

# Technology Issues Regarding Refrigerant Blends

Buffalo Research Laboratory

**Honeywell**

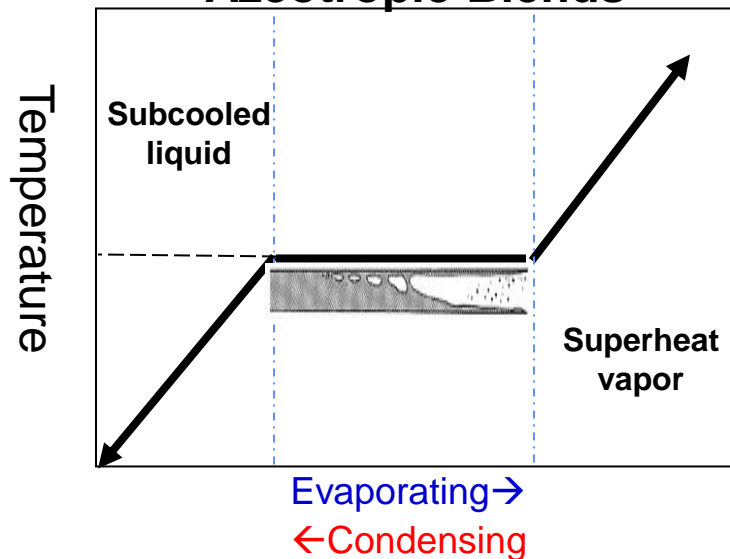
# Agenda

- 1) Introduction
- 2) Condenser
- 3) Evaporator
- 4) Compressor
- 5) Fractionation
- 6) Conclusions

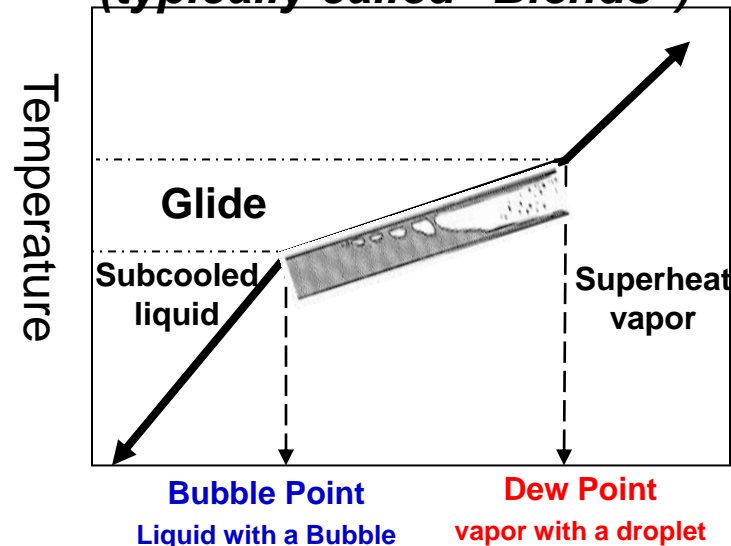
# Introduction

# Blends with Glide

## Single component or Azeotropic Blends

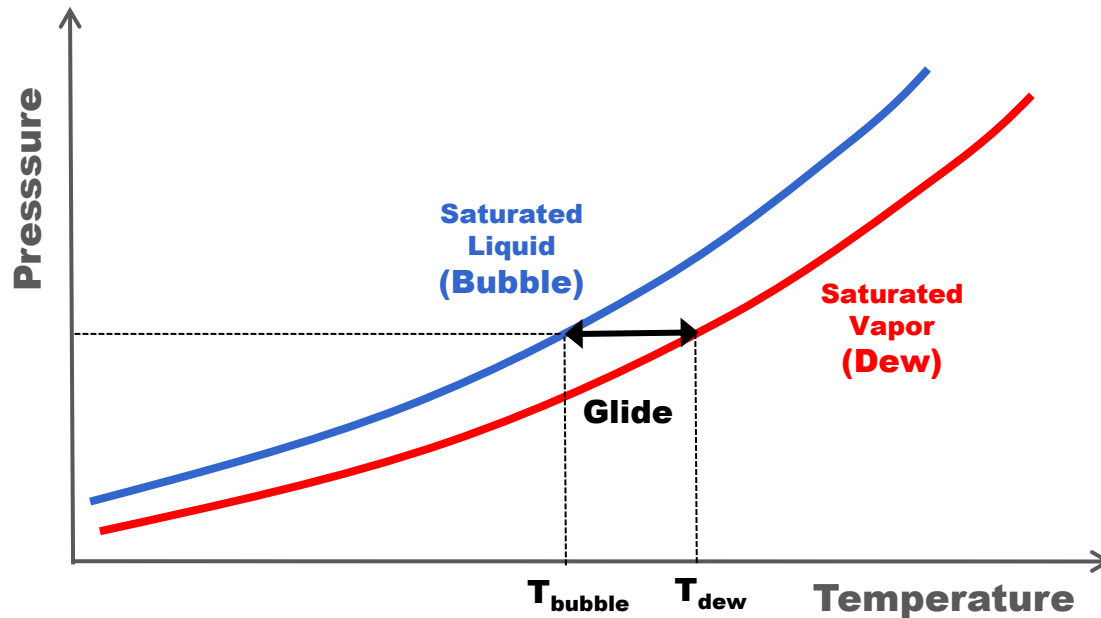


## Zeotropic Blends (typically called "Blends")



- 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 or just "Blends", the temperature varies between **dew (saturated vapor)** temperature and **bubble (saturated liquid)** points in a constant pressure process
  - 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, particularly R404A and R22 replacements have larger temperature glides that must be treated differently and that is the focus of this presentation.

# Pressure-Temperature (P-T) Chart of a Blend



**P-T table**

Pressure (bar)	Bubble (Liq) Temp (°C)	Dew (Vap) Temp (°C)
2.4	-26.8	-20.7
3.8	-14.9	-9.1
5.1	-6.1	-0.4
6.5	1.2	6.7
7.9	7.3	12.6
12.0	21.9	26.8
13.4	25.9	30.7
14.8	29.6	34.3
16.2	33.1	37.7

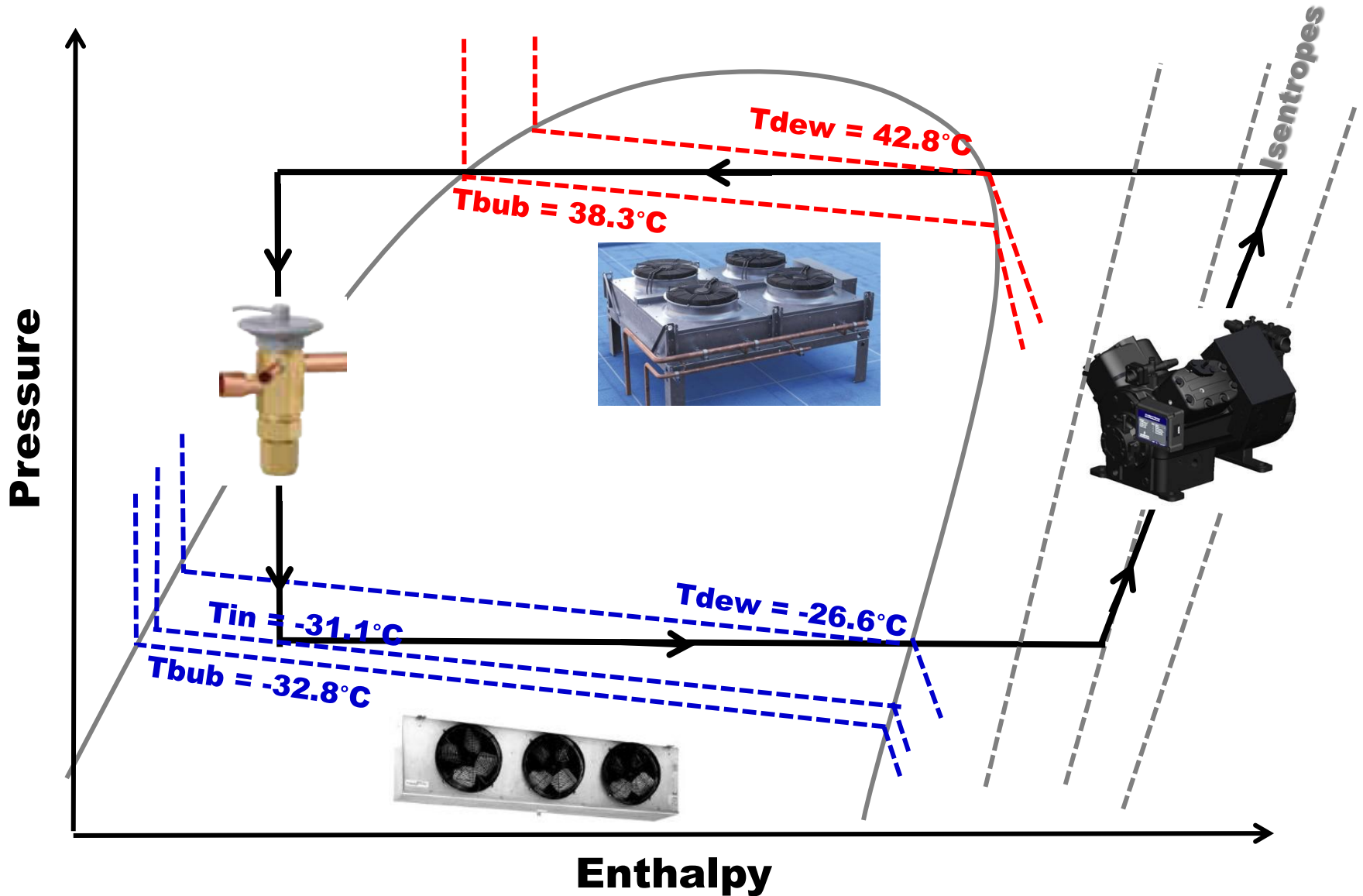
**T-P table**

Temp (°C)	Bubble (Liq) Pressure (bar)	Dew (Vap) Pressure (bar)
-29	2.2	1.7
-23	2.7	2.1
-18	3.4	2.7
-12	4.2	3.3
-7	5.0	4.1
21	11.8	10.2
27	13.7	12.0
32	15.8	14.0
38	18.2	16.2

**Glide = 37.7 - 33.1 = 4.6°C**

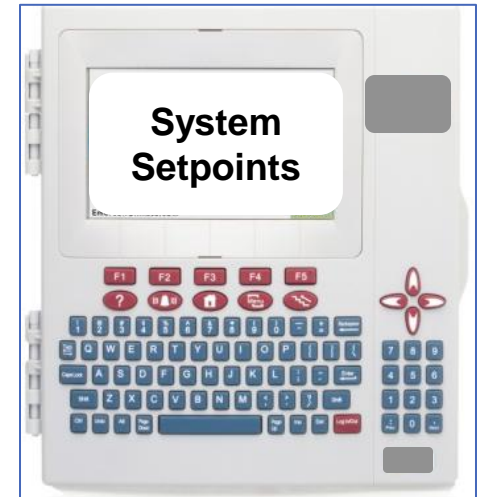
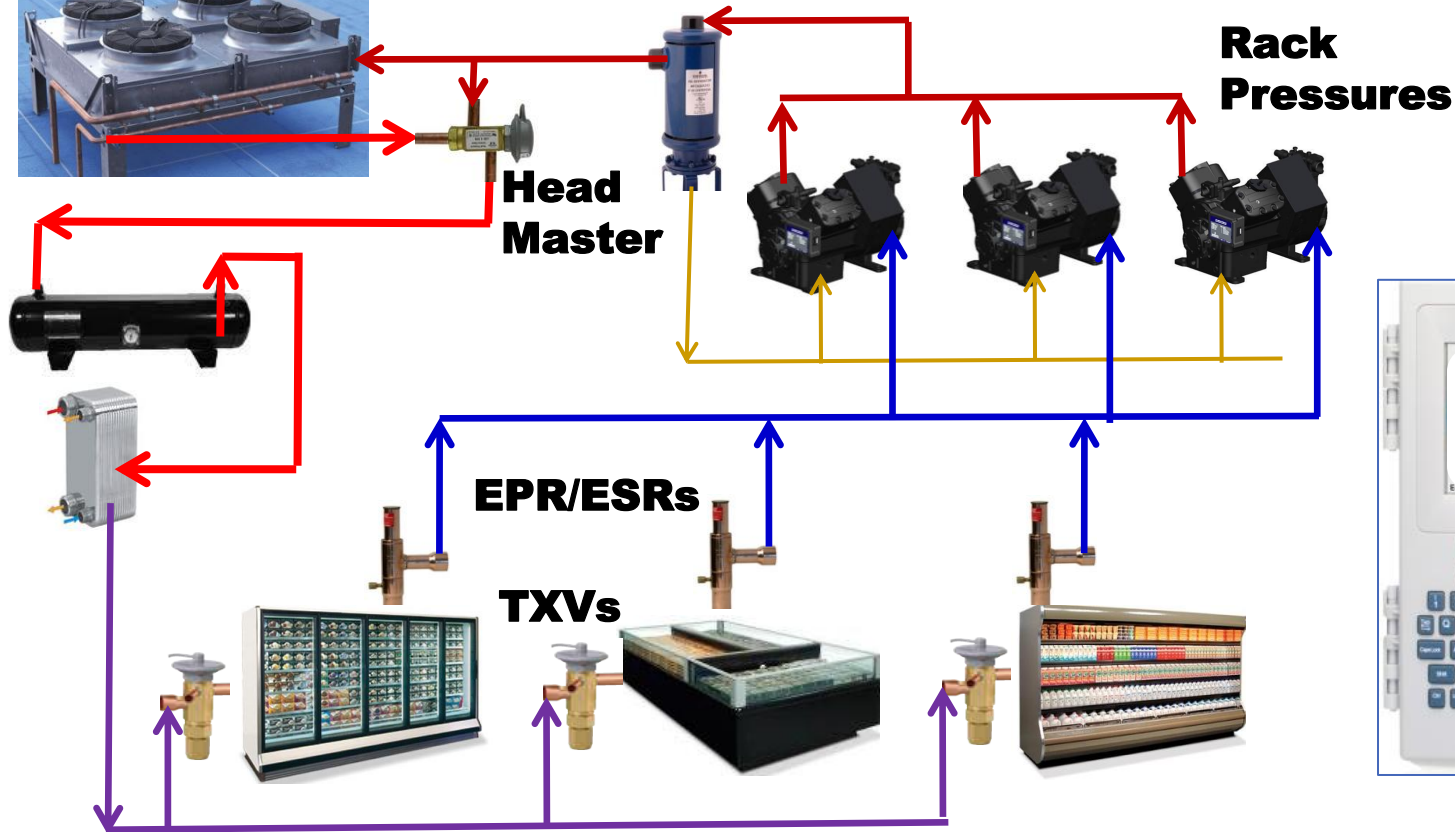
# P-h Diagram for a Blend – Example in Low Temp

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# Typical Supermarket System

**TD controls**  
**Min. Cond Temp**



***Understanding how glide affects both system controls and component sizing is key for a successful retrofit or new store design***

# Condenser



# Average (Midpoint) Condensing Temperature

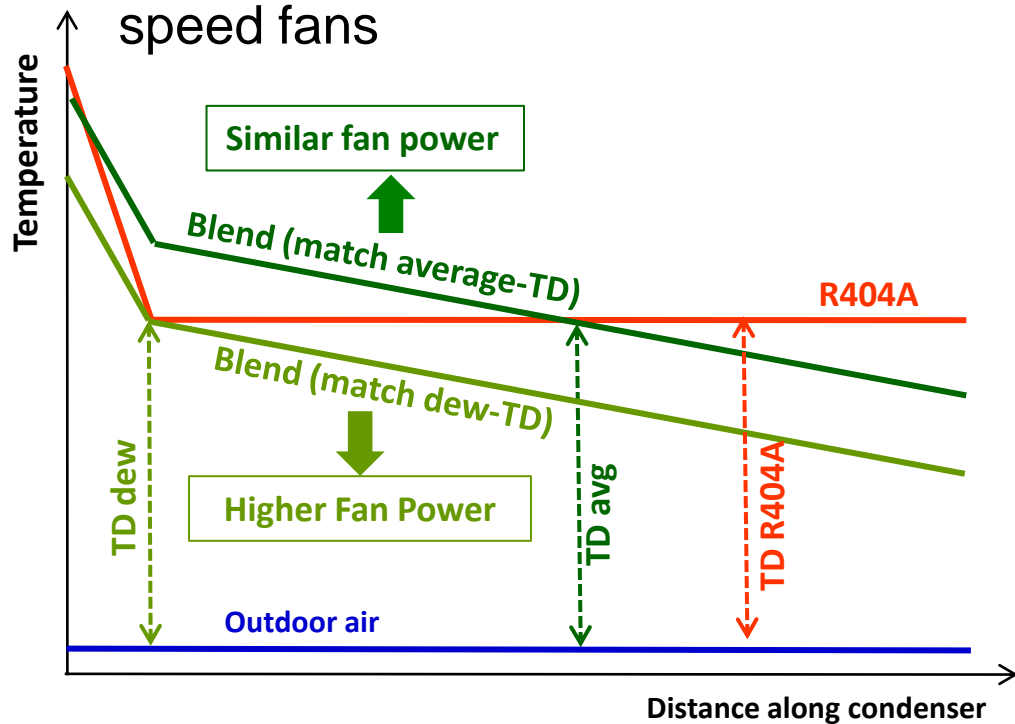
	R404A	R407F	
Pressure	Dew Temp	Bubble Temp	Dew Temp
(bar)	(°C)	(°C)	(°C)
12.0	23.7	21.9	26.8
13.4	27.9	25.9	30.7
14.8	31.8	29.6	34.3
16.2	35.4	33.1	37.7
17.5	38.5	36.3	40.8
18.9	41.7	39.4	43.8
20.3	44.7	42.3	46.6
21.7	47.5	45.1	49.2

$$T_{\text{cond}} = T_{\text{average}} = 35.4^{\circ}\text{C}$$

*The condensing temperature for a blend with glide should be the average (midpoint) of bubble and dew temperatures*

# Condenser Controls

The condenser TD is typically maintained constant by cycling or variable speed fans



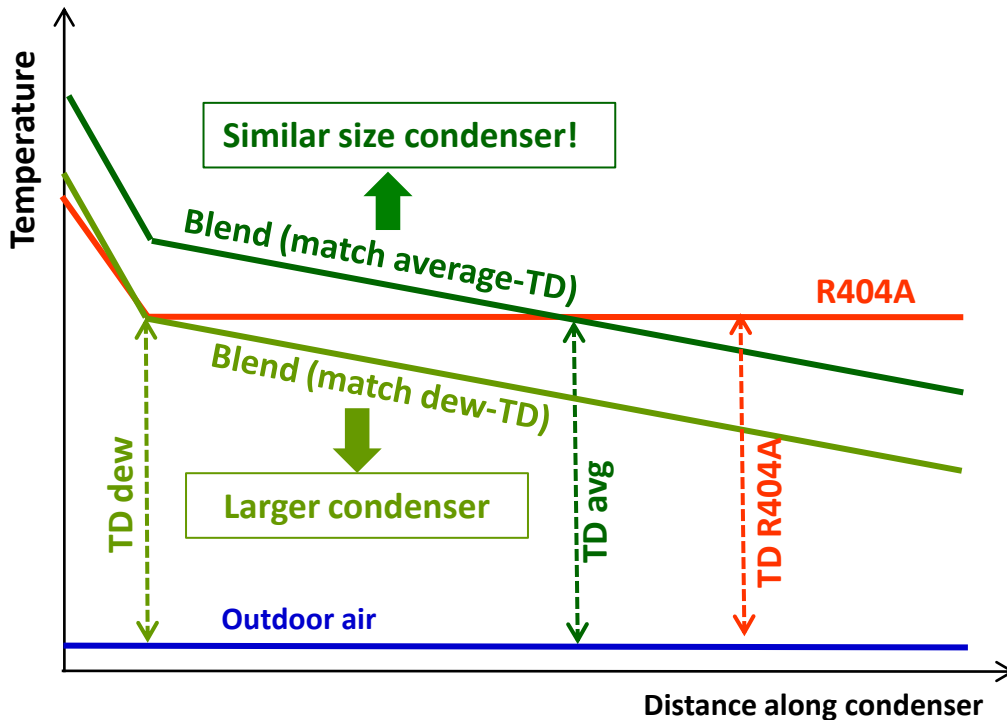
$$TD_{cond} = T_{condensing} - T_{ambient}$$

- 1) If system software uses dew temp:
  - Same setpoint TD will result in higher fan power
  - TD setpoint should be increased by half the glide for similar fan power
- 2) If system software uses average (bubble and dew) cond. temp for TD: recommendation is to keep same setpoint

***TD controls should be based on the average of bubble and dew point***

# Condenser Sizing

Air-cooled condensers sizing based on **dew temperature** can lead to erroneous design.



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

- 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***

# Actual Condenser TD (R407F and R404A)

- We tested a fully instrumented system comprising a **3 hp semi-hermetic condensing** unit and a **walk-in cooler/freezer** evaporator with **R404A** and **R407F**
- The ambient air was fixed (35°C) but the condensing temperature was floating to capture natural response of refrigerant in the heat exchanger

## Actual System Results (-26°C Box, 35°C Ambient)

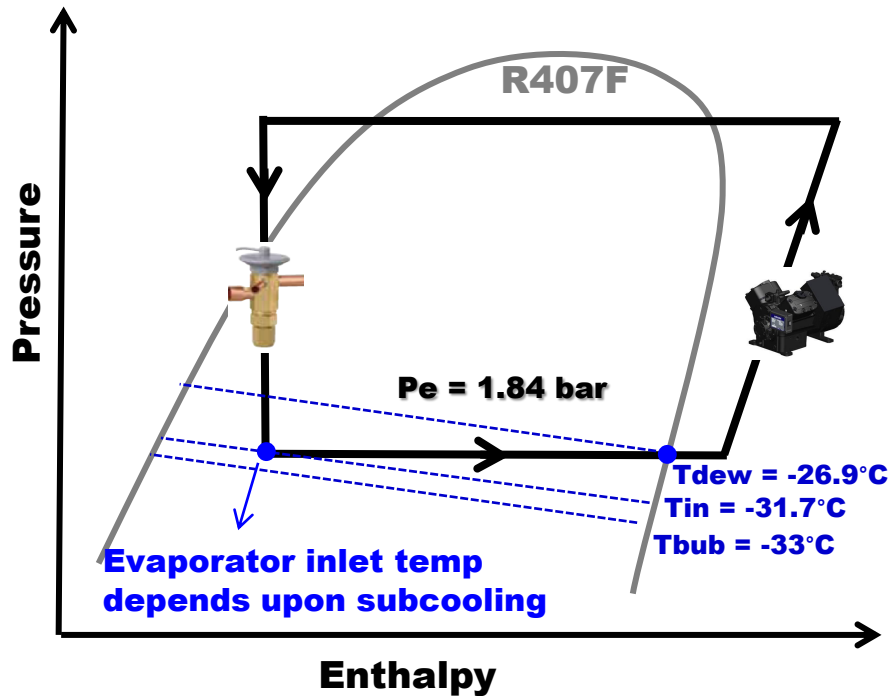
	TD-dew	TD-avg	Capacity	COP
	[°C]	[°C]	[%]	
R404A (Baseline)	5.8	5.6	100%	100%
R407F (Retrofit)	7.7	5.4	100%	106%

- Data indicates no need to oversize condenser, since R407F **TD-average (midpoint)** is a close match to R404A.

***Design TD should be based on average of bubble and dew points to avoid oversizing the condenser for a blend***

# Evaporator

# Average (Midpoint) Evaporating Temperature



	R404A	R407F	
Pressure	Dew Temp	Bubble Temp	Dew Temp
(bar)	(°C)	(°C)	(°C)
1.77	-33.2	-33.9	-27.7
1.84	-32.3	-33.0	-26.9
1.91	-31.4	-32.2	-26.0
1.98	-30.5	-31.3	-25.2
2.05	-29.7	-30.5	-24.4

- 1) A rough estimate of evaporating temperature is given by average of bubble and dew:

**Example @ 1.84 bar:  $T_{evap} = T_{bub} * 0.5 + T_{dew} * 0.5 = (-33) * 0.5 + (-26.9) * 0.5 = -29.9^{\circ}\text{C}$**

- 2) A better estimate is given by **40% bubble + 60% dew**:

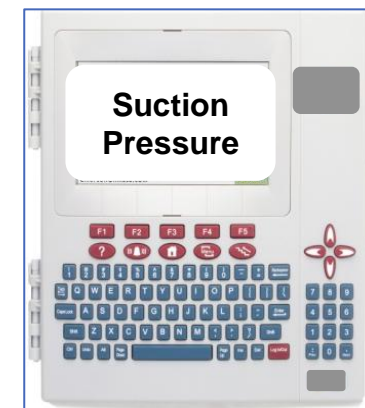
**Example @ 1.84 bar:  $T_{evap} = T_{bub} * 0.4 + T_{dew} * 0.6 = (-33) * 0.4 + (-26.9) * 0.6 = -29.3^{\circ}\text{C}$**

# Low-side Controls: EPRs and Suction Pressure Settings

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	R404A	R407F	
Temp	Pressure	Bubble Pressure	Dew Pressure
(°C)	(bar)	(bar)	(bar)
-30.0	2.02	2.09	1.60
-29.4	2.07	2.14	1.64
-28.9	2.12	2.19	1.68
-28.3	2.17	2.24	1.72
-27.8	2.21	2.29	1.76
-27.2	2.27	2.34	1.81



- 1) First convert pressure setting of R404A into temperature.
  - Assuming a R404A setting of **2.02 bar**, saturation temp of R22 is **-30°C**
- 2) Find bubble and dew pressures for the blend at -30°C
  - **At -30°C, P<sub>bub</sub> = 2.09 bar, P<sub>dew</sub> = 1.60 bar**
- 3) Calculate the average evap pressure based on the 40%/60% rule:
  - **P<sub>avg</sub> = 0.40\*2.09 + 0.6\*1.60 = 1.8 bar**

***Average (40% bubble /60% dew) evaporating pressure should be used. Use of the dew pressure may result in higher energy consumption***

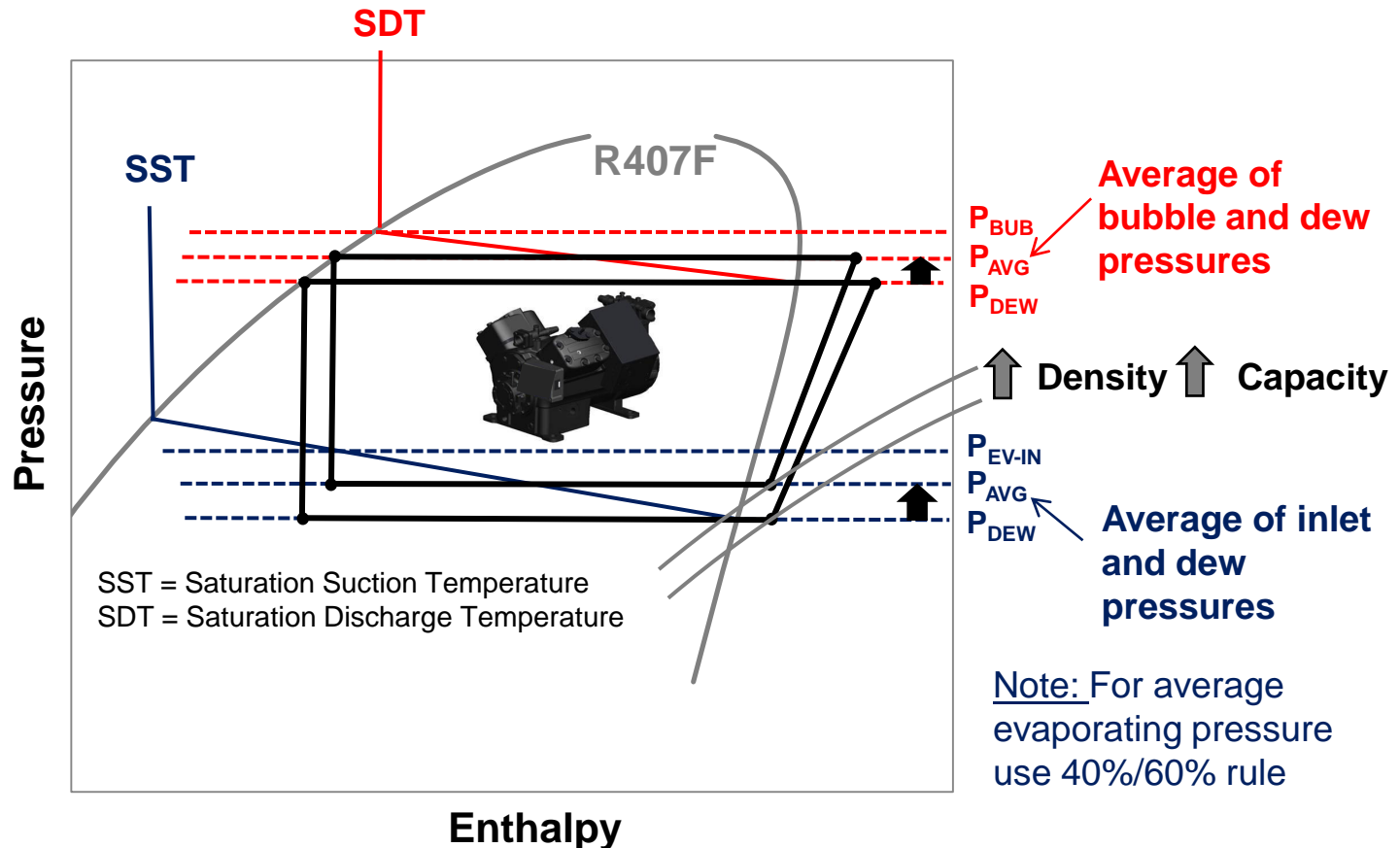
# Compressor



# Compressor Rating vs. System Performance: Effect of Glide

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- Compressor rating is based on dew pressures, but average pressures better reflect the natural response of the blend in the heat exchangers

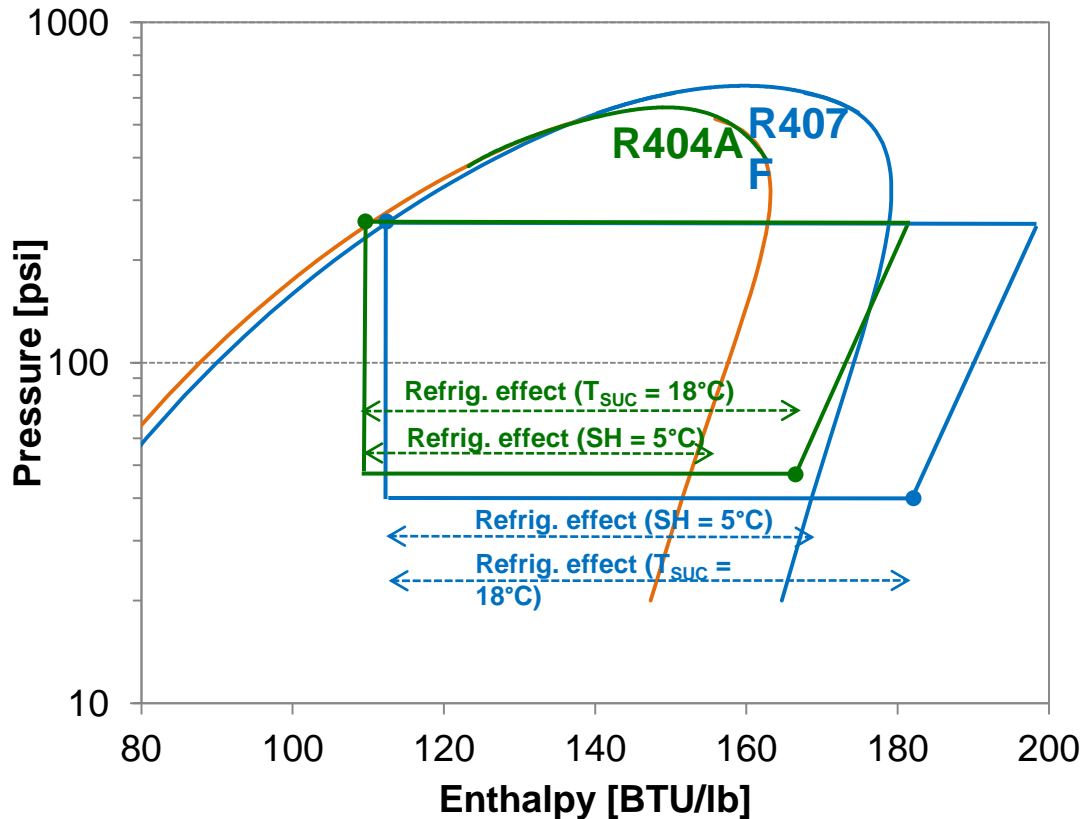


***Using dew pressure, compressor is evaluated at a lower evaporating temperature than the actual system***

# Compressor Rating vs. System Performance: Refrigerating Effect

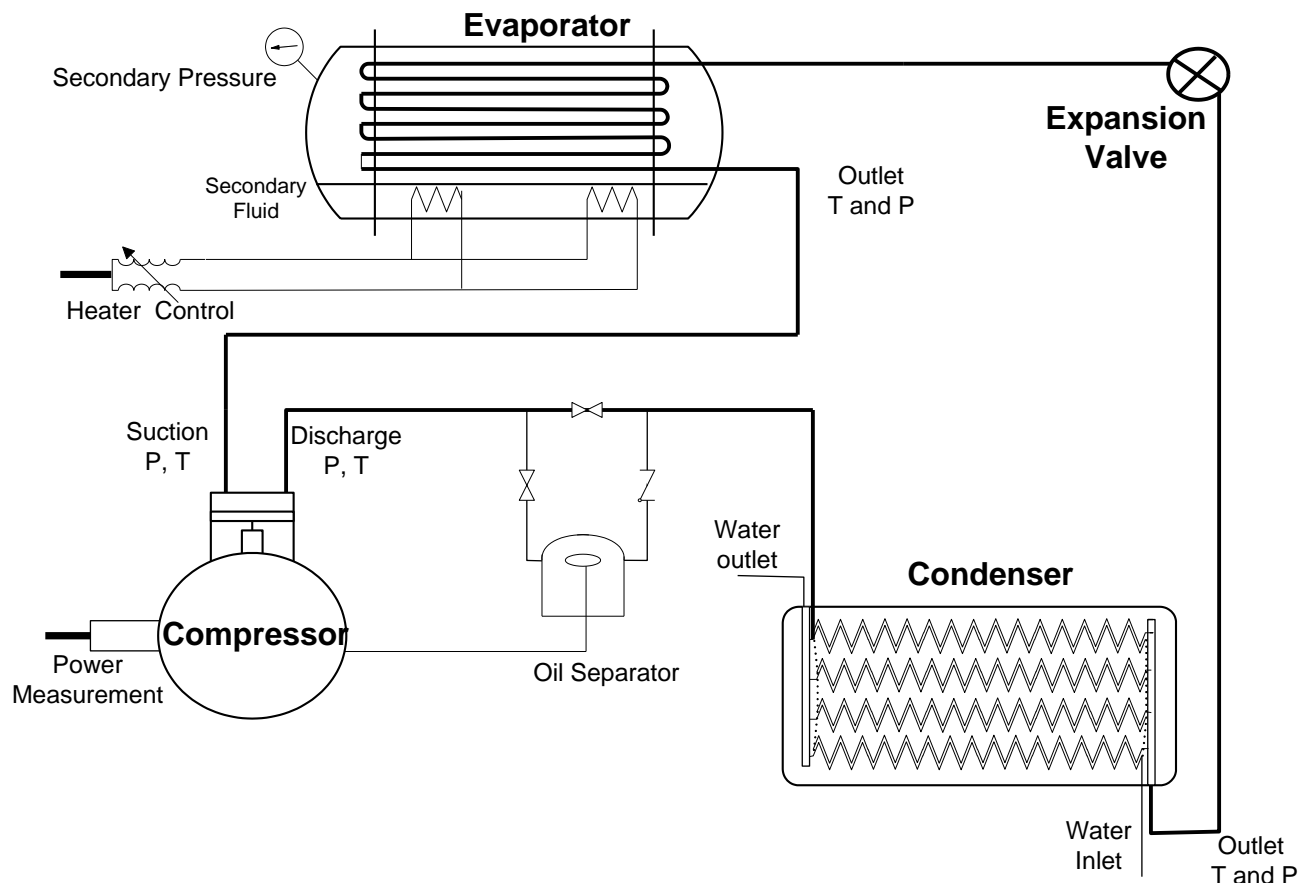
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- Compressor rating is based on refrigerating effect with 100% useful superheat at 18°C (AHRI 540), but typical evaporator superheat is between 3°C and 7°C .
- When calculated at 18°C, the capacity of some refrigerants (R404A) is artificially increased



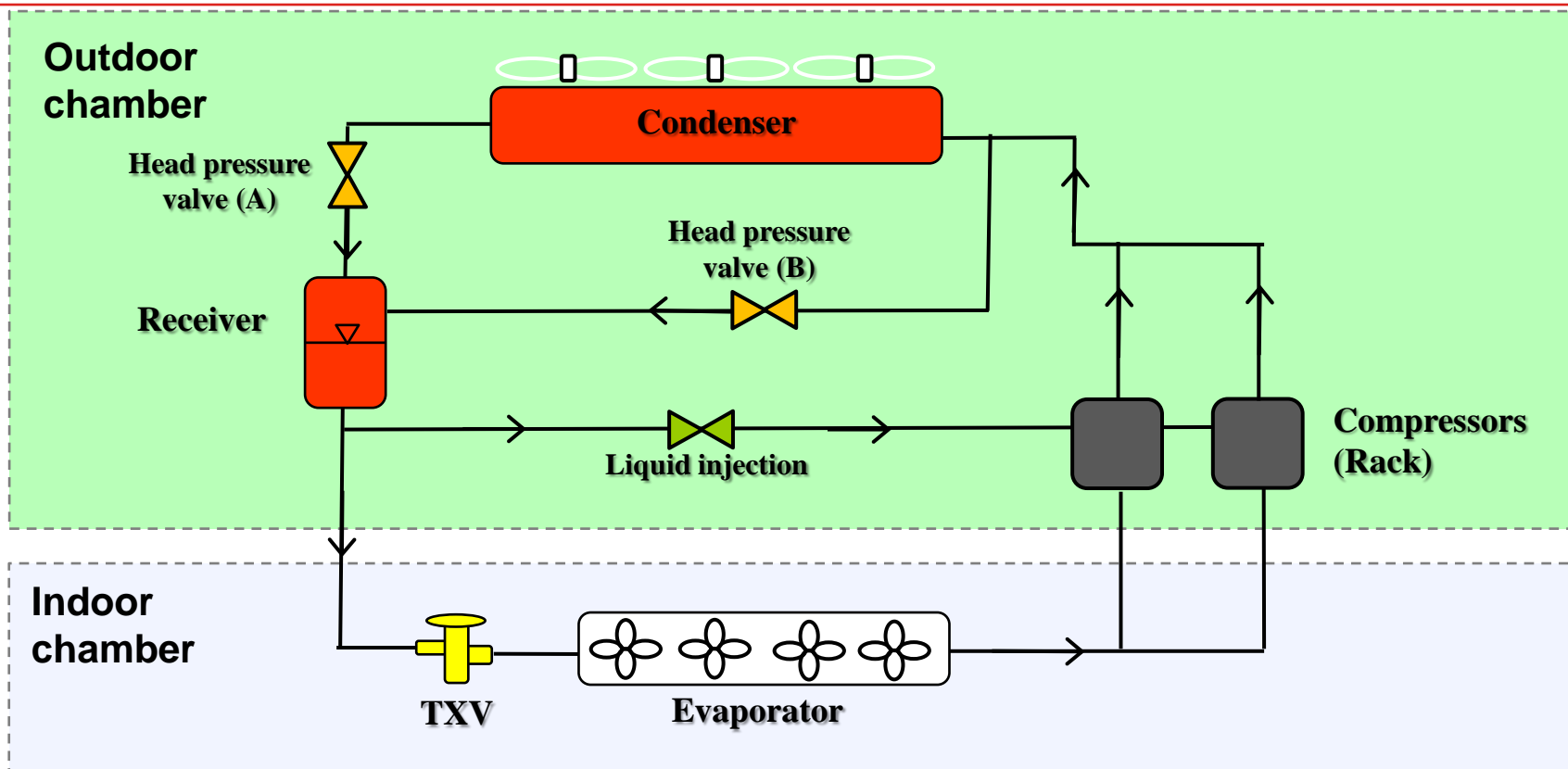
***The actual capacity of a system is given at a superheat range of 3 to 7°C***

# Compressor Calorimeter Evaluations



- Employed a fully-instrumented 50k BTU/h Secondary-Fluid Calorimeter
- Tested a 38.3kBTU/h semi-hermetic compressor, using R404A and R407F
- Operating Conditions as required by AHRI standard 540:
  - Evaporating temperature (SST) of  $-32^{\circ}\text{C}$  and condensing temperature (SDT) of  $40^{\circ}\text{C}$
  - Ambient temperature of  $35^{\circ}\text{C}$ , saturated liquid at the inlet of expansion device.
  - Used “Dew” or “average” pressures and a fixed value of  $18^{\circ}\text{C}$  gas temperature at the suction.

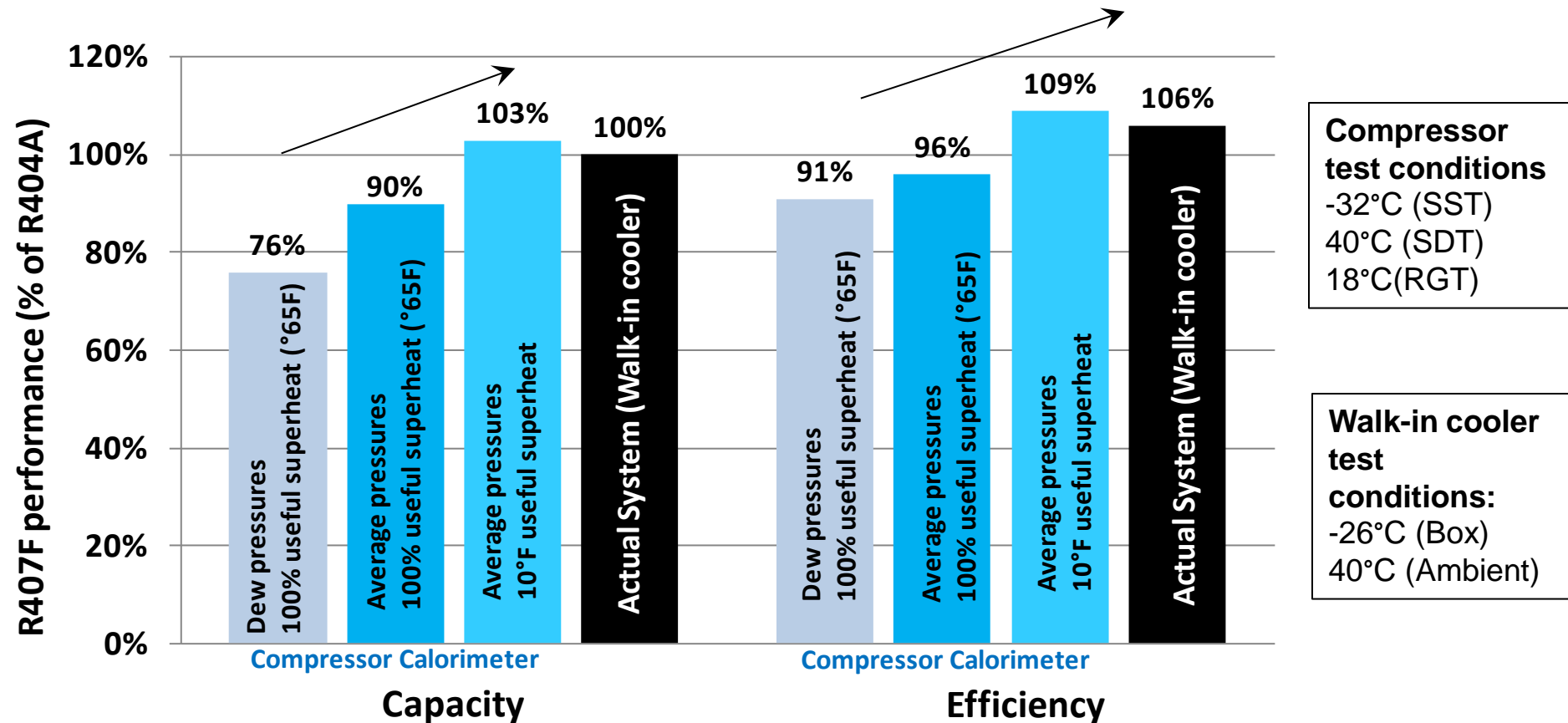
# Actual System Evaluation



- 3 HP semi-hermetic condensing unit with evaporator for walk-in freezer/cooler fully instrumented with pressure, temperature and mass flow (Coriolis) transducers.
- Used long connecting lines (typical of supermarkets), to allow more realistic suction pressure drop and temperature rise effects.
- Operating Conditions:
  - Low temperature: -26°C and -18°C Box Temperature; 13°C, 24°C and 35°C Outdoor Ambient Temperature
  - Medium Temperature: 35°C and 10°C Box Temperature; 13°C, 24°C and 35°C Outdoor Ambient Temperature

# Compressor Rating vs. System Performance: Results for R407F

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- Compressor rating data should be used with caution, since actual system performance can be significantly different for blends with glide

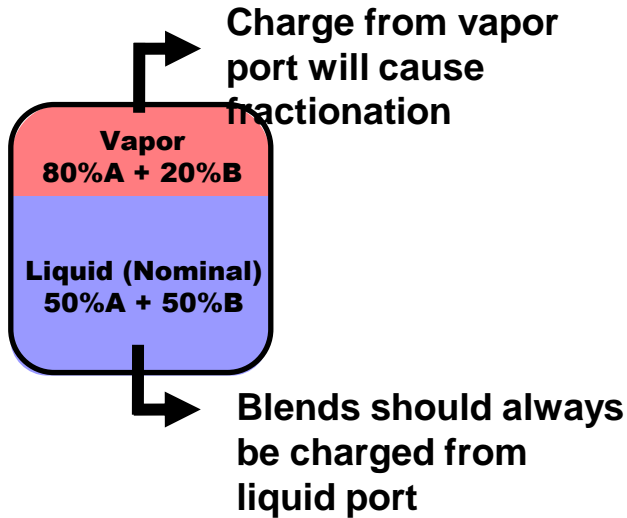
***Compressor evaluated at average pressures and 3 to 7°C superheat resembles better actual system performance***

# Fractionation

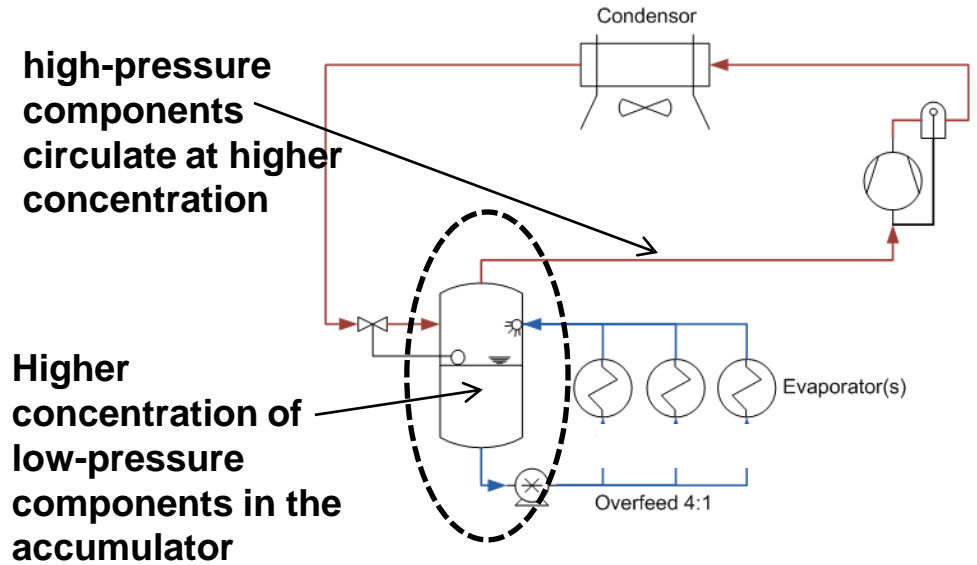
# Fractionation of Blends

Fractionation is the change in the **circulating (system) composition** relative to the nominal composition

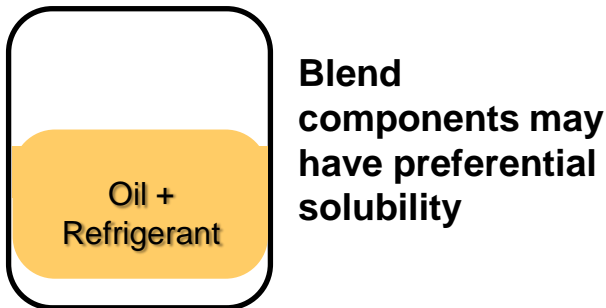
## 1) Refrigerant Charging:



## 2) Flooded Evaporators:



## 3) Lubricant:



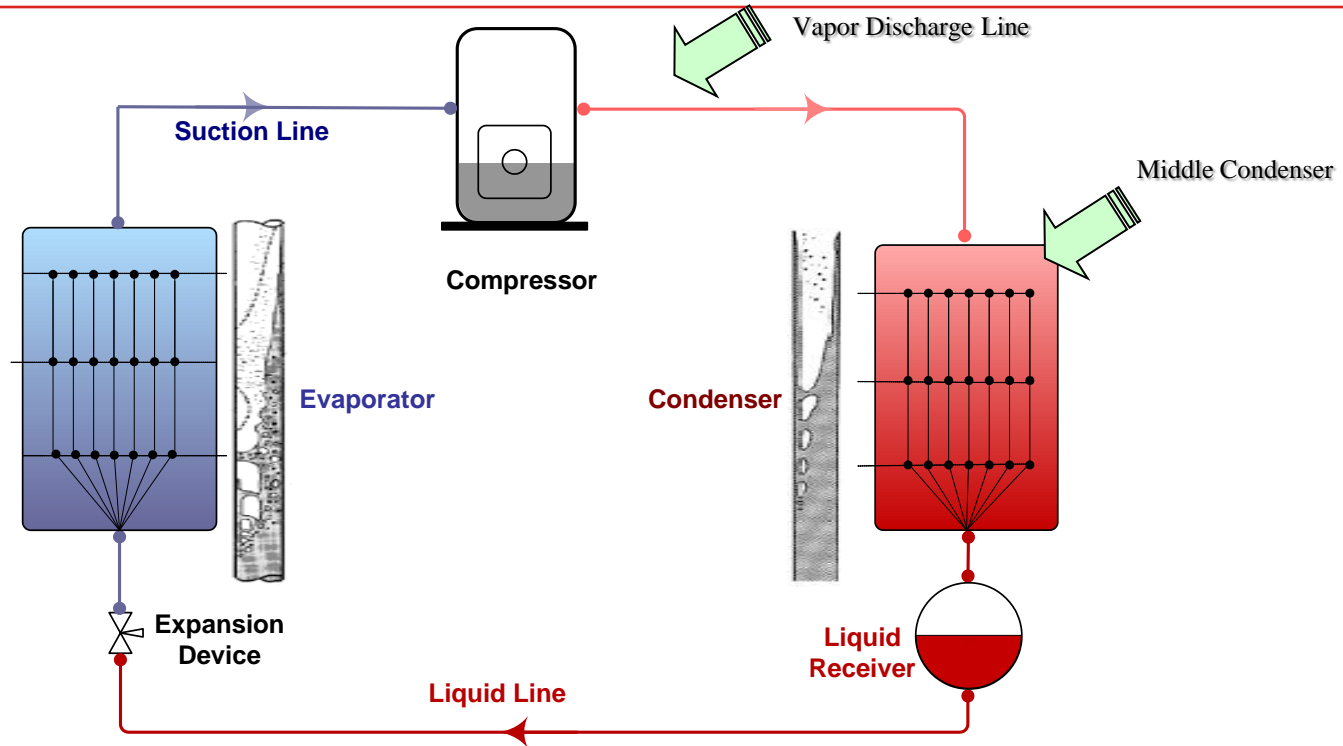
## 4) During Leak Events



Higher pressure components of the blend may leak first, causing change in composition.

**Next.....**

# Fractionation of Blends during Leak Events



- Leak events were simulated using a 0.1mm ID orifice in a 1-Ton walk-in cooler/freezer system (Box temp of  $-25^{\circ}\text{C}$ ). Outdoor varied from  $10^{\circ}\text{C}$  to  $20^{\circ}\text{C}$ .
- 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 of Blends during Leak Events

R407F	Description	Start	System ON	System ON	System OFF
			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 ( $\pm 2\%$ )
- Performance decreased less than 5% due to the fractionation
- If the charge is topped-off, composition and performance get even closer to original values

# Concluding Remarks

- **Refrigeration controls should be adjusted carefully during retrofit to a high-glide refrigerant blend**
  - Use of average evaporating and condensing temperature (pressure) leads to closer performance relative to R404A
- **Condenser, evaporator and compressor sizing for a blend with glide should also be reviewed carefully to avoid oversizing**
- **Fractionation study under realistic “leak” events shows little impact on actual system performance.**
  - Effects of actual working conditions (turbulence/mixing) and oil presence seem to attenuate composition change.
- **This presentation aims to increase awareness about use of blends in refrigeration systems**

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