Technology issues regarding Blends of Refrigerants

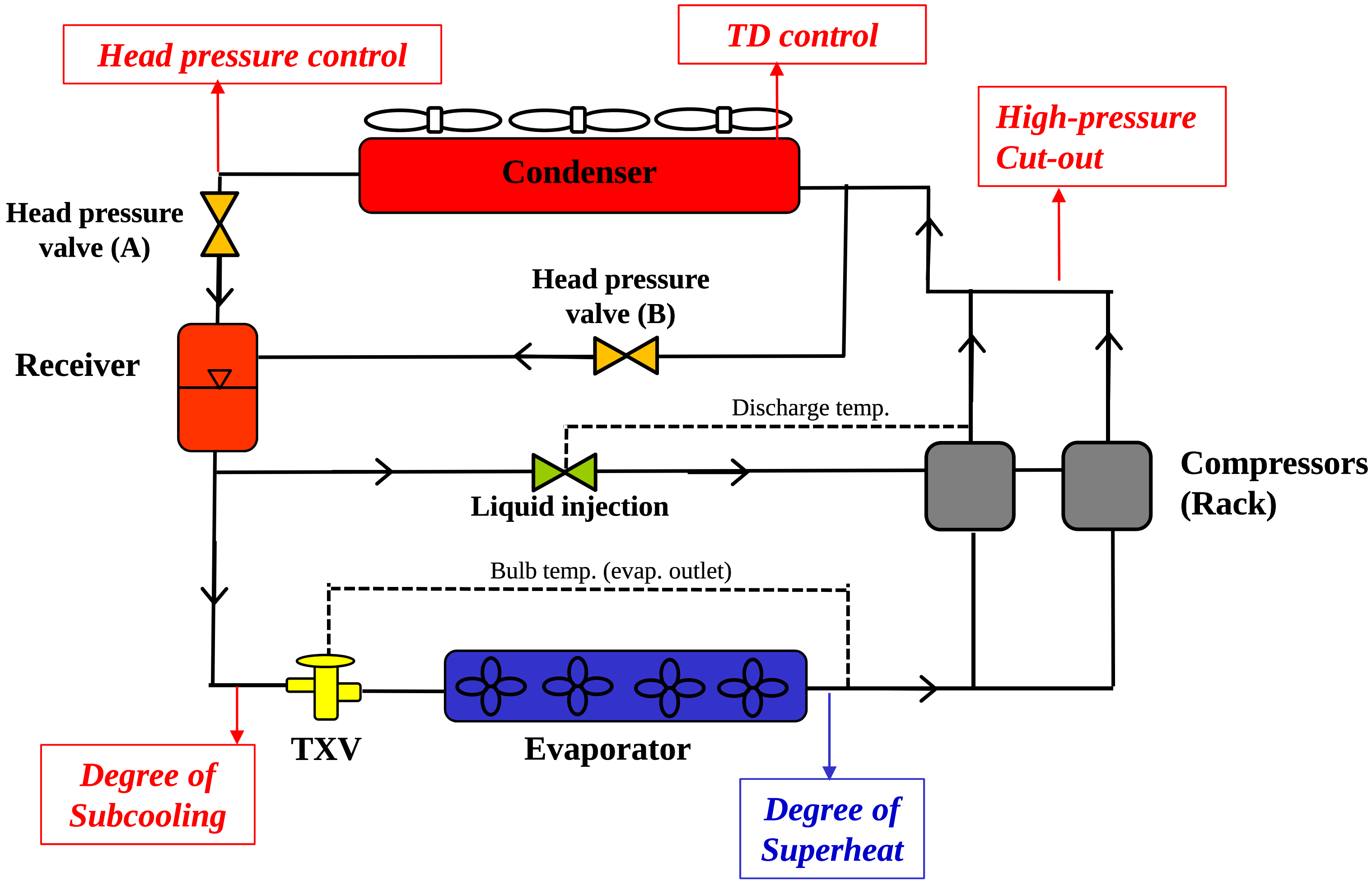
Buffalo Research Laboratory

Honeywell

Agenda

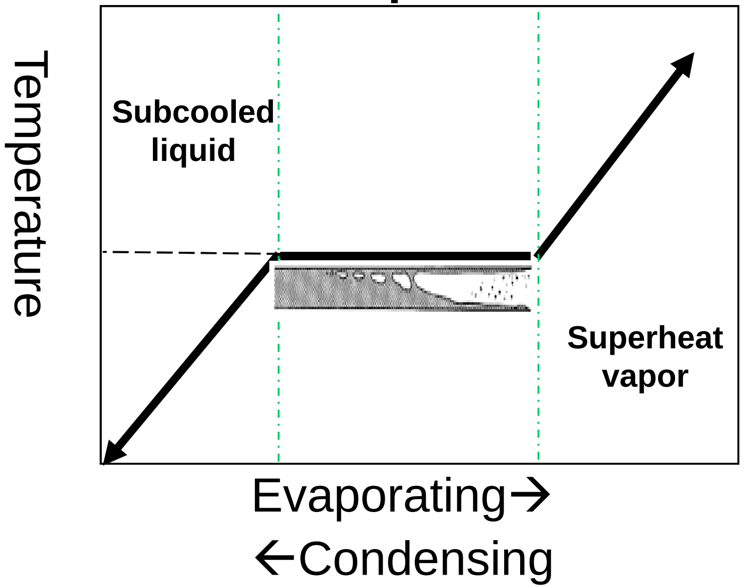
- Basic Characteristics
  - Background
  - Degree of Superheat, degree of subcooling, average coil temperature
- Handling and setting up systems with blends
  - Control Settings
    - Condenser: High-side pressure regulator, Demand "TD" controls
    - Thermostatic Expansion Valve: Degree of Superheat
  - Fractionation
    - Nominal composition vs Circulating composition
    - Effect of leaks on composition and performance
- Sizing systems with blends
  - Condenser sizing:
  - Compressor sizing: manufacturer data vs. actual system performance

Typical supermarket system

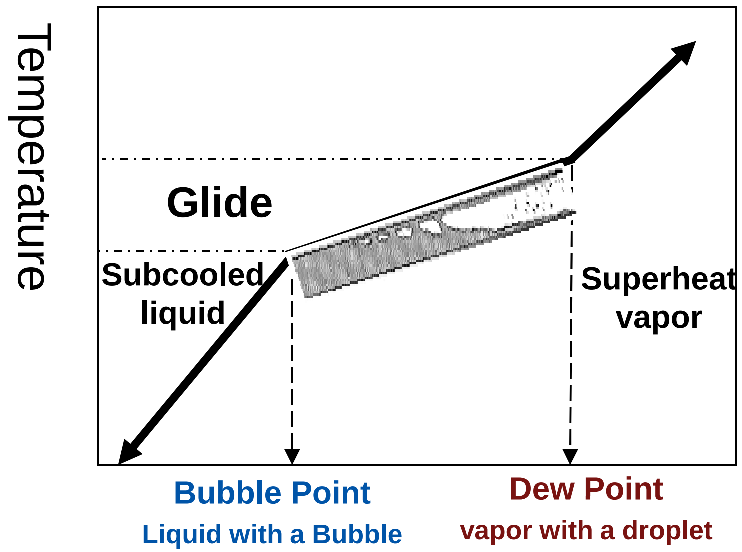


What is a Blend?

Single component or Azeotropic Blends



Non-Azeotropic Blends *(typically called "Blends")*



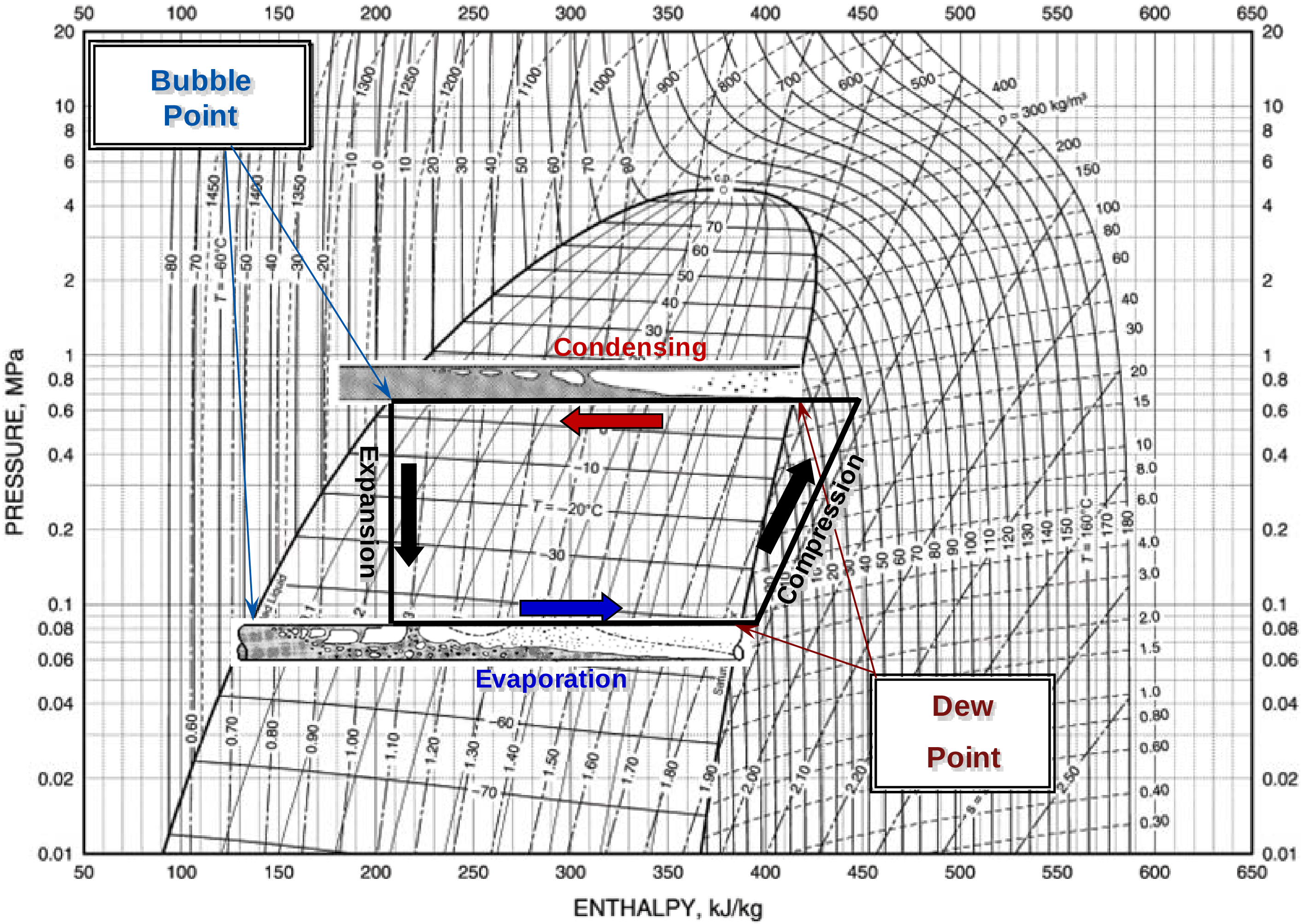
- ASHRAE classifies blends in **azeotropic** (R500 series) and **non-azeotropic** (R400 series)
- Single refrigerants and azeotropic blends evaporate or condense at constant temperature, in a process at constant pressure.
- Non-azeotropic blends or just "Blends" have two distinct points:
  - When the first droplet of vapor occurs (**Dew Temperature**), and
  - When the first bubble of vapor happens (**Bubble Temperature**)
  - The difference between these temperatures is called "**Glide**"

Blend in a P-h diagram

In a phase-change process (Evaporating or Condensing):

The point when the first bubble of vapor appears is called “**Bubble**”

The point where the first droplet of vapor occurs is called “**Dew**”



Degree of Superheat

Pressure-Temperature Chart

	R22	AZ-20 (410A*)		404A*		Performax LT (407F)	
Temp.	Pressure	Bubble Pressure	Dew Pressure	Bubble Pressure	Dew Pressure	Bubble Pressure	Dew Pressure
(°C)	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]
-40	105	176	175	135	131	135	100
-35	132	219	218	169	164	169	127
-30	164	270	269	208	202	209	160
-25	201	331	329	254	248	257	200
-20	245	401	399	307	300	312	246
-15	296	482	480	369	361	376	301
-10	355	575	573	439	431	450	364
-5	422	681	678	519	510	534	438
0	498	801	798	610	600	629	522
5	584	936	933	713	702	737	618
10	681	1088	1085	827	816	858	728
15	789	1258	1254	955	943	993	851
20	910	1448	1443	1097	1084	1144	989
25	1044	1657	1652	1255	1241	1311	1144
30	1192	1889	1884	1428	1414	1496	1316
35	1355	2145	2139	1620	1605	1699	1507
40	1534	2426	2419	1829	1815	1921	1719
45	1729	2734	2726	2059	2044	2165	1953

- **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 Performax LT (407F) when the pressure at the evaporator outlet reads 160 kPa and your surface thermometer reads -25°C.
  - **160 kPa yields ~ -30°C (using dew point)**
  - **Degree of Superheat = -25°C - (-30°C) = 5°C**

* R404A and R410A are blends but have negligible glide and are treated as single refrigerants for all practical purposes.

Degree of Subcooling

Pressure-Temperature Chart

	R22	AZ-20 (410A*)		404A*		Performax LT (407F)	
Temp.	Pressure	Bubble Pressure	Dew Pressure	Bubble Pressure	Dew Pressure	Bubble Pressure	Dew Pressure
(°C)	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]
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40	1534	2426	2419	1829	1815	1921	1719
45	1729	2734	2726	2059	2044	2165	1953
50	1943	3071	3063	2311	2296	2431	2211

- **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 Performax LT when the liquid line temperature reads 30°C and the liquid line pressure is 1700 kPa.
  - **1700 kPa yields ~ 35°C (using Bubble point)**
  - **Degree of Subcooling = 35°C - 30°C = 5°C**

* R404A and R410A are blends but have negligible glide and are treated as single refrigerants for all practical purposes.

Average condenser coil temperature

Pressure-Temperature Chart

	R22	AZ-20 (410A*)		404A*		Performax LT (407F)	
Temp.	Pressure	Bubble Pressure	Dew Pressure	Bubble Pressure	Dew Pressure	Bubble Pressure	Dew Pressure
(°C)	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]
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-35	132	219	218	169	164	169	127
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35	1355	2145	2139	1620	1605	1699	1507
39.6							1699
40	1534	2426	2419	1829	1815	1921	1719
45	1729	2734	2726	2059	2044	2165	1953
50	1943	3071	3063	2311	2296	2431	2211

- **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 R407F when the gauge pressure at the condenser outlet reads 1700 kPa.
  - **Find ~ 1700 kPa in Bubble column: 35°C**
  - **Find ~ 1700 kPa in Dew column: 39.6°C**
  - **The average coil temp = (35+39.6)/2 = 37.3°C**

* R404A and R410A are blends but have negligible glide and are treated as single refrigerants for all practical purposes.

Average evaporator coil temperature

Pressure-Temperature Chart

Temp. (°C)	R22 Pressure [kPa]	AZ-20 (410A) Bubble Pressure [kPa]	AZ-20 (410A) Dew Pressure [kPa]	404A Bubble Pressure [kPa]	404A Dew Pressure [kPa]	Performax LT (407F) Bubble Pressure [kPa]	Performax LT (407F) Dew Pressure [kPa]
-40	105	176	175	135	131	135	100
-35	132	219	218	169	164	169	127
-30	164	270	269	208	202	209	160
-29							169
-25	201	331	329	254	248	257	200
-20	245	401	399	307	300	312	246
-15	296	482	480	369	361	376	301
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50	1943	3071	3063	2311	2296	2431	2211

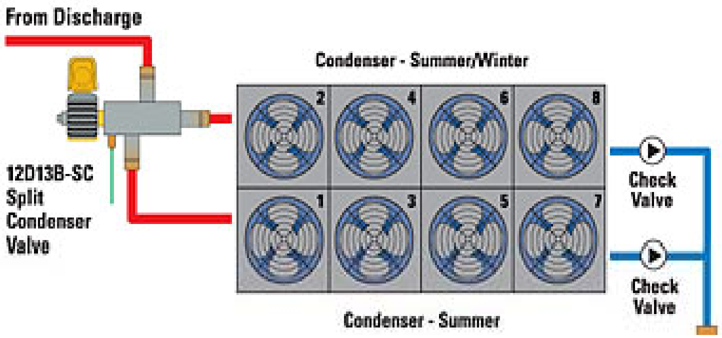
- **Similarly to the condenser coil:**
  - Using gauges, determine the pressure at the outlet of your evaporator
  - Find the corresponding Bubble temperature using the "Bubble" column.
  - Likewise, find the Dew temperature using the dew column.
  - Evaporating Temp. = (Bubble Temp + Dew Temp)/2
- **Example:** Find the average evaporator temperature of a system using R407F as the refrigerant when the gauge pressure at the evaporator outlet reads 169 kPa.
  - **Find ~169kPa in Bubble column: -35°C**
  - **Find ~ 169kPa in Dew column: -29°C**
  - **The average coil temp = (-35+(-29))/2 = -32°C**

- **Note:** a more accurate estimate would account for inlet quality. So instead of average, multiply bubble by 1/3, dew by 2/3 and sum:
  - **Find ~ 169kPa in Bubble column: -35°C**
  - **Find ~ 169kPa in Dew column: -29°C**
  - **The average coil temp = 1/3*(-35) + 2/3*(-29)= -31°C**

Condenser Controls

1) **Fan Cycling/ Variable Speed:**
   - Low head pressure can result in poor operation of expansion valve and system
   - At low ambient conditions, fans will either cycle or reduced their speed to maintain head pressure

2) **Splitting circuits**
   - remove a portion from the condenser circuit in order to maintain head pressure at low ambient conditions



- **Controls are typically based on ambient dry-bulb or wet-bulb temperature, condensing temperature or air-refrigerant temperature difference (TD).**
- **TD is the difference between the condensing and the air inlet temperature.**
- **Condensing temperature and TD values should be based on the average (bubble and dew)**

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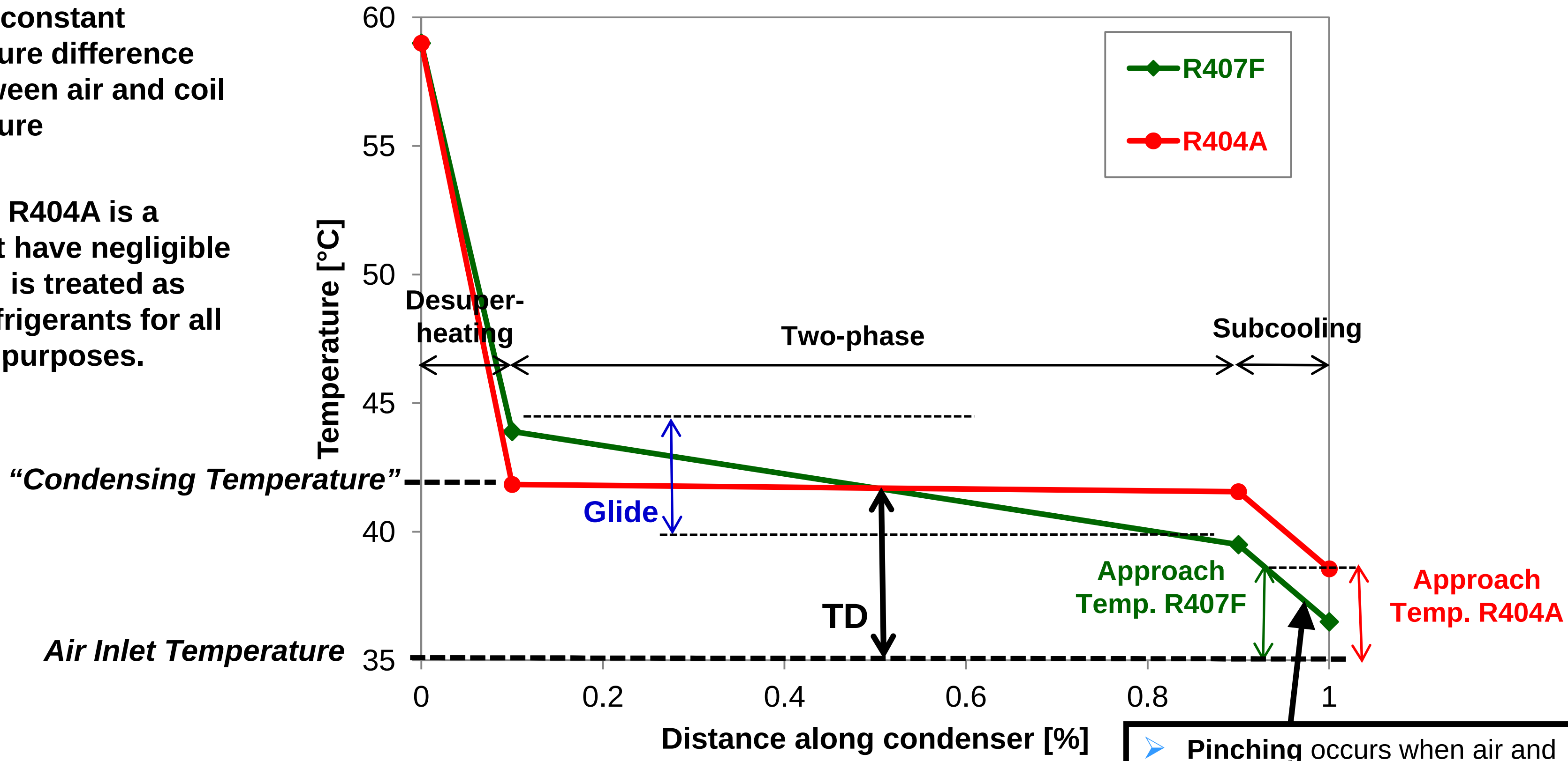
TD-controlled condensers: R404A vs. R407F

- **Maintain constant temperature difference (TD) between air and coil temperature**
- **Note that R404A is a blend but have negligible glide and is treated as single refrigerants for all practical purposes.**



- **Pinching** occurs when air and refrigerant temperatures get too close.
- High glide blends pinch earlier, so for the same subcooling, exit temp will be typically lower than that of R404A

- **Correct setting of “TD controlled” condensers:**
  - **Use the average condensing temp. (average of dew and bubble points).** This results in similar TD between air and coil temperature (similar heat transfer) for a blend and a single refrigerant
- **Using solely bubble or dew temperatures may reduce the system performance**

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Setting TD-control for blends

- **Example: obtaining the condensing pressure setting of R404A to R407F retrofit for an ambient air of 30°C and a TD setting of 10°C:**

	R22	AZ-20 (410A)		404A		Performax LT (407F)	
Temp.	Pressure	Bubble Pressure	Dew Pressure	Bubble Pressure	Dew Pressure	Bubble Pressure	Dew Pressure
(°C)	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]
35	1355	2145	2139	1620	1605	1699	1507
40	1534	2426	2419	1829	1815	1921	1719
45	1729	2734	2726	2059	2044	2165	1953

- **The condensing temp. should be = 30+10 = 40°C.**
- **For 40°C, find 1921 kPa for the bubble pressure**
- **For 40°C, find 1719 kPa for the dew pressure**
- **The R407F setting should be equal to the average of bubble and dew pressures:**
  - **Average pressure = (1921+1719)/2 = 1820kPa**

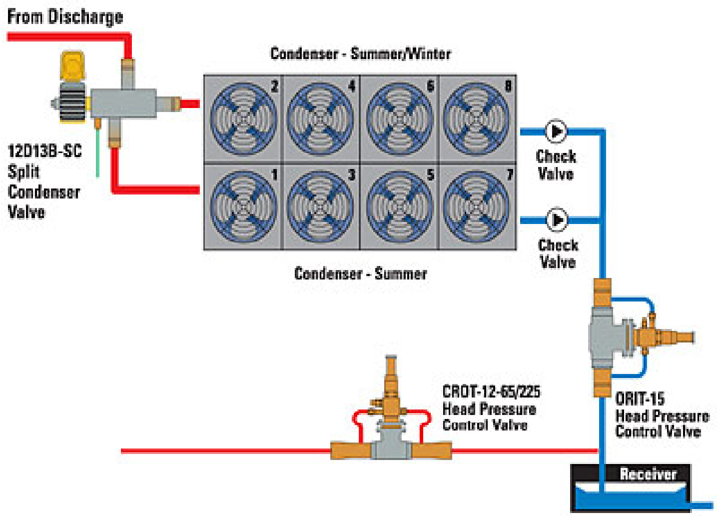
Remember: use the average of bubble and dew points

- *Note1: If setting is based on dew pressure rather than the average, the resulting average coil temperature would be less than 10°C . **This may yield higher fan power!***
- *Note2: If setting is based on bubble pressure, the resulting average condensing temperature would be higher than 10°C **This leads to system penalty due to higher discharge pressures!***

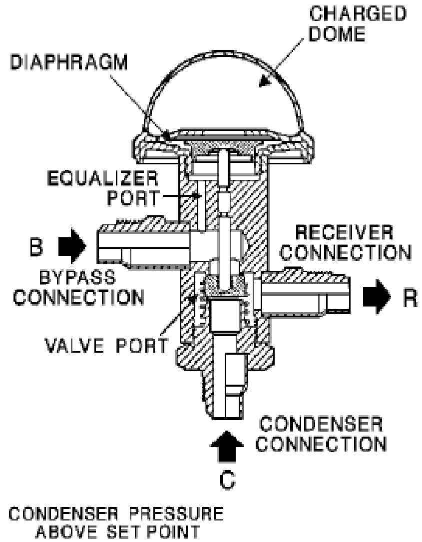
Condenser Controls: Head-Master (Condenser flooding)

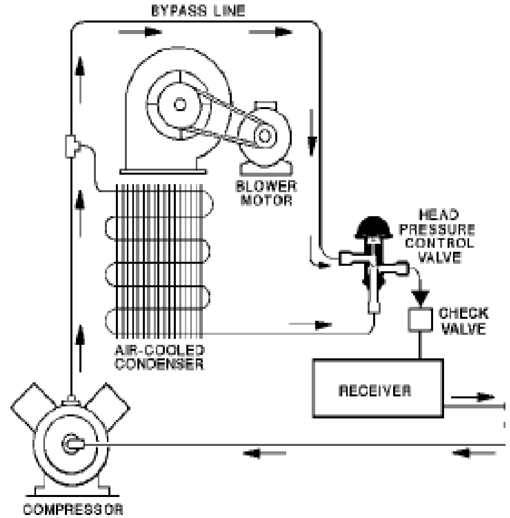
- Used during winter operation to maintain certain head pressure so to keep appropriate pressure differential across expansion device

Two 2-way valves setup



One 3-way valve setup





	R22	AZ-20 (410A)		404A		Performax LT (407F)	
Temp.	Pressure	Bubble Pressure	Dew Pressure	Bubble Pressure	Dew Pressure	Bubble Pressure	Dew Pressure
(°C)	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]
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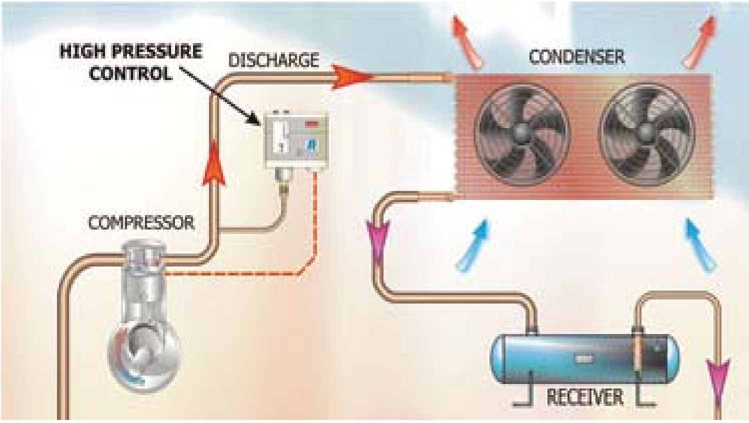
- **In a retrofit, we should keep the same differential pressure across the expansion valve.**
- **Example: Find the pressure setting for the head master valve of a R407F system at an evaporation of -35°C and a TXV with a minimum differential pressure of 1530 kPa**
  - **For -35°C, find ~169kPa in Bubble column**
  - **The pressure setting is equal to sum of evaporation pressure (bubble) and minimum differential pressure = 1530 + 169 = 1699 kPa**

High-side pressure cut-out control and relief valve

- **Used to protect the system from high pressure damage.**



- **If the original compressor and lines are maintained, the high-side cut-out pressure and relief valve setting should not be changed, unless allowed by manufacturers of compressor and other high-side components**
- **In a retrofit from R404A to R407F, this will result in similar condensing temperature cut-out, due to similar pressures values**

Thermostatic Expansion Valve: Superheat Setting

- **Superheat setting should be corrected for the blends in order to account for the glide**

Pressure-Temperature Chart

	R22	AZ-20 (410A)		404A		Performax LT (407F)	
Temp.	Pressure	Bubble Pressure	Dew Pressure	Bubble Pressure	Dew Pressure	Bubble Pressure	Dew Pressure
(°C)	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]
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- **The new superheat setting (based on dew point) should be equal to the original superheat setting (measured) minus 1/3 of the total glide. Keeping the same R404A superheat setting may result in lower capacity.**

- **Example:** Find the R407F superheat setting for a system originally operating with R404A at a superheat of 7°C
  - **Measure the evaporator outlet pressure in the R407F system. For example, suppose you measure 169 kPa**
  - **Find ~169kPa in Bubble column: -35°C**
  - **Find ~169kPa in Dew column: -29°C**
  - **Calculate the Glide = -35 – (-29)= 6°C**
  - **New R407F superheat setting = 7°C – 1/3*(6°C) = 5°C**

Remember: Superheat calculation should be based on dew point! (see previous slide for instructions)

Nominal versus Circulating Composition

The nominal composition is given by the refrigerant manufacturer, based on the liquid-phase.

The circulating (actual) composition may differ from the nominal:

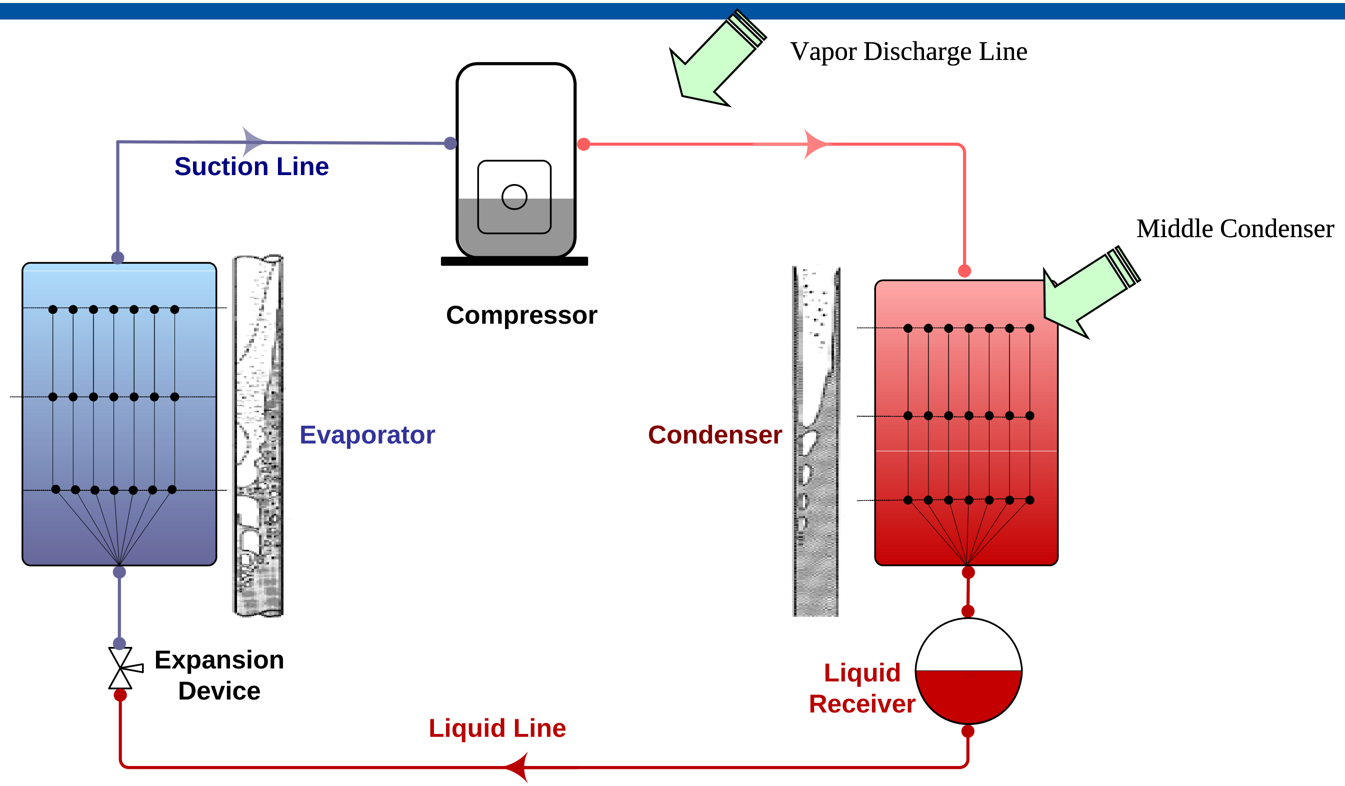
1) **Due to system lubricant:**
   – Components of a blend may have preferential solubility in a lubricant

2) **During start-up**

3) **Due to mishandled charging**
   – Charge from vapor port will cause fractionation (change in composition). **Blends should always be charged from the liquid port.**

3) **Due to fractionation during leak events**
   – Higher pressure components of the blend may leak first, causing change in composition. It may affect performance but can be corrected with top-off

Fractionation of Blends during Leak Events



- System description
  - 1-Ton walk-in cooler/freezer system (Box temp of -25°C). Outdoor from 10°C to 20°C
  - Charge of R407F and POE lubricant

- Leak events were simulated using a 0.1mm ID orifice during two scenarios:
  - System ON: 1) Vapor discharge line, 2) Middle of condenser (liquid-vapor)
  - System OFF: in the middle of the condenser (vapor while system OFF)

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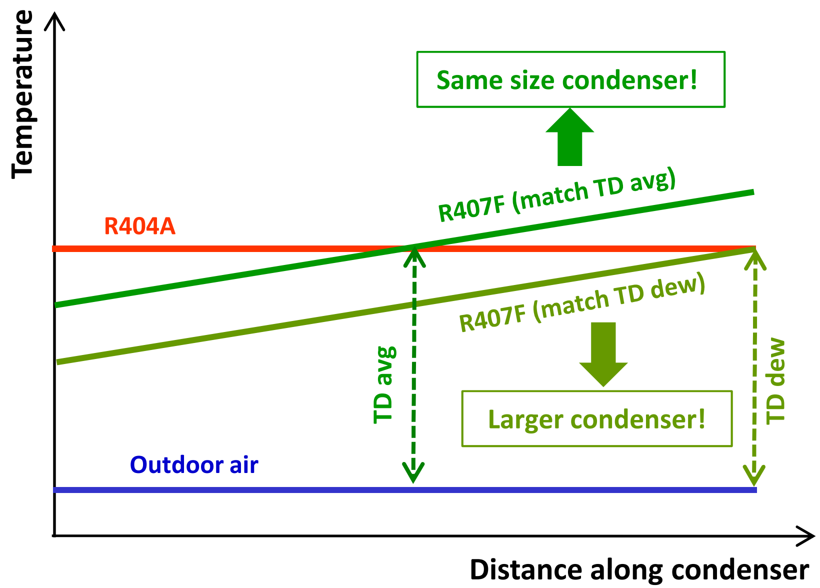
Fractionation of Blends during Leak Events

			System ON	System ON	System OFF
	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%	31.8%	28.3%	29.2%
	R125	30%	30.0%	28.0%	29.8%
	R134a	40%	38.2%	43.7%	41.1%
Performance before top-off	Capacity	100%	102%	96%	99%
	COP	100%	100%	100%	100%
Performance after top-off	Capacity (%)	N/A	101%	97%	99%
	COP (%)	N/A	100%	100%	100%

- Took small samples (4g each) from the liquid line and measured composition
- Vapor leaks at the discharge line (System ON) caused no changes in composition
- Two-phase leaks (System ON) and slow vapor leaks (System OFF) seem to cause minor changes in composition and performance.
  - For approximately 20% charge loss, overall composition is still within typical tolerances (±2%)
  - Changes in performance are within experimental error (±5%)
- If the charge is topped-off, composition and performance return even closer to original values

Condenser Sizing

- Condenser sizing is typically carried out using TD based on dew point temperature.
- For a blend, however, design TD should be based on the average coil temperature. (bubble and dew points)



Simulation Design Tool Results:

	TD dew [°C]	TD avg [°C]	Condenser Area [%]
Baseline R404A	10.0	9.8	100%
R407F drop-in	11.4	9.3	100%
R407F matching TD dew	10.0	7.9	120%

- A R407F condenser sized to match the TD-dew of R404A may result in a 20% larger HX

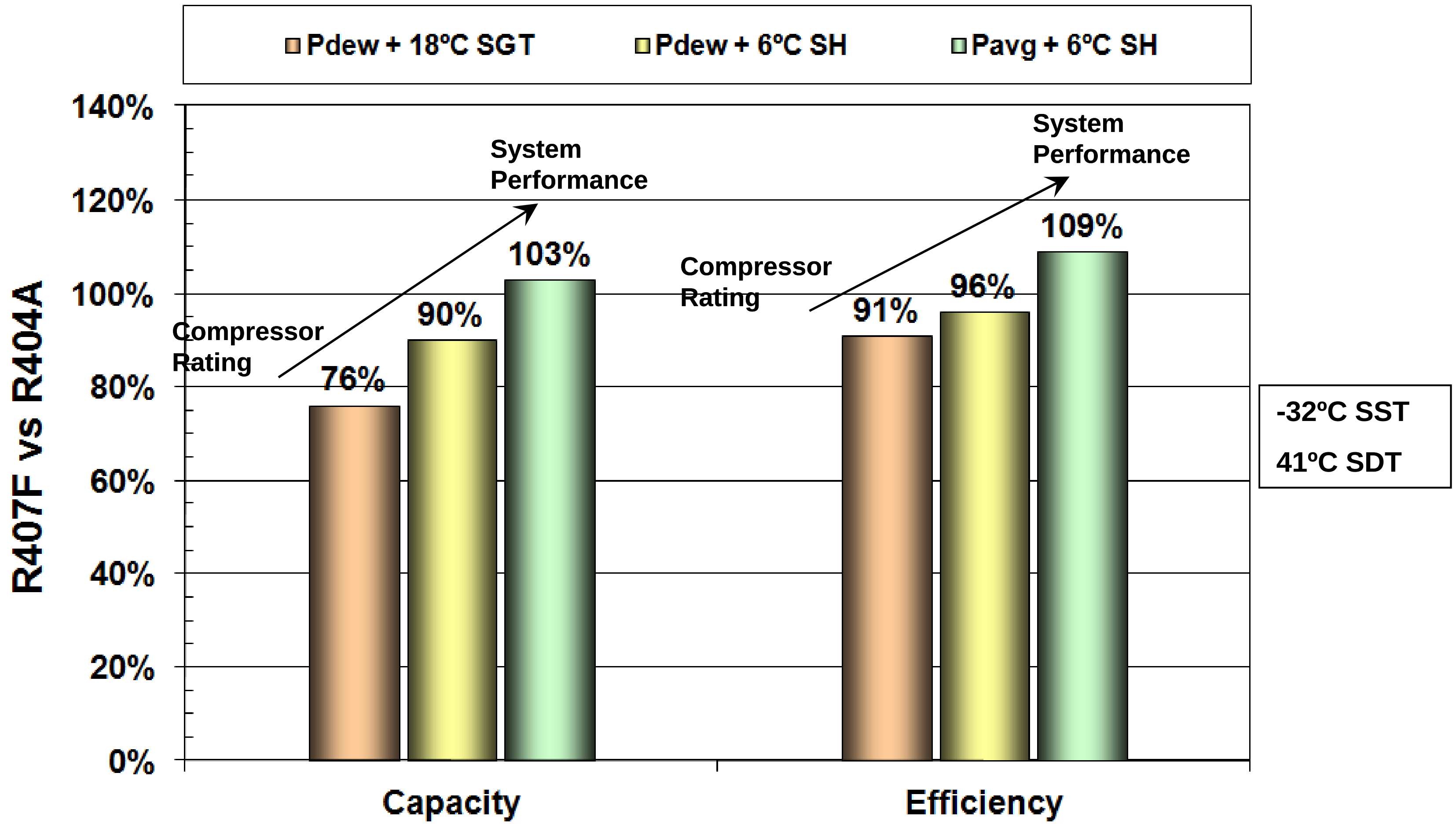
Experimental Results with R407F retrofit in a R404A 3-Ton walk-in freezer (-18°C Box, 35°C Outdoor)

	TD dew [°C]	TD avg [°C]	Capacity [%]
Baseline R404A	8.1	7.9	100%
R407F retrofit	9.4	7.4	102%

- Actual data show no need to oversize condenser, since TD-avg is actually lower for R407F

While sizing a condenser for a blend, design TD should be based on the average coil temperature (average of bubble and dew points) and not solely on dew point.

Honeywell Compressor Performance: Calorimeter Evaluations



- Compressor rating data should be used with caution for blends with glide.
- Actual system performance can be significantly different.
- Data suggests review of Testing Conditions in AHRI Standard 540