Technology Issues Regarding Refrigerant Blends

Buffalo Research Laboratory

Honeywell

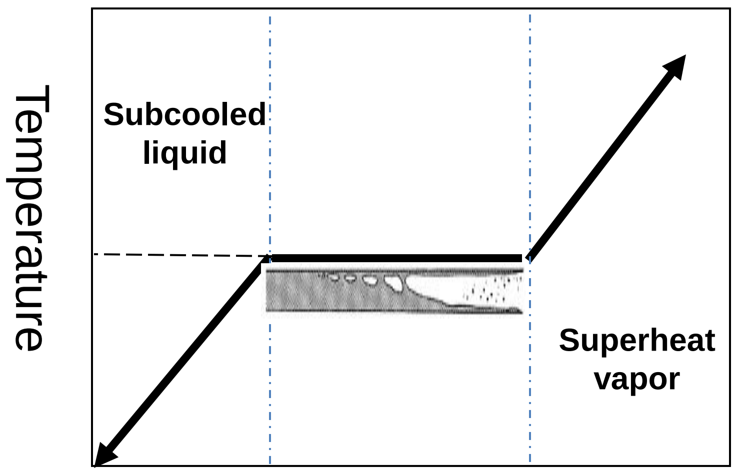
Agenda

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

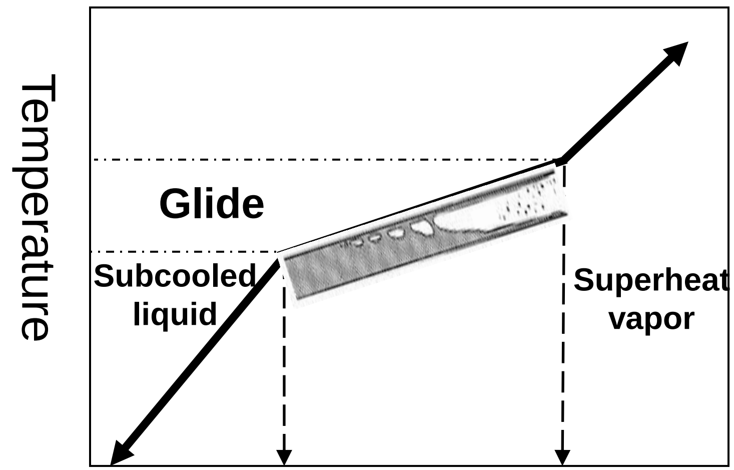
Introduction

Blends with Glide

Single component or Azeotropic Blends

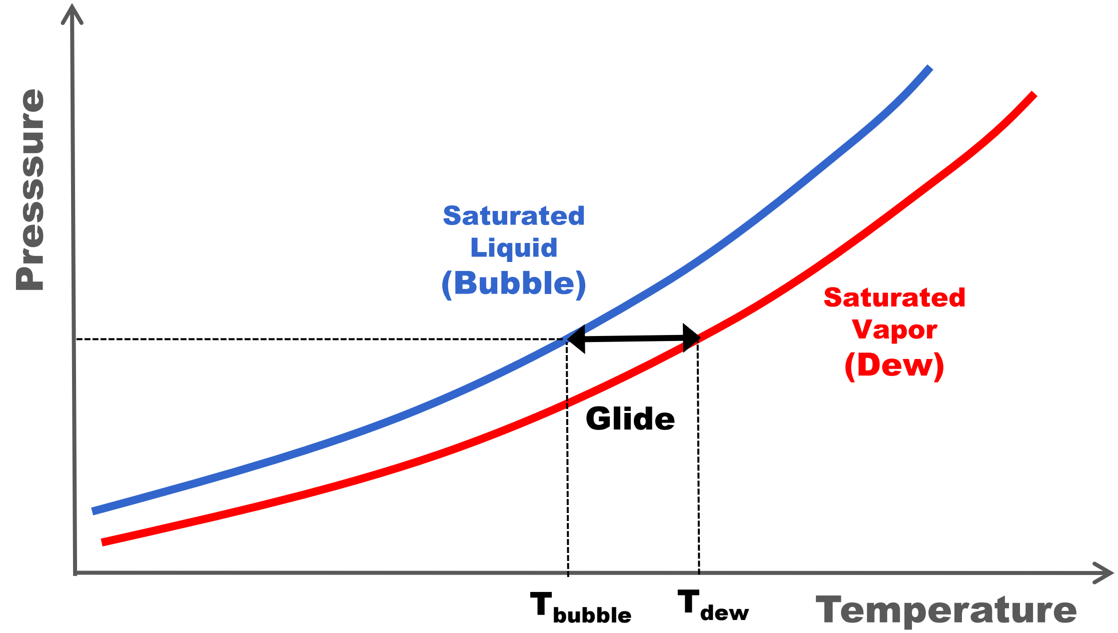


Zeotropic Blends *(typically called "Blends")*



- 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

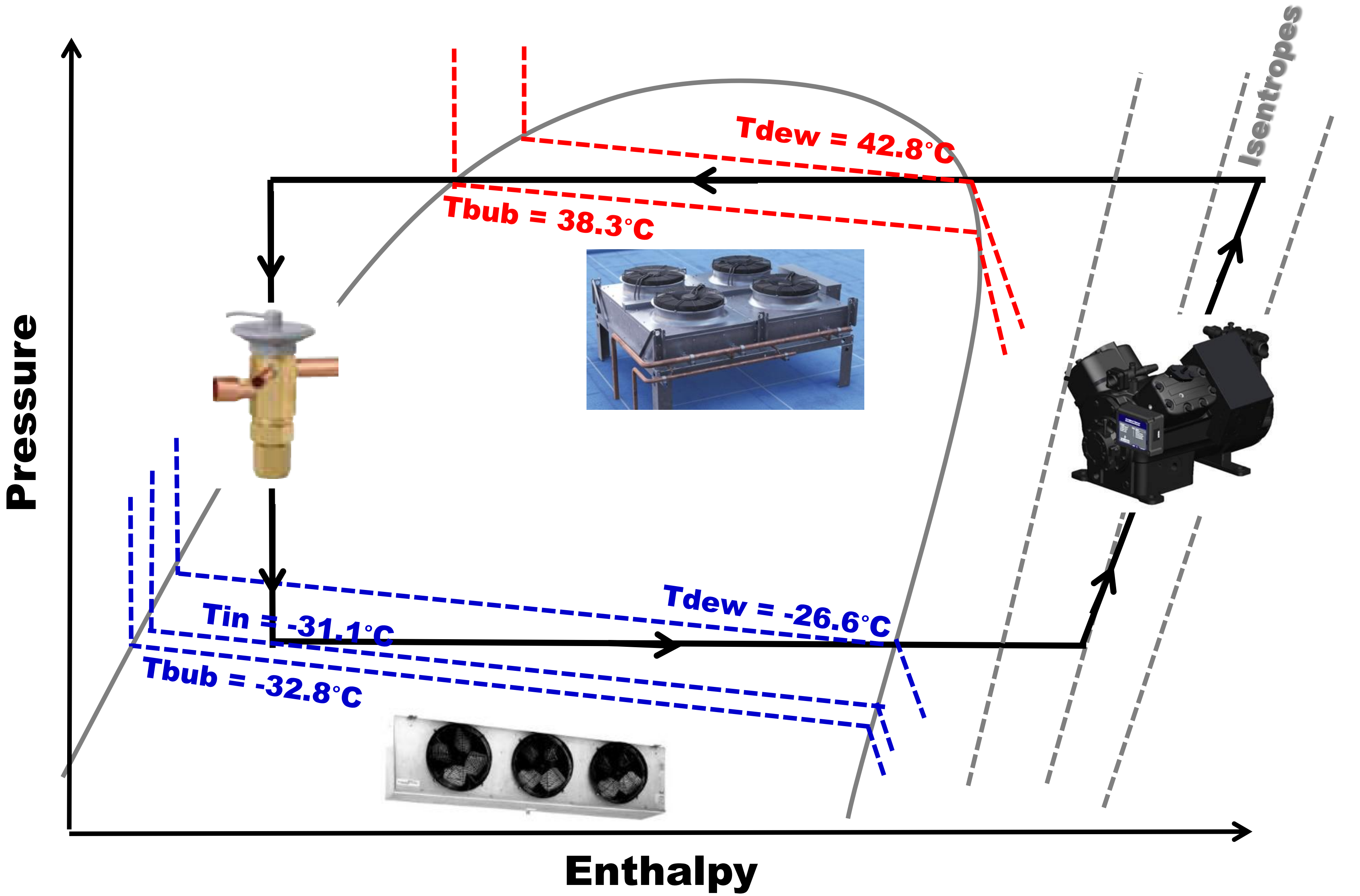
Pressure	Bubble (Liq) Temp	Dew (Vap) Temp
(bar)	(°C)	(°C)
2.4	-26.8	-20.7
3.8	-14.9	-9.1
5.1	-6.1	-0.4
6.5	1.2	6.7
7.9	7.3	12.6
12.0	21.9	26.8
13.4	25.9	30.7
14.8	29.6	34.3
16.2	33.1	37.7

Glide = 37.7 – 33.1 = 4.6°C

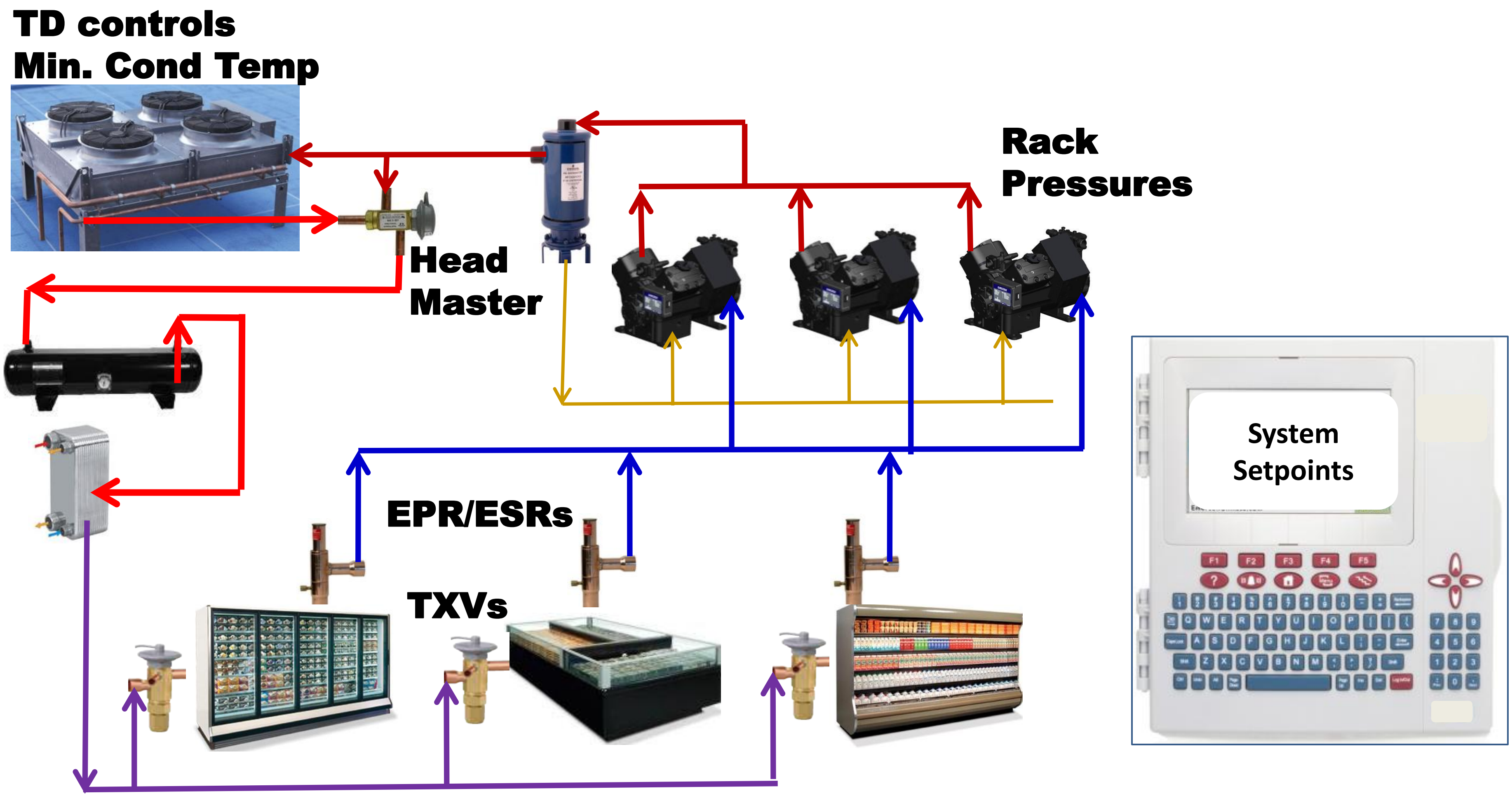
T-P table

Temp	Bubble (Liq) Pressure	Dew (Vap) Pressure
(°C)	(bar)	(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

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



Typical Supermarket System



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

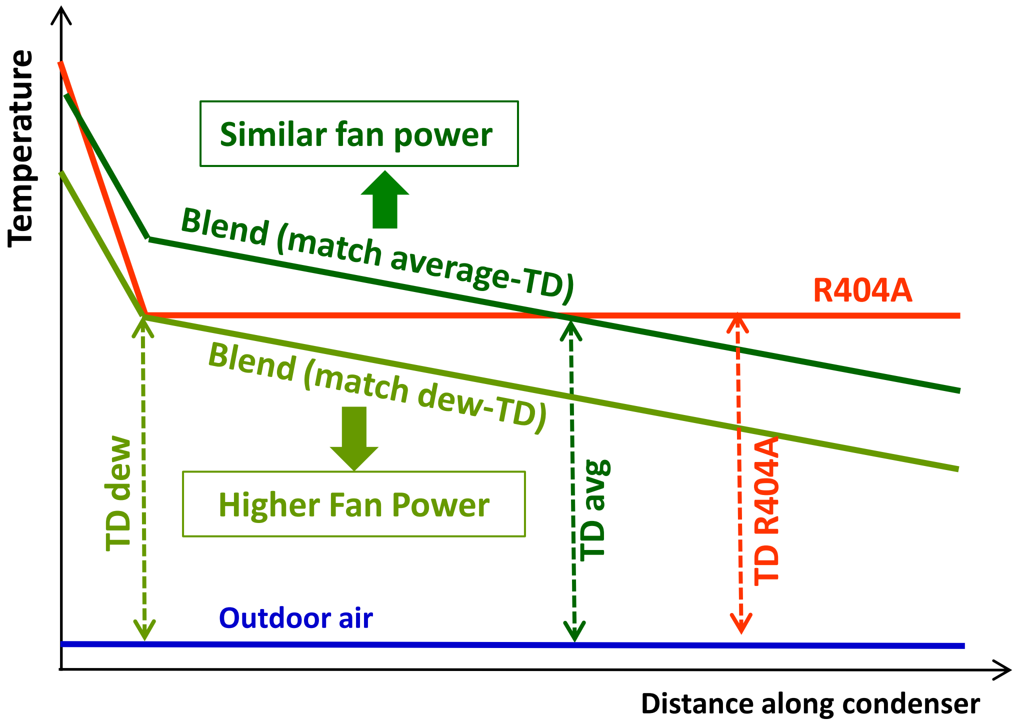
	R404A	R407F	
Pressure	Dew Temp	Bubble Temp	Dew Temp
(bar)	(°C)	(°C)	(°C)
12.0	23.7	21.9	26.8
13.4	27.9	25.9	30.7
14.8	31.8	29.6	34.3
16.2	35.4	33.1	37.7
17.5	38.5	36.3	40.8
18.9	41.7	39.4	43.8
20.3	44.7	42.3	46.6
21.7	47.5	45.1	49.2

$T_{cond} = T_{average} = 35.4°C$

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 mantained constant by cycling or variable speed fans



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

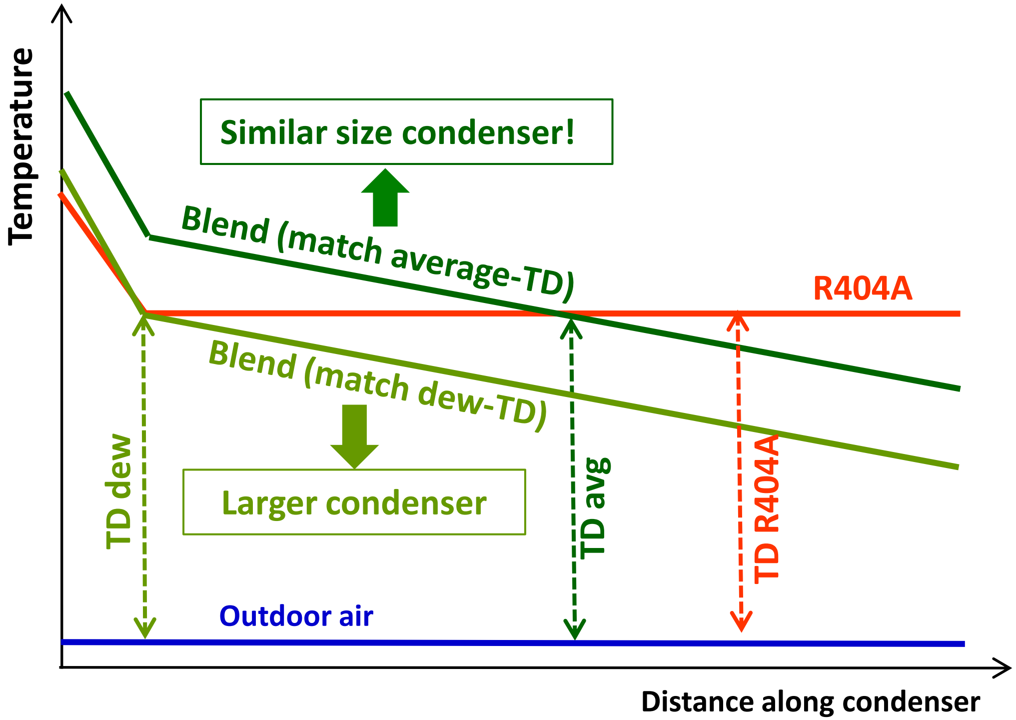
1) If system software uses **<u>dew temp</u>**:
   - Same setpoint TD will result in higher fan power
   - TD setpoint should be increased by half the glide for similar fan power

2) If system software uses **<u>average (bubble and dew)</u>** cond. temp for TD: recommendation is to **<u>keep same setpoint</u>**

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.



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

- 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

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)

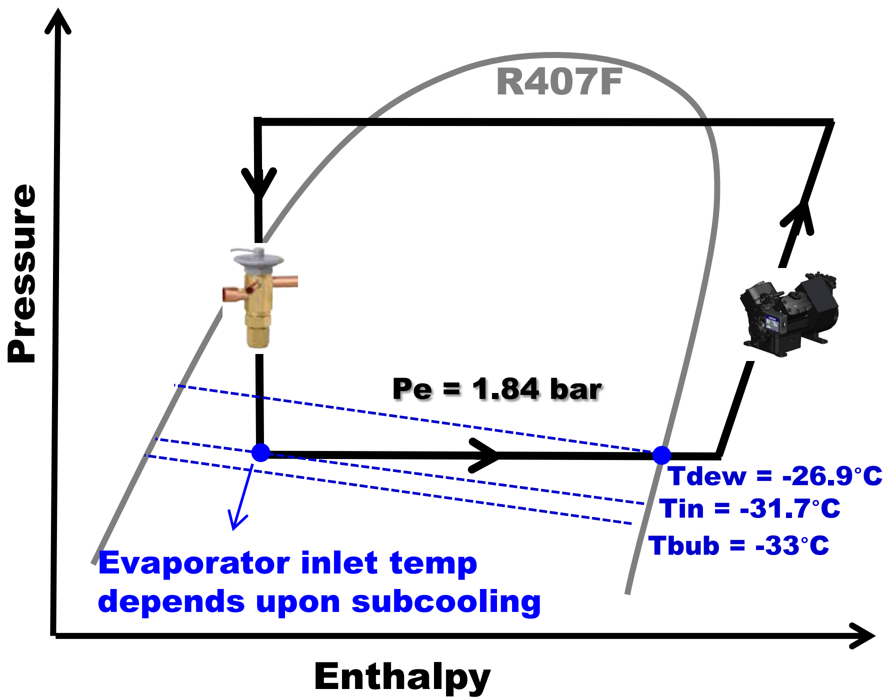
	TD-dew [°C]	TD-avg [°C]	Capacity [%]	COP
R404A (Baseline)	5.8	5.6	100%	100%
R407F (Retrofit)	7.7	5.4	100%	106%

- 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



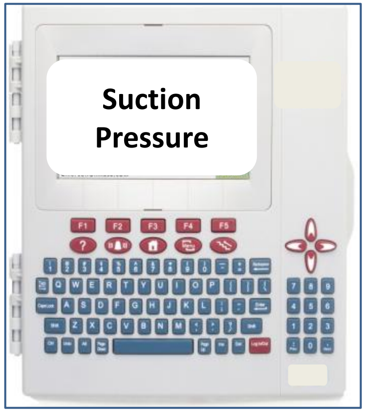
	R404A	R407F	
Pressure	Dew Temp	Bubble Temp	Dew Temp
(bar)	(°C)	(°C)	(°C)
1.77	-33.2	-33.9	-27.7
1.84	-32.3	-33.0	-26.9
1.91	-31.4	-32.2	-26.0
1.98	-30.5	-31.3	-25.2
2.05	-29.7	-30.5	-24.4

1) A rough estimate of evaporating temperature is given by average of bubble and dew:
   Example @ 1.84 bar: Tevap = Tbub*0.5 + Tdew*0.5 = (-33)*0.5 + (-26.9)*0.5 = -29.9°C

2) A better estimate is given by **40% bubble + 60% dew**:
   Example @ 1.84 bar: Tevap = Tbub*0.4 + Tdew*0.6 = (-33)*0.4 + (-26.9)*0.6 = -29.3°C

Low-side Controls: EPRs and Suction Pressure Settings

	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



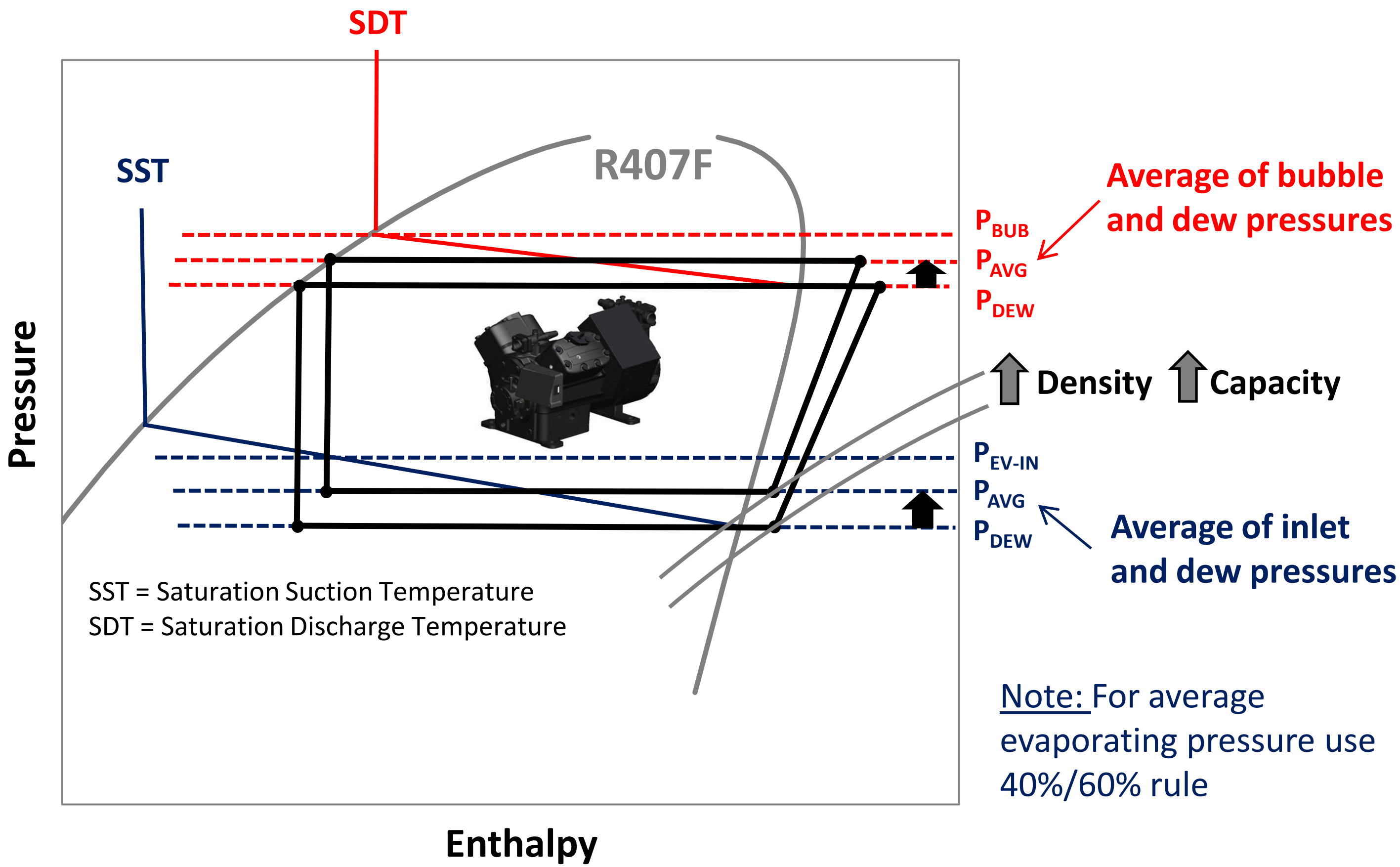
1) First convert pressure setting of R404A into temperature.
   - Assuming a R404A setting of **2.02 bar**, saturation temp of R22 is **-30°C**
2) Find bubble and dew pressures for the blend at -30°C
   - **At -30°C**, Pbub = 2.09 bar, Pdew= 1.60 bar
3) Calculate the average evap pressure based on the 40%/60% rule:
   - **Pavg** = 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

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

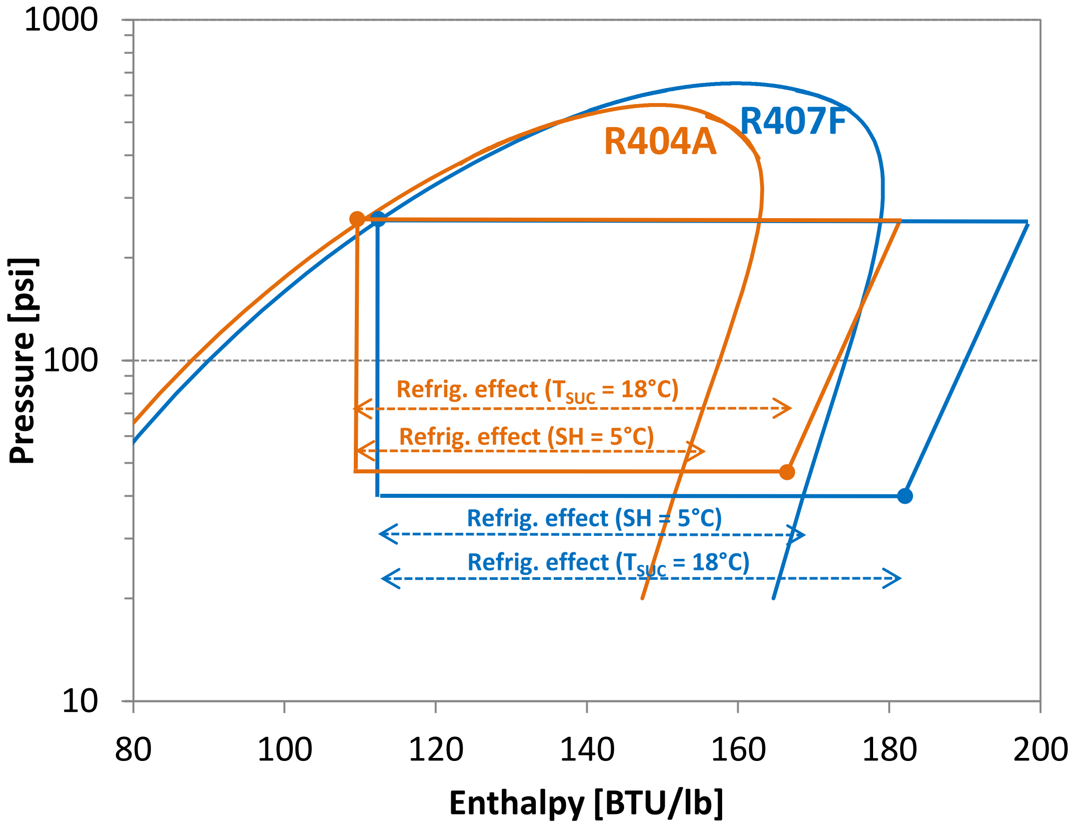


Note: For average evaporating pressure use 40%/60% rule

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

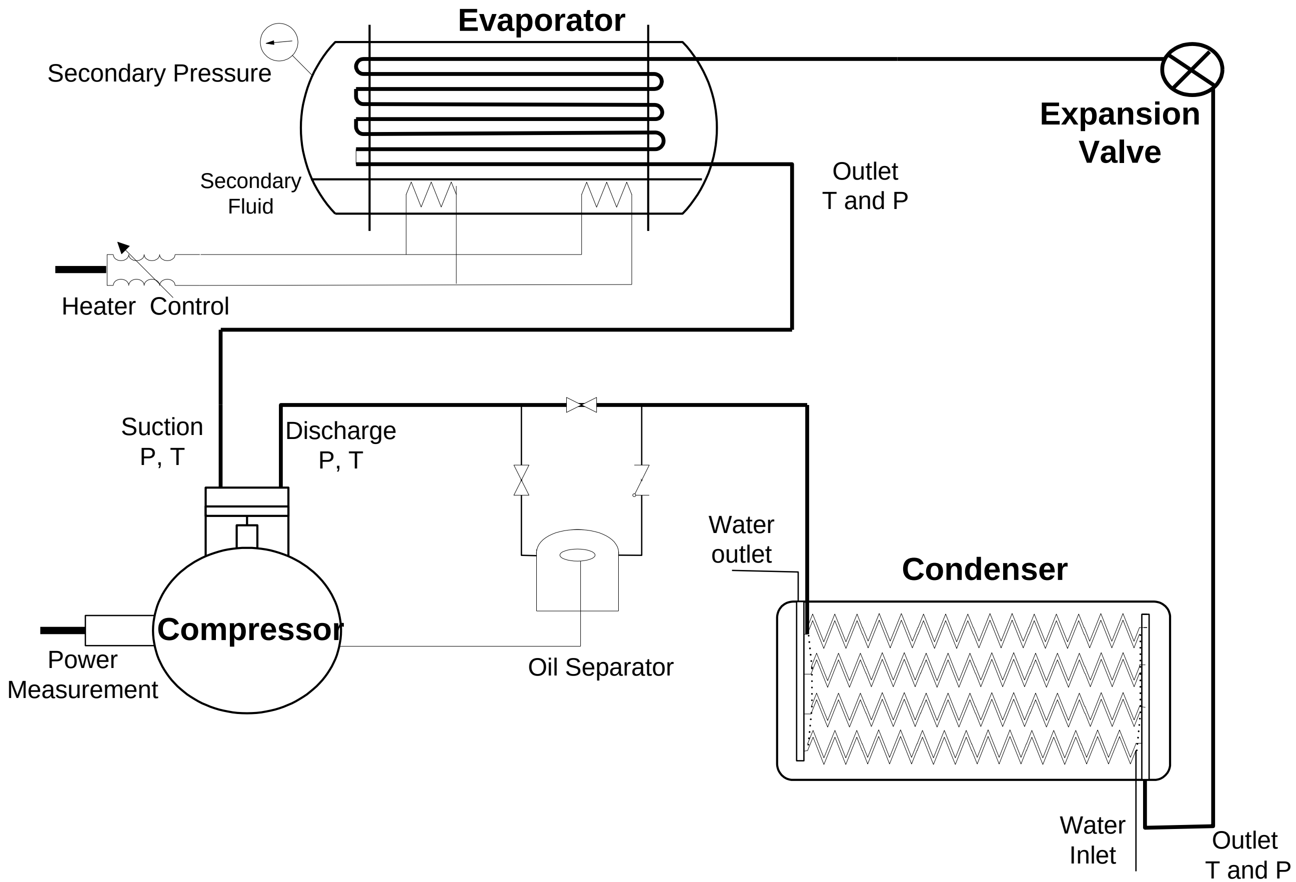
Compressor Rating vs. System Performance: Refrigerating Effect

- **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**



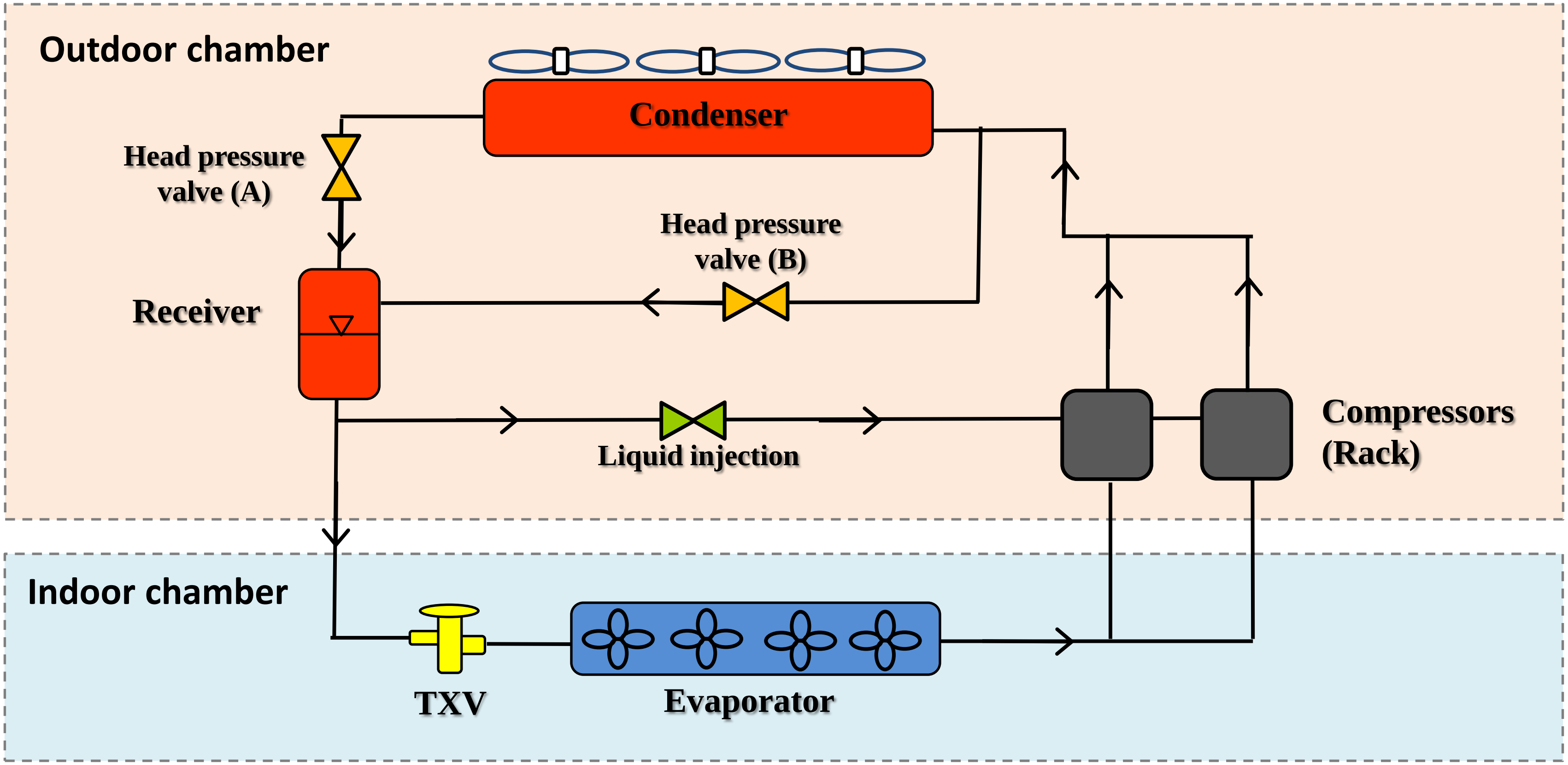
The actual capacity of a system is given at a superheat range of 3 to 7°C

Compressor Calorimeter Evaluations



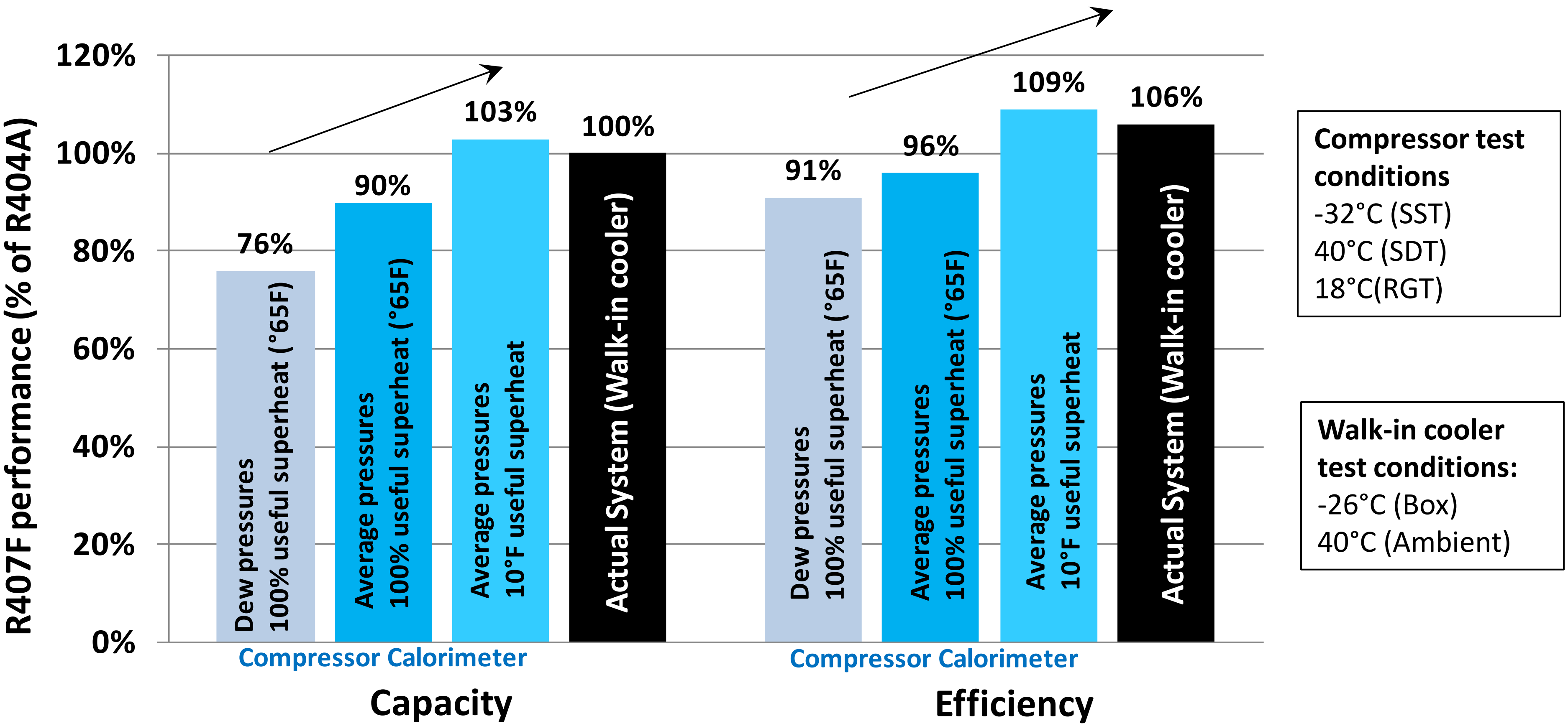
- **Employed a fully-instrumented 50k BTU/h Secondary-Fluid Calorimeter**
- **Tested a 38.3kBTU/h semi-hermetic compressor, using R404A and R407F.**
- **Operating Conditions as required by AHRI standard 540:**
  - Evaporating temperature (SST) of -32°C and condensing temperature (SDT) of 40°C
  - Ambient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



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

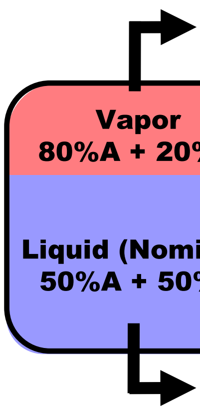
Compressor evaluated at average pressures and 3 to 7°C superheat resembles better actual system performance

Fractionation

Fractionation of Blends

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

1) Refrigerant Charging:



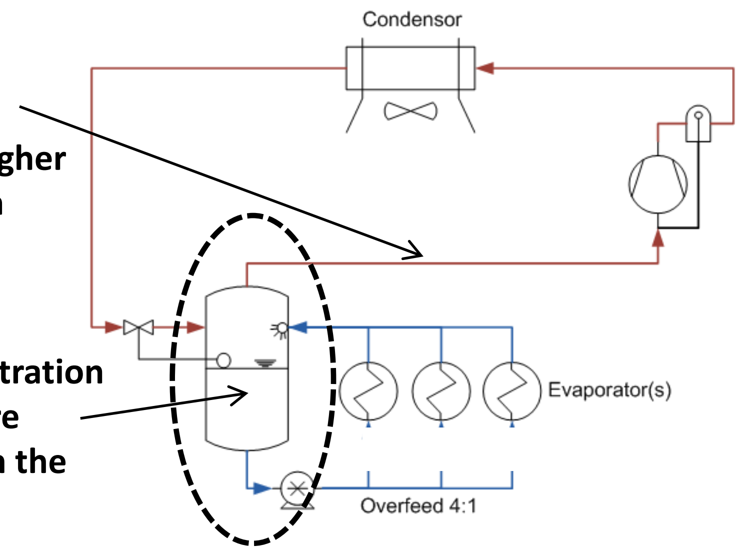
Charge from vapor port will cause fractionation

Blends should always be charged from liquid port

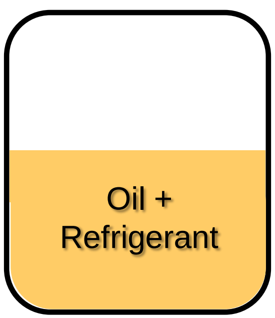
2) Flooded Evaporators:

high-pressure components circulate at higher concentration

Higher concentration of low-pressure components in the accumulator



3) Lubricant:



Blend components may have preferential solubility

4) During Leak Events

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

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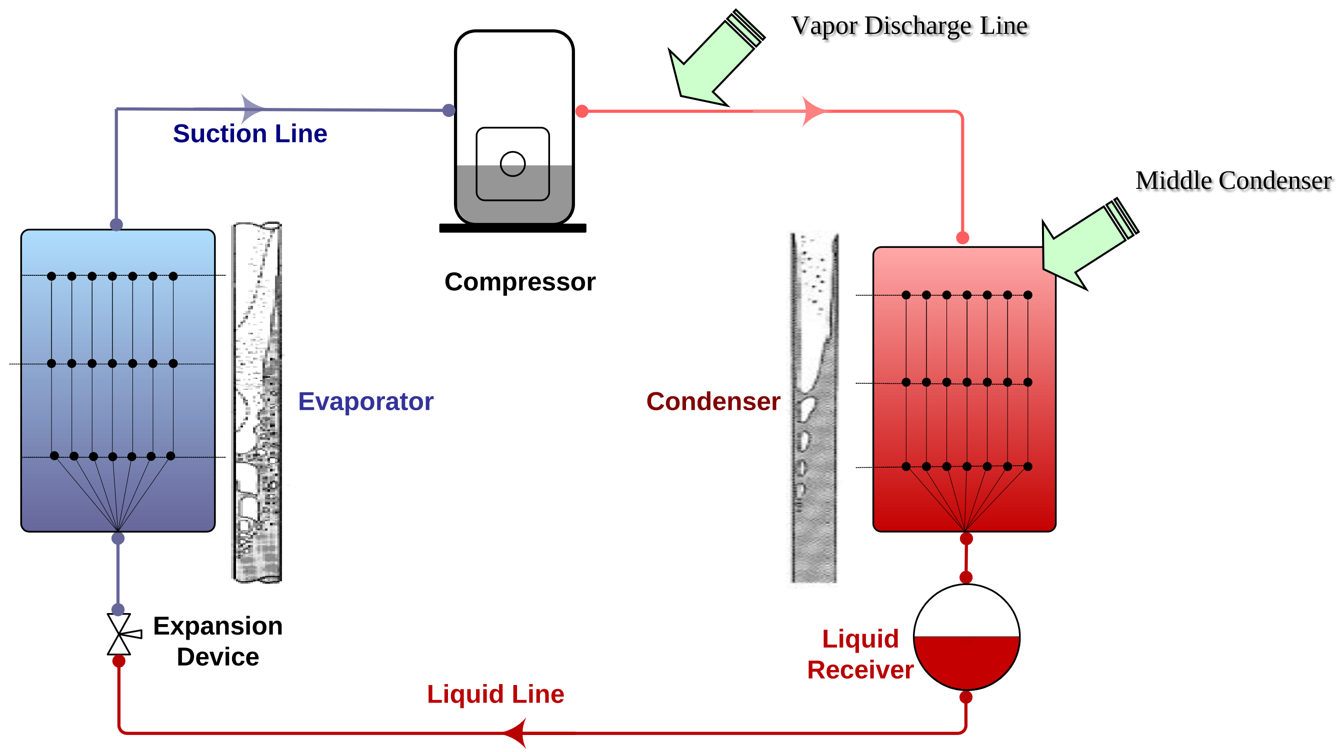
Fractionation of Blends during Leak Events



- Leak events were simulated using a 0.1mm ID orifice in a 1-Ton walk-in cooler/freezer system (Box temp of -25°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 of Blends 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

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**