when the gauge pressure at the condenser outlet reads 183 psig.**
  - Find ~183 psig in Bubble Column: 90°F
  - Find ~183 psig in Dew Column: 95°F
  - The Average Coil Temp = (90+95)/2 = 92.5°F

Actual Example of Condenser Sizing

- Honeywell tested a fully instrumented system comprising a 3 hp semi-hermetic condensing unit and a walk-in cooler/freezer evaporator with R404A and N40
- The ambient air was fixed (95°F), but the condensing temperature was floating to capture the natural response of refrigerant in the heat exchanger
- Data indicates no need to oversize condenser, since TDs (average of bubble and dew) are the same for R404A and N40 blend

Actual System Results (0°F Box, 95°F Ambient)

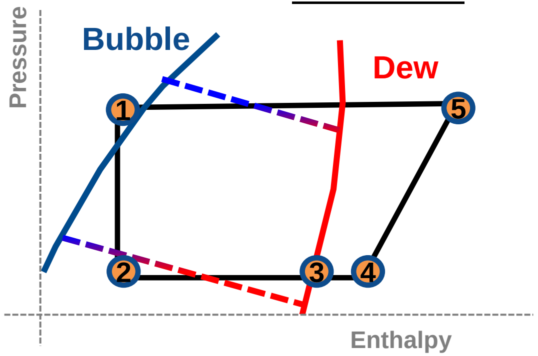


	TD dew [°F]	TD avg [°F]	Capacity [%]	COP
R404A (Baseline)	14.6	14.1	100%	100%
N40 (Retrofit)	18.3	14.3	102%	107%

Design TD Should Be Based on Average of Bubble and Dew Points to Avoid Oversizing the Condenser for a Blend.

Compressor Selection Example
Dew Point vs. Mid-Point

	Refrigerant	**T_{EVAP} (°F)**	**P_{EVAP} (psia)**	**T_{COND} (°F)**	**P_{COND} (psia)**	**T_{RG} (°F)**	**T_{LIQ} (°F)**	**$T_{EVAP\ SH}$ (F)**
Design Condition (Dew Point):	R-407A	-25	20.446	110	259.93	65	50	10
Bubble Point:		-36		102				



	T (°F)	**P (psia)**	**h (Btu/lbm)**
State 1 (Cond Out)	50	259.93	92.141
State 2 (Evap In)	-33.7	20.446	92.141
State 3 (Evap Out)	-15	20.446	165.2
State 4 (Compr In)	65	20.446	180.59
State 5 (Compr Out)*	243.1	259.93	212.81

**Assuming Isentropic Compression*

	Refrigerant	**T_{EVAP} (°F)**	**P_{EVAP} (psia)**	**T_{COND} (°F)**	**P_{COND} (psia)**	**T_{RG} (°F)**	**T_{LIQ} (°F)**	**$T_{EVAP\ SH}$ (F)**
Operating Condition (Mid Point):	R-407A	-25		110				
Compr. "Design Condition" (Dew Point):		-20.7		113.9		65	50	10

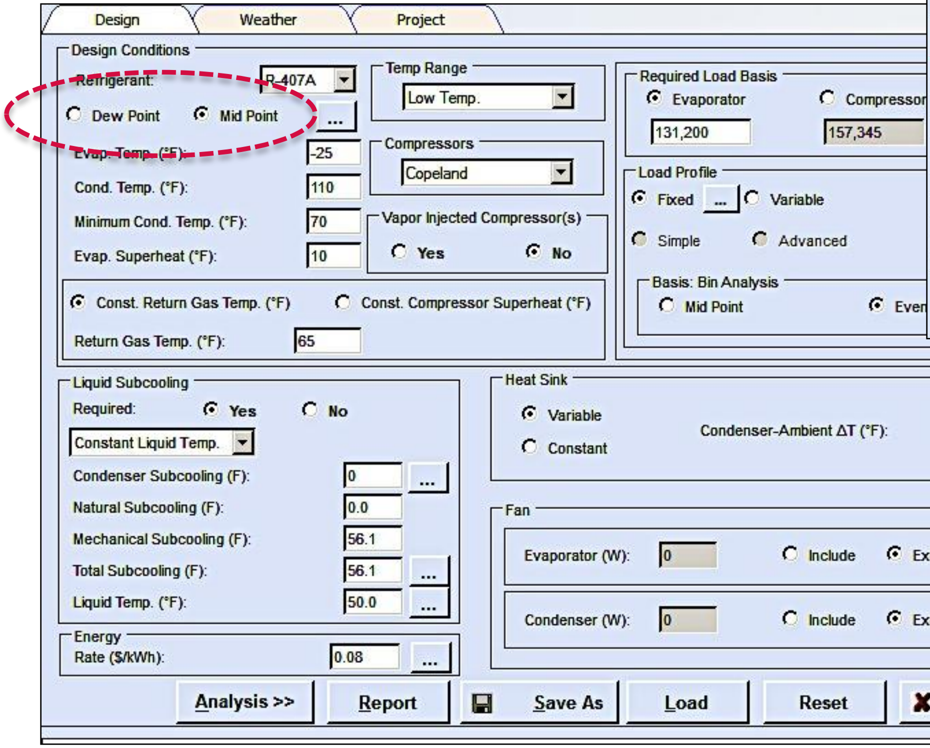
Evaporator Load = 131.2MBH

Using Mid-Point, You Can Select Smaller Compressors and Still Meet the Required Design Load.

Design Condition DEW POINT	Model No.	Compressor Capacity, Btu/h	NRE, Btu/h	"Mid Point Based" Design Condition DEW POINT	Model No.	Compressor Capacity, Btu/h	NRE, Btu/h
-25/110/65/50	3DSDF**46**KL-TFC	33,900	26,400	-21/114/65/50	3DFDF**40**KL-TFC	33,000	25,800
	3DF3F**40**KL-TFC	30,900	24,100		3DF3F**40**KL-TFC	33,000	25,800
	4DHNF**63**KL-TSK	48,500	37,800		4DHNF**63**KL-TSK	51,700	40,400
	4DJNF**76**KL-TSK	58,900	45,900		4DHNF**63**KL-TSK	51,700	40,400
TOTAL		172,200	134,200			169,400	132,400
% vs. Design Load		131%	102%			129%	101%

Emerson Product Selection Software v. 1.0.39

Select Compressors Based on Mid-Point and Compare Energy



Design Conditions

Refrigerant: R-407A
○ Dew Point ● Mid Point ...
Evap. Temp. (°F): -25
Cond. Temp. (°F): 110
Minimum Cond. Temp. (°F): 70
Evap. Superheat (°F): 10

Temp Range
Low Temp.

Compressors
Copeland

Vapor Injected Compressor(s)
○ Yes ● No

● Const. Return Gas Temp. (°F) ○ Const. Compressor Superheat (°F)
Return Gas Temp. (°F): 65

Required Load Basis
● Evaporator ○ Compressor
131,200 157,345

Load Profile
● Fixed ... ○ Variable
○ Simple ○ Advanced

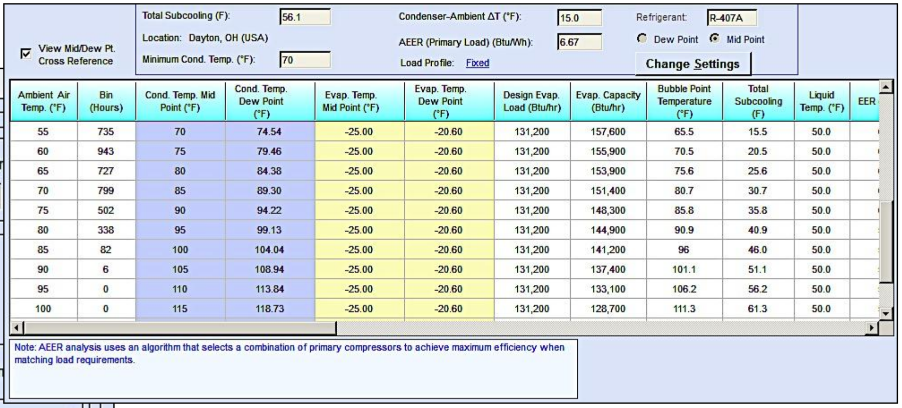
Basis: Bin Analysis
○ Mid Point ● Even

Liquid Subcooling
Required: ● Yes ○ No
Constant Liquid Temp.
Condenser Subcooling (F): 0 ...
Natural Subcooling (F): 0.0
Mechanical Subcooling (F): 56.1
Total Subcooling (F): 56.1 ...
Liquid Temp. (°F): 50.0 ...

Energy
Rate ($/kWh): 0.08 ...

Heat Sink
● Variable ○ Constant
Condenser-Ambient ΔT (°F): 15

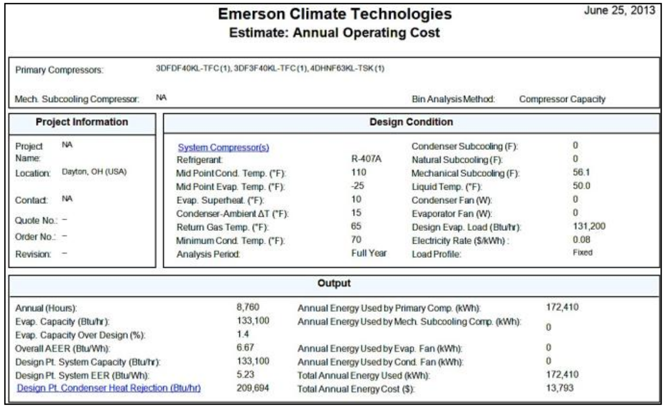
Fan
Evaporator (W): 0 ○ Include ● Exclude
Condenser (W): 0 ○ Include ● Exclude



☑ View Mid/Dew Pt. Cross Reference
Total Subcooling (F): 56.1
Location: Dayton, OH (USA)
Minimum Cond. Temp. (°F): 70
Condenser-Ambient ΔT (°F): 15.0
AEER (Primary Load) (Btu/Wh): 6.67
Load Profile: Fixed
Refrigerant: R-407A
○ Dew Point ● Mid Point

Ambient Air Temp. (°F)	Bin (Hours)	Cond. Temp. Mid Point (°F)	Cond. Temp. Dew Point (°F)	Evap. Temp. Mid Point (°F)	Evap. Temp. Dew Point (°F)	Design Evap. Load (Btu/hr)	Evap. Capacity (Btu/hr)	Bubble Point Temperature (°F)	Total Subcooling (F)	Liquid Temp. (°F)	EER
55	735	70	74.54	-25.00	-20.60	131,200	157,600	65.5	15.5	50.0	
60	943	75	79.46	-25.00	-20.60	131,200	155,900	70.5	20.5	50.0	
65	727	80	84.38	-25.00	-20.60	131,200	153,900	75.6	25.6	50.0	
70	799	85	89.30	-25.00	-20.60	131,200	151,400	80.7	30.7	50.0	
75	502	90	94.22	-25.00	-20.60	131,200	148,300	85.8	35.8	50.0	
80	338	95	99.13	-25.00	-20.60	131,200	144,900	90.9	40.9	50.0	
85	82	100	104.04	-25.00	-20.60	131,200	141,200	96	46.0	50.0	
90	6	105	108.94	-25.00	-20.60	131,200	137,400	101.1	51.1	50.0	
95	0	110	113.84	-25.00	-20.60	131,200	133,100	106.2	56.2	50.0	
100	0	115	118.73	-25.00	-20.60	131,200	128,700	111.3	61.3	50.0	

Note: AEER analysis uses an algorithm that selects a combination of primary compressors to achieve maximum efficiency when matching load requirements.



Emerson Climate Technologies
Estimate: Annual Operating Cost
June 25, 2013

Primary Compressors: 3DFDF40KL-TFC (1), 3DF3F40KL-TFC (1), 4DHNF63KL-TSK (1)
Mech. Subcooling Compressor: NA
Bin Analysis Method: Compressor Capacity

Project Information

Project Name: NA
Location: Dayton, OH (USA)
Contact: NA
Quote No.: –
Order No.: –
Revision: –

Design Condition

System Compressor(s)

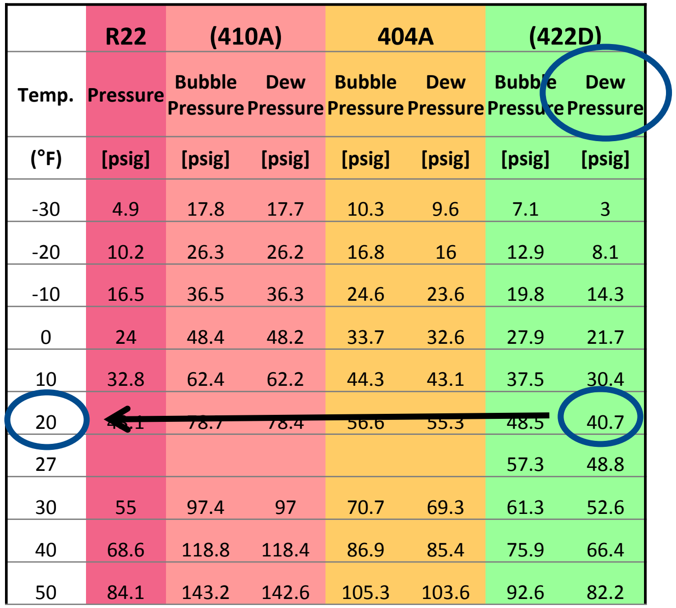
Refrigerant	R-407A	Condenser Subcooling (F):	0
Mid Point Cond. Temp. (°F):	110	Natural Subcooling (F):	0
Mid Point Evap. Temp. (°F):	-25	Mechanical Subcooling (F):	56.1
Evap. Superheat. (°F):	10	Liquid Temp. (°F):	50.0
Condenser-Ambient ΔT (°F):	15	Condenser Fan (W):	0
Return Gas Temp. (°F):	65	Evaporator Fan (W):	0
Minimum Cond. Temp. (°F):	70	Design Evap. Load (Btu/hr):	131,200
Analysis Period:	Full Year	Electricity Rate ($/kWh):	0.08
		Load Profile:	Fixed

Output

Annual (Hours):	8,760	Annual Energy Used by Primary Comp. (kWh):	172,410
Evap. Capacity (Btu/hr):	133,100	Annual Energy Used by Mech. Subcooling Comp. (kWh):	0
Evap. Capacity Over Design (%):	1.4		
Overall AEER (Btu/Wh):	6.67	Annual Energy Used by Evap. Fan (kWh):	0
Design Pt. System Capacity (Btu/hr):	133,100	Annual Energy Used by Cond. Fan (kWh):	0
Design Pt. System EER (Btu/Wh):	5.23	Total Annual Energy Used (kWh):	172,410
Design Pt. Condenser Heat Rejection (Btu/hr)	209,694	Total Annual Energy Cost ($):	13,793

Degree of Superheat

Pressure-Temperature Chart

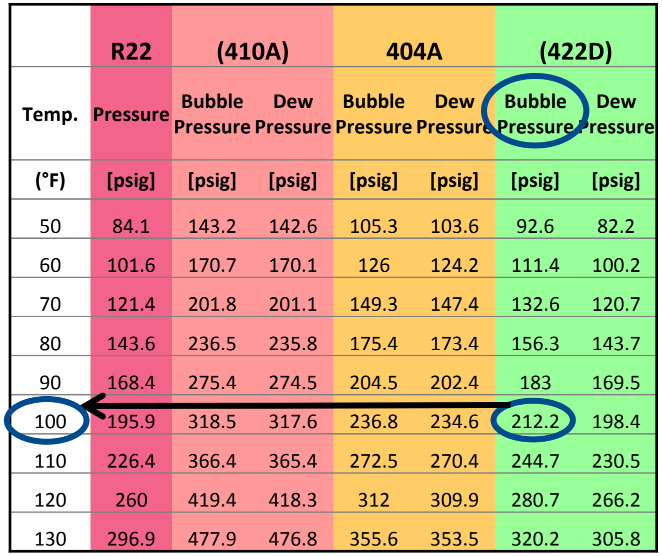


	R22	(410A)		404A		(422D)	
Temp.	Pressure	Bubble Pressure	Dew Pressure	Bubble Pressure	Dew Pressure	Bubble Pressure	Dew Pressure
(°F)	[psig]	[psig]	[psig]	[psig]	[psig]	[psig]	[psig]
-30	4.9	17.8	17.7	10.3	9.6	7.1	3
-20	10.2	26.3	26.2	16.8	16	12.9	8.1
-10	16.5	36.5	36.3	24.6	23.6	19.8	14.3
0	24	48.4	48.2	33.7	32.6	27.9	21.7
10	32.8	62.4	62.2	44.3	43.1	37.5	30.4
20	4[illegible].1	78.7	78.4	56.6	55.3	48.5	40.7
27						57.3	48.8
30	55	97.4	97	70.7	69.3	61.3	52.6
40	68.6	118.8	118.4	86.9	85.4	75.9	66.4
50	84.1	143.2	142.6	105.3	103.6	92.6	82.2

- **The refrigerant is in superheated vapor state at the end of the evaporator.**
- **To determine superheat, use nearest saturated state (Dew Point) in your P-T Chart.**
- **Procedure:**
  - Use gauges to determine the pressure at the coil outlet, and a thermometer to get the actual temperature at the same point.
  - Get the Dew Temperature from the "Dew" Column.
  - Superheat = Actual Temperature – Dew Temperature
- **Example:** Find the superheat on a system which uses R422D when the pressure at the evaporator outlet reads 41 psig and your surface thermometer reads 30°F.
  - 41 psig yields ~ 20°F (Using Dew Point)
  - Degree of Superheat = 30°F – (20°F) = 10°F

Degree of Subcooling

Pressure-Temperature Chart

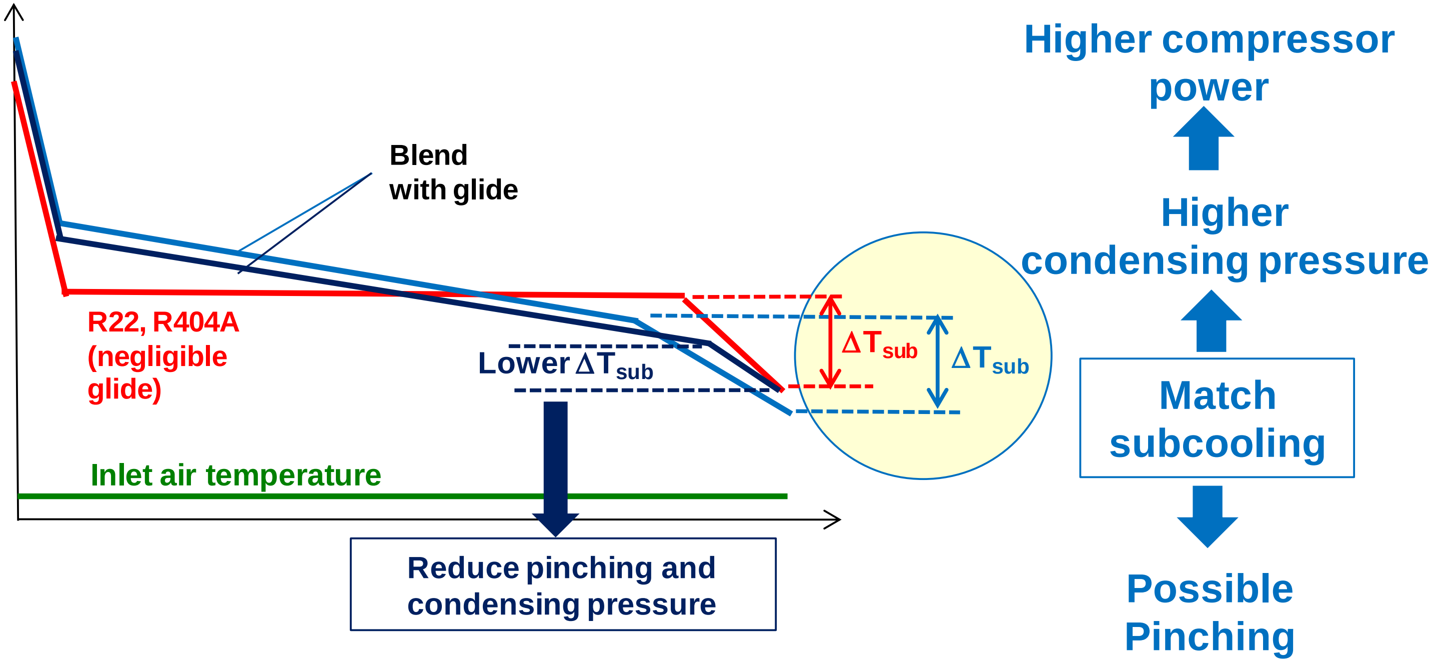


	R22	(410A)		404A		(422D)	
Temp.	Pressure	Bubble Pressure	Dew Pressure	Bubble Pressure	Dew Pressure	Bubble Pressure	Dew Pressure
(°F)	[psig]	[psig]	[psig]	[psig]	[psig]	[psig]	[psig]
50	84.1	143.2	142.6	105.3	103.6	92.6	82.2
60	101.6	170.7	170.1	126	124.2	111.4	100.2
70	121.4	201.8	201.1	149.3	147.4	132.6	120.7
80	143.6	236.5	235.8	175.4	173.4	156.3	143.7
90	168.4	275.4	274.5	204.5	202.4	183	169.5
100	195.9	318.5	317.6	236.8	234.6	212.2	198.4
110	226.4	366.4	365.4	272.5	270.4	244.7	230.5
120	260	419.4	418.3	312	309.9	280.7	266.2
130	296.9	477.9	476.8	355.6	353.5	320.2	305.8

- **The Refrigerant will be in liquid state at the end of the condenser.**
- **To determine subcooling, use the nearest saturated state (Bubble Point) in your P-T Chart.**
- **Procedure:**
  - Use gauges to determine the pressure at the coil outlet, and a thermometer to get the actual temperature at the same point.
  - Use the “Bubble” Column to get the Bubble Temperature.
  - Subcooling = Actual Temperature – Bubble Temperature
- **Example:** Find the amount of subcooling on a system using R422D when the liquid line temperature reads 96°F and the liquid line pressure is 212 psig.
  - 212 psig yields ~ 100°F (Using Bubble Point)
  - Degree of Subcooling = 100°F – 96°F = 4°F

Subcooling and Refrigerant Charging in Systems Without Liquid Receiver

- **Systems Without Liquid Receiver** are known **as Critically Charged**
- **Common Practice** is to charge those systems to **Match the Subcooling (From Bubble Point)**
- For **Blends With Glide,** this will result in an **Overcharged** System



Reduce pinching and condensing pressure

Higher compressor power

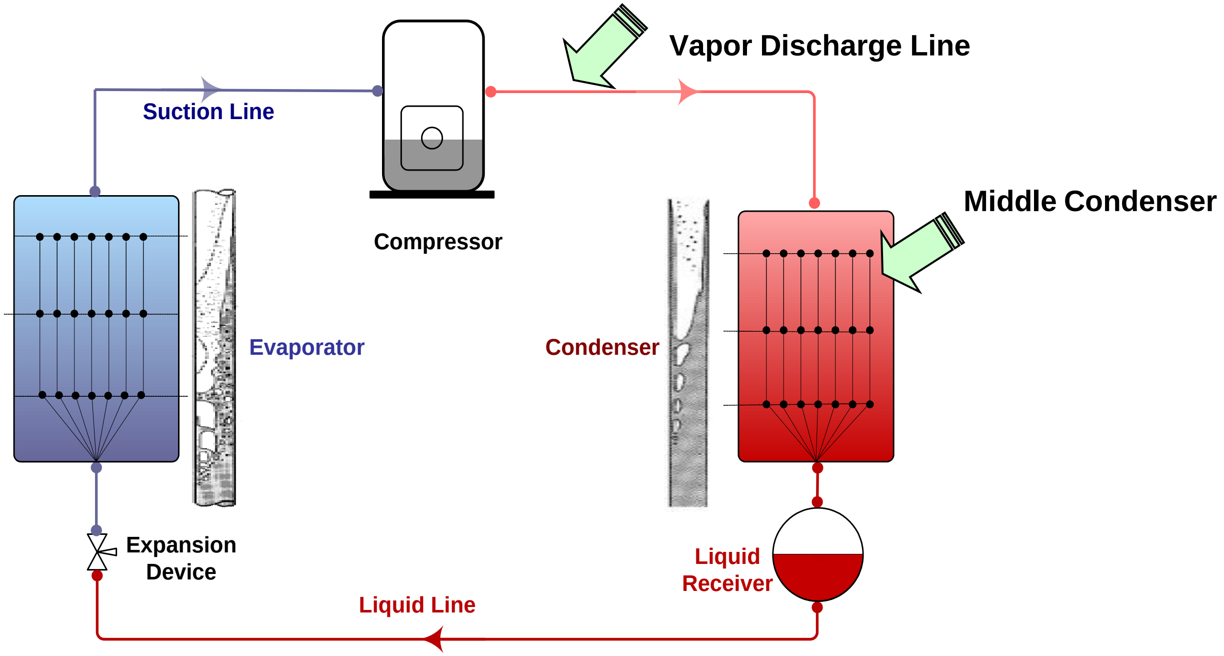
Higher condensing pressure

Match subcooling

Possible Pinching

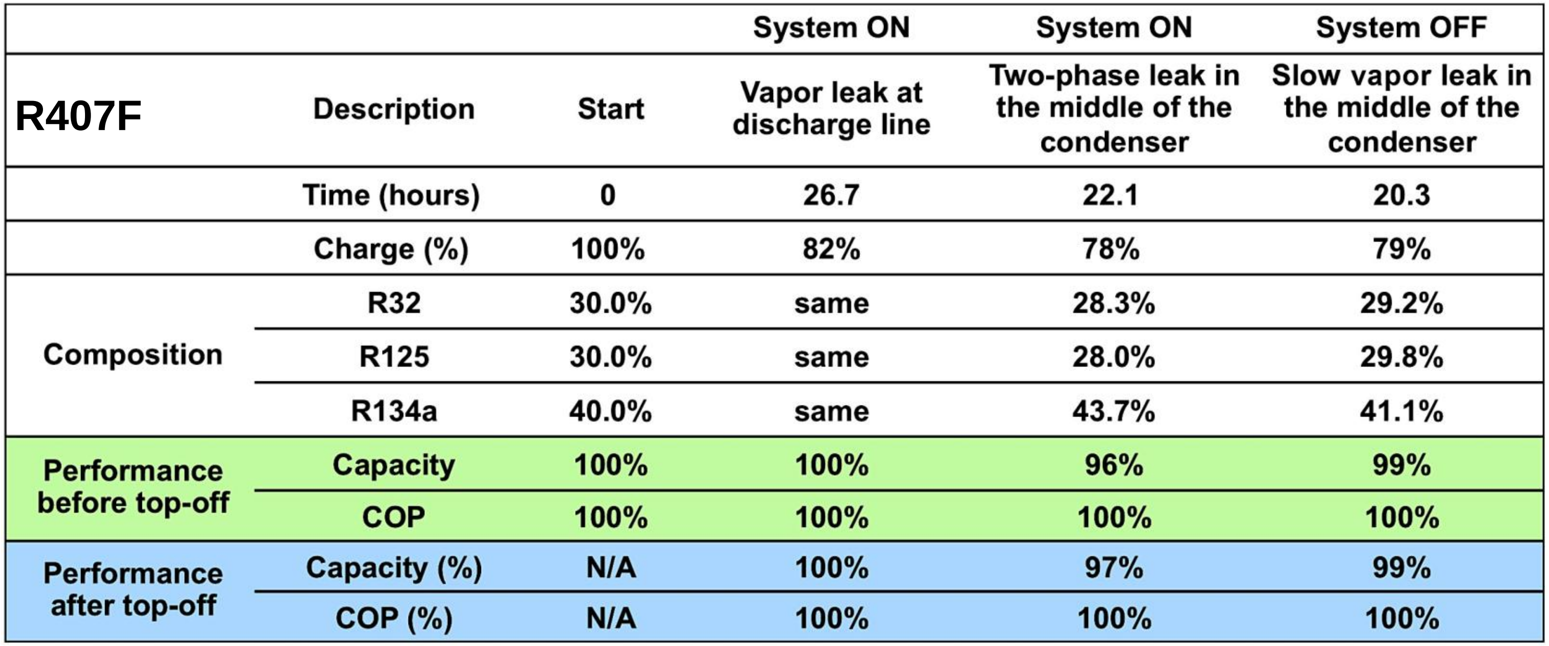
Subcooling (from Bubble Point) should be lowered by about ½ of the glide when working with blends in critically charged systems

Fractionation of Blends During Leak Events



- **Leak Events Were Simulated Using a 0.1 mm ID Orifice in** a 1-Ton Walk-in Cooler/Freezer System (Box Temp of -25°C). Outdoor varied from 10°C to 20°C.
- **Charge of R407F and POE Lubricant**
- **Two Types of Leaks Were Evaluated in Two Locations:**
  - System ON: 1) Vapor Discharge Line, 2) Middle of Condenser (Liquid-vapor)
  - System OFF: In the Middle of the Condenser (Vapor While System OFF)

Fractionation During Leak Events



			System ON	System ON	System OFF
R407F	Description	Start	Vapor leak at discharge line	Two-phase leak in the middle of the condenser	Slow vapor leak in the middle of the condenser
	Time (hours)	0	26.7	22.1	20.3
	Charge (%)	100%	82%	78%	79%
Composition	R32	30.0%	same	28.3%	29.2%
	R125	30.0%	same	28.0%	29.8%
	R134a	40.0%	same	43.7%	41.1%
Performance before top-off	Capacity	100%	100%	96%	99%
	COP	100%	100%	100%	100%
Performance after top-off	Capacity (%)	N/A	100%	97%	99%
	COP (%)	N/A	100%	100%	100%

- There were no changes in composition during vapor leaks at the discharge line
- Leaks in the middle of the condenser with system ON or OFF caused minor changes in composition, **Mostly Within Typical Refrigerant Tolerances (±2%)**
- Performance decreased less than **5% Due to the Fractionation**
- If the charge is topped off, composition and performance get even closer to original values

Final Comments

- Blends behave differently than single component refrigerants when liquid+vapor are present in equilibrium
- Compressor selection should be made knowing how the *system* will actually operate, not how the compressor was tested
- Heat exchangers will operate at different refrigerant temperatures when blends are used, which should be taken into account when selections are made
- System charging, subcooling, setting superheat, topping off after a leak — all deserve special attention
- This presentation is for information only – consult individual component and equipment manufacturers for specific guidelines on the use of their equipment

Thank You!

We thank Honeywell BRL for their assistance with several of the charts and content of this presentation.

Questions and Answers