Tecumseh

Impact of refrigerants R1234yf, R455A, R454C on the behaviour of direct expansion refrigeration circuits

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1. Context:

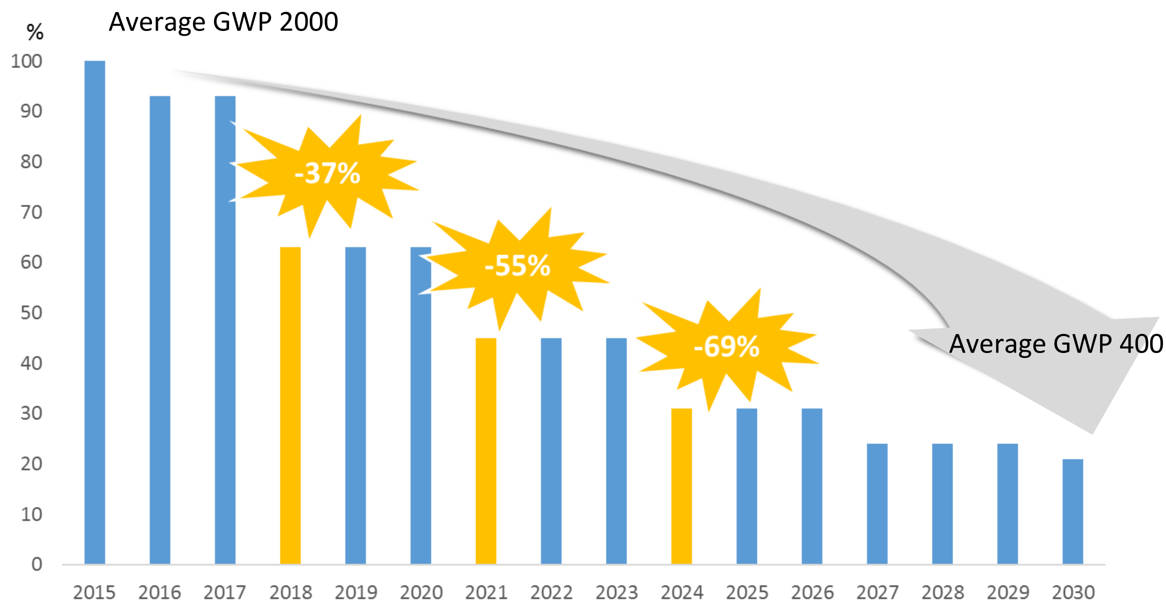
Two main regulations control the choice of refrigerants and the design of the refrigeration systems.

European Directive 517/2014 F Gas aims to limit direct carbon dioxide emissions.
It prohibits the use of refrigerants, with Global Warming Potential (GWP) exceeding the limits mentioned, in new refrigeration systems.
It aims to gradually reduce the market introduction of high GWP refrigerants.

The EU 2015/1095 Eco Design Directive enforces minimum energy efficiencies for air cooled condensing units and some refrigeration systems.

Hydrofluoro-olefin (HFO) R1234yf, R455A, R454C refrigerants meet these requirements.

The down phase of the F Gas Directive:



2. Refrigerants environmental data:

2.1. ISO 817 rating

Flammability	Toxicity	
	Low	High
Non-flammable	A1	B1
Slightly flammable	A2L	B2L
Mildly flammable	A2	B2
Highly flammable	A3	B3

Refrigerants	R454C	R455A	R1234yf
ASHRAE classification	A2L		

2.2. Definition – Refrigerants composition

Refrigerants	R454C	R455A	R1234yf
Compounds of the Blends.	Difluoromethane (R32) 2,3,3,3-Tetrafluoroprop-1-ene (R1234yf)	Difluoromethane (R32) 2,3,3,3-Tetrafluoroprop-1-ene (R1234yf) Carbon dioxide (R744)	2,3,3,3-Tetrafluoroprop-1-ene
Refrigerant composition (Mass %)	R32/R1234yf 21.5/78.5	R32/R1234yf/CO2 21.5/75.5/3	Single component

2.3. Environmental data

Global Warming Potential defines direct emissions.

The Ozone Depletion Potential (ODP) of a chemical compound is the theoretical relative degradation that this compound inflicts on the ozone layer, by the destruction of ozone in the upper atmosphere.

Refrigerants	R454C	R455A	R1234yf
Ozone Potential Depletion (ODP) (following EN378-1 version 2016)	0	0	0
Global Warning Potential (GWP) 100 years - (following EN378-1 version 2016 + A1 2019)	146	146	4

2.4. Some safety data

Refrigerants	R454C	R455A	R1234yf
PED Security Group EN378-1 version 2016	1	1	1
T critical (°C/°F)	82.4/180.3	86.6/187.9	94.7/202.5
Critical pressure (bar)	38.6	46.6	33.8
Normal boiling point (°C/°F) EN378-1 version 2016 + A1 2019	-46/-37.8°C -50.8/-36°F	-52.1/-39.1°C -61.8/-38.4°F	-29.5°C -21.1°F
Lower Flammability Limit (LFL) – (Kg/m^3) EN378-1 version 2016 + A1 2019	0.293	0.431	0.289
Practical limit (Kg/m^3) EN378-1 version 2016 + A1 2019	0.059	0.086	0.058
Upper Flammability Limit (UFL) - (Kg/m^3)	nd	0.462	nd

The use of these slightly flammable refrigerants (A2L classification) requires reference to products standards CEI 60335 series and generic standards for systems EN 378 or ISO 5149 series, for commissioning, maintenance and disposal of refrigeration systems.
A dedicated recommendations guide is available.

It is strictly prohibited to retrofit to HFO, a refrigeration system operating with HFCs.

3. Thermodynamic data

3.1. Refrigerant R1234yf

3.1.1. Mollier diagram

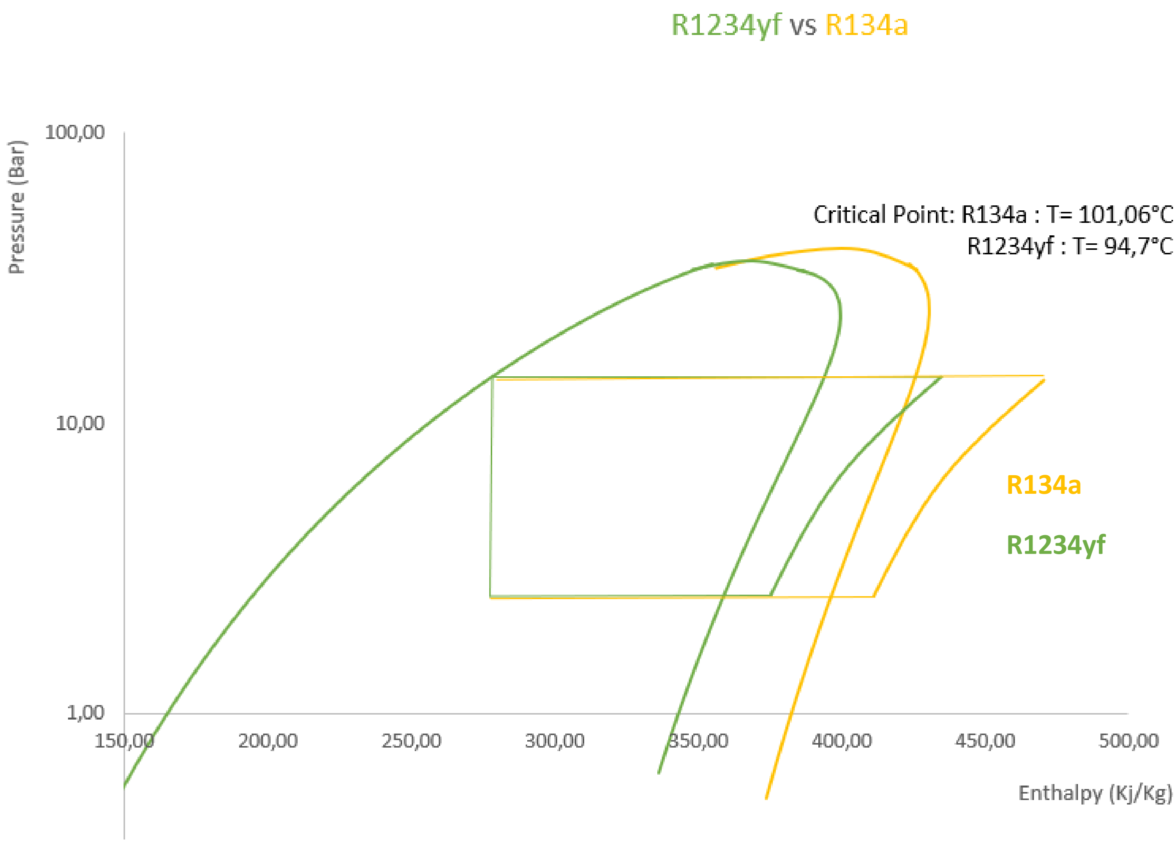


Fig 1

		R1234yf	R134a	Deviation (%) R1234yf vs. R134a
Latent heat (J/Kg)	Tdew = +5°C	159860	194732	-17.9
	Tdew= -10°C	169447	206032	-17,8
Gas density @ Tdew +20K (Kg/m^3)	Tdew = +5°C	18.8	15.6	+20.8
	Tdew= -10°C	11.4	9.2	+24.9

- ➔ The R1234yf's higher gas density compensates for its lower latent heat.
- ➔ No increase in cylinder capacity is required.

The cooling capacity differentials with the R134a are described in Paragraph 7.

3.1.2. Temperatures-Pressures curves

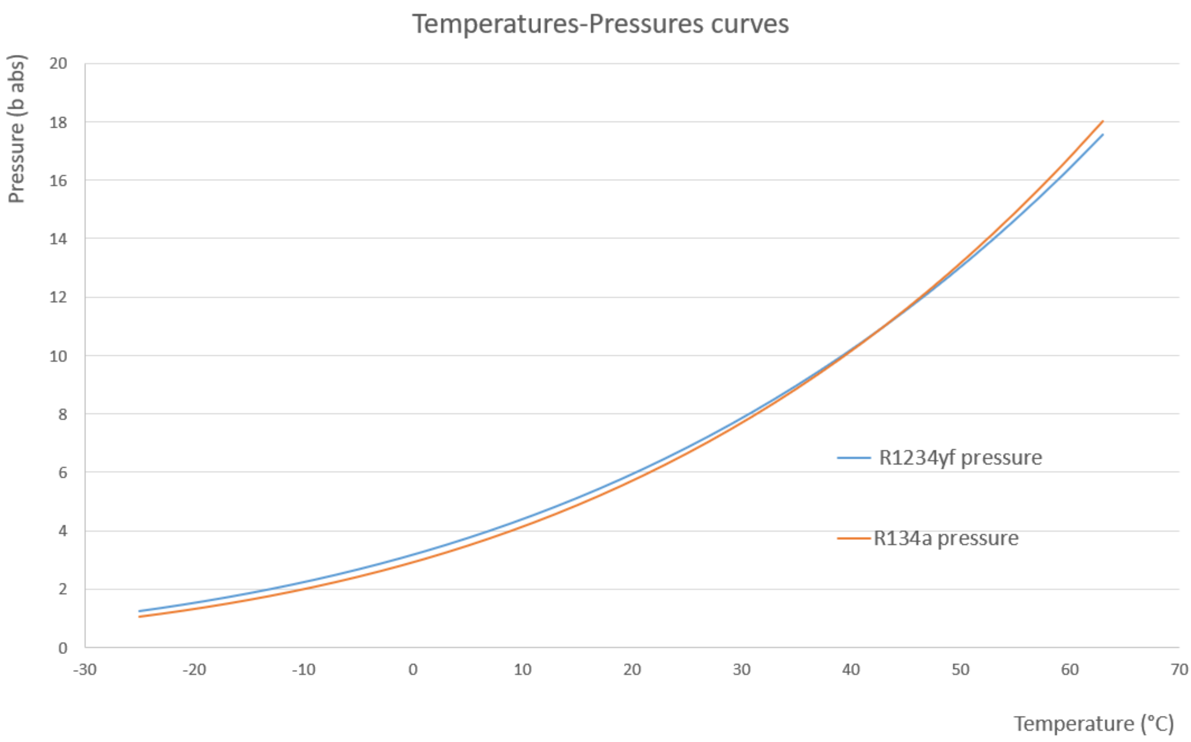


Fig 2.

Pressures ratio at rating conditions Tevap / Tcond= -10/45°C

Refrigerants	R134a	R1234yf
Pressure differential (bar)	9.56	9.3
Compression ratio	5.77	5.18

- ➔ With R1234yf, the operating pressures of the refrigeration system will be almost identical to those obtained with a system operating with R134a.
- ➔ For the aforementioned rating conditions, the pressure differential and the compression ratio are almost identical.
- ➔ The application window remains unchanged.

3.2. Refrigerants R455A - R454C

3.2.1. Mollier diagram

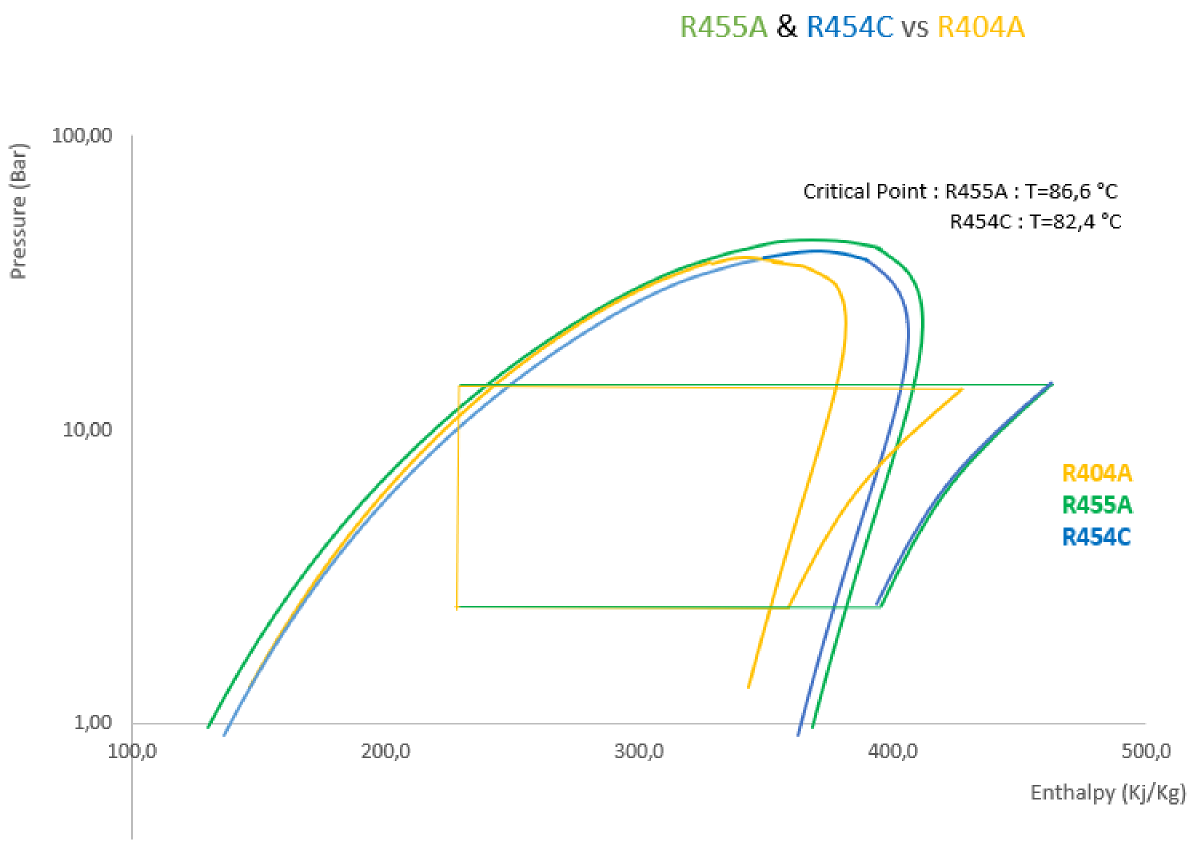


Fig. 3.

		R404A	R455A	R454C
To mid = -10°C (Tc mid = 45°C)	Corresponding To dew (°C)	-10	-6.5	-7.7
	Latent heat (J/Kg)	174444	214247	203481
	Deviation vs R404A (%)	/	23.3	17.1
	Gas density @ Tdew +20K (Kg/m^3)	19.9	15.2	14.3
	Deviation vs R404A (%)	/	-23.1	-27.9
To mid = -30°C (Tc mid = 40°C)	Corresponding To dew (°C)	-30	-26.7	-27.9
	Latent heat (J/Kg)	189555	229717	218285
	Deviation vs R404A (%)	/	32.2	25.6
	Gas density @ Tdew +20K (Kg/m^3)	9.7	7.3	6.8
	Deviation vs R404A (%)	/	-11.7	-14.2

- ➔ The increase in latent heat partially compensates for a lower density.
- ➔ The cooling capacity obtained from the refrigerating system will also be related to the refrigerant heating during its compression, to the glide impact and to the design of the heat exchangers.

3.2.2. Temperatures-Pressures curves

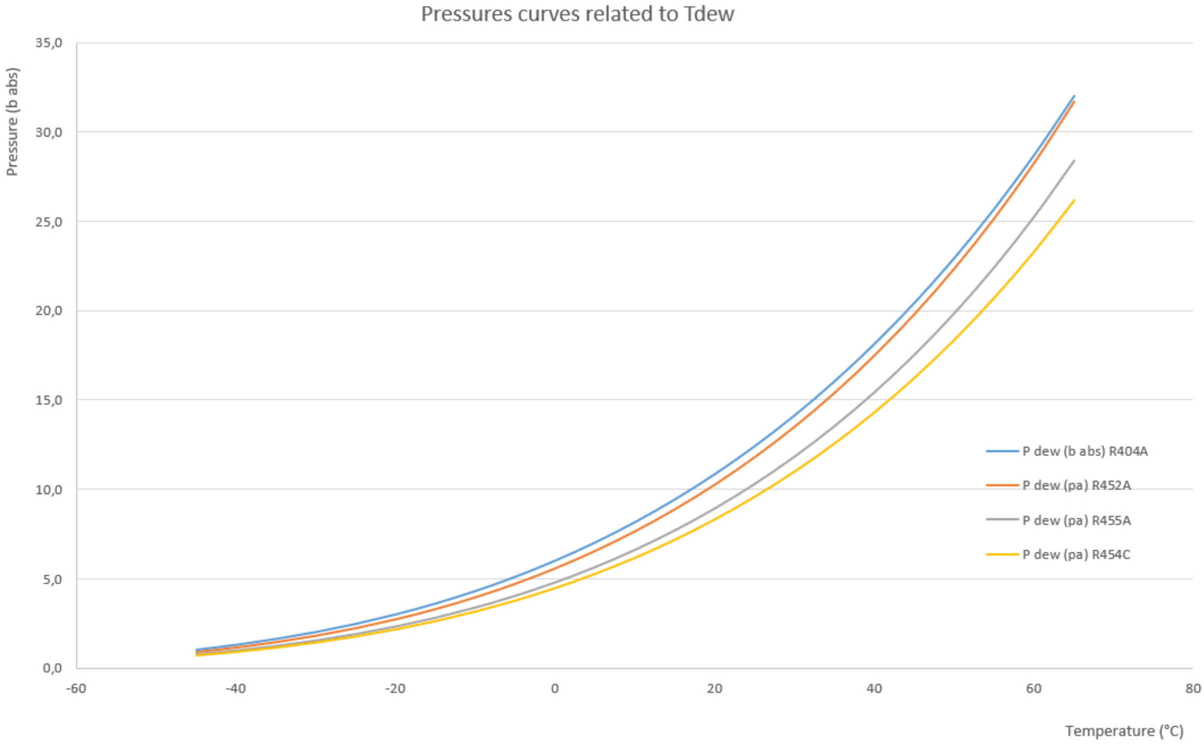


Fig 4.

Rating conditions: Mid/Mid, Tevap / Tcond = : -10/45°C

Refrigerants	R404A	R455A	R454C
Pressure difference (bars)	16.2	15.8	14.1
Compression rate	4.7	5.1	5.1

Rating conditions: Mid/Mid, Tevap / Tcond =: -30/40°C

Refrigerants	R404A	R455A	R454C
Pressure difference (bars)	16.2	15.7	14
Compression rate	8.9	9.9	9.9

- ➔ For a given running conditions, the differences in pressure and compression rates are very close.

The application window and release temperature differences are described in Paragraph 9.

4. Mollier diagram and glide

4.1. Mollier diagram

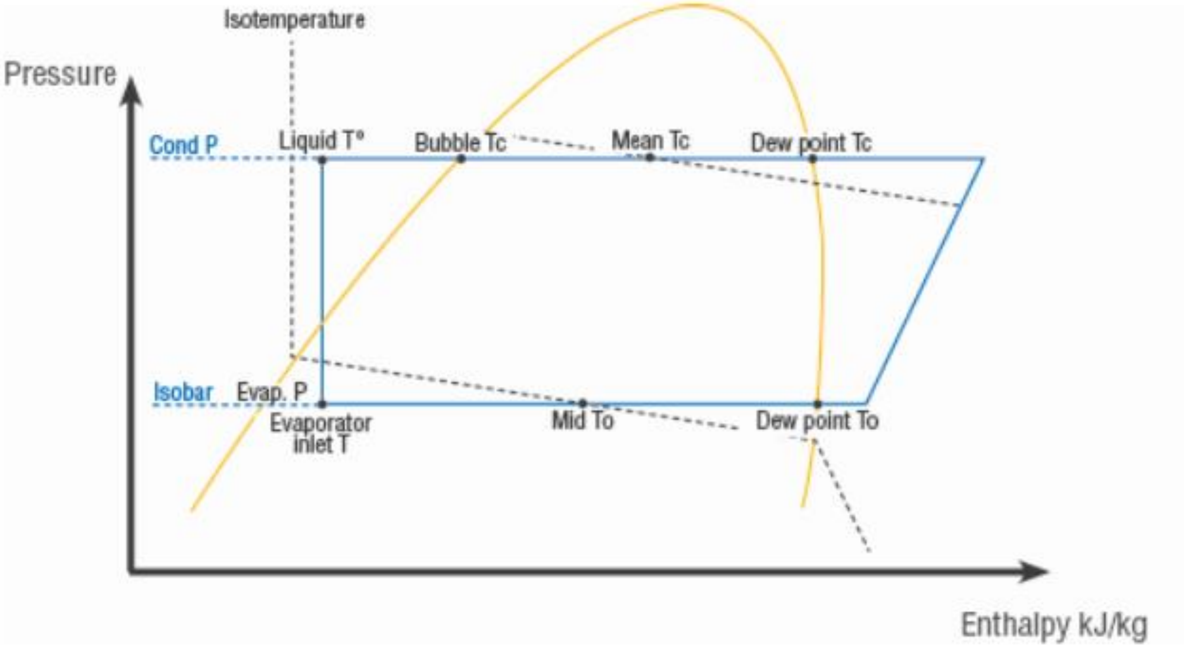


Fig 5

4.2. Explanation of the glide

The azeotropic mixtures (such as R404A) have a similar behaviour to the single refrigerants (such as R134a). They condense and evaporate at an almost constant temperature.

The refrigerants R454C, R455A and R448A are non-azeotropic mixtures, also called "zeotropic mixtures". They show significant variation in temperature during the change of state at constant pressure. This temperature variation is called glide.

Figure 5 illustrates iso-bar, iso-temperature curves, dew point, average and bubble temperature.

For a given pressure, glide is the temperature difference of the refrigerant between the bubble point and the dew point.

4.3. Examples of glide

Refrigerants	R454C	R455A
Glide @ P=1 bar abs Tdew	8.1 -38.1	12.4 -39.4
Condenser glide (K) : Tdew = 40°C Tdew = 50°C Tdew = 60°C	 6.8 6.2 5.3	 10 9.1 7.8
Total/actual estimated glide at the evaporator (K): To mid = -10°C (Tc mid=45°C) To mid= -30°C (Tc mid =40°C) To mid= -35°C (Tc mid =40°C)	 8 / 4.6 8.1 / 4.2 8.1 / 4.1	 11.9 / 7 12.2 / 6.5 12.3 / 6.3

➔ Actual evaporator glide represents an average 54% of the total glide.

4.4. Superheating and Subcooling

Superheating (SH) is determined from the Dew Point Temperature:

SH= T vapor – T dew

Subcooling (SC) is determined from the Bubble Temperature:

SR = Tc bubble – T liquid

For evaporation pressure:

- ✓ The average temperature reflects the exchange temperature of the primary refrigerant with the secondary.
- ✓ Dew point temperature is commonly used to calculate the compressor's mass flow

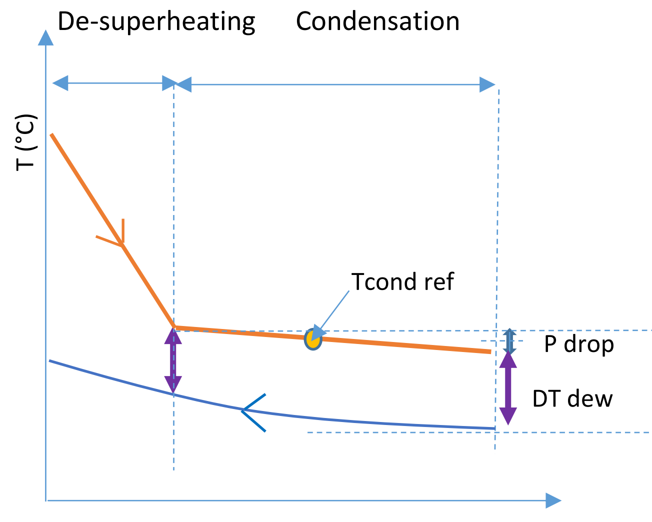
5. Impact of the glide

5.1. Glide impact on Temperatures Difference (DT) and condenser capacity

5.1.1. Glide impact on the condenser sizing when it is selected by using a dew condensation temperature

The condenser is counterflow type.

<table>
<tr><th>Single substance refrigerant or azeotropic mixture</th><th>Zeotropic mix (with glide)</th></tr>
<tr><td>

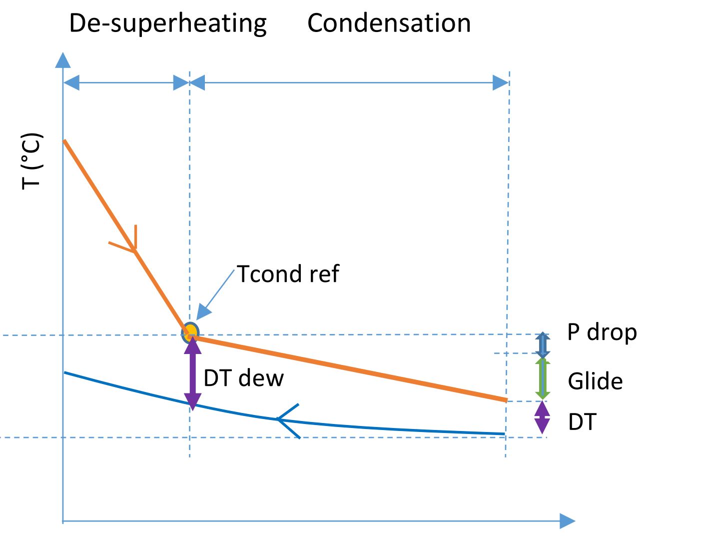


Refrigerant temperature
Air temperature

DT = T mid cond – Tcond air inlet
With T cond dew ≈ T cond bubble

So DT ≈ T cond dew – T air inlet
With Q = k x A x DT

</td><td>



Refrigerant temperature
Air temperature

DT average = T air inlet – Taverage dew cond
DT bubble= T air inlet – T cond bubble

The condensation temperature decreases when the refrigerant circulates in the condenser and will therefore always be lower than the dew point temperature.

The surface between the air temperature curves and refrigerant, which represents the DT, is therefore also reduced.

</td></tr>
</table>

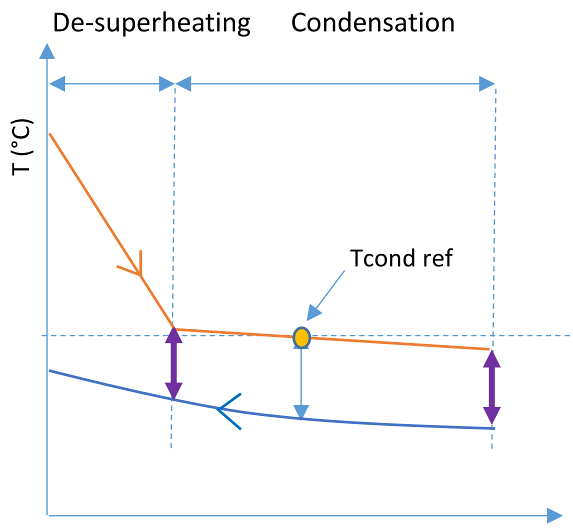
Fig 6.

➔ The use of a Dew Temperature instead of a Mid Temperature to select a condenser, lowers the calculated DT and thus leads to oversize the heat exchanger.

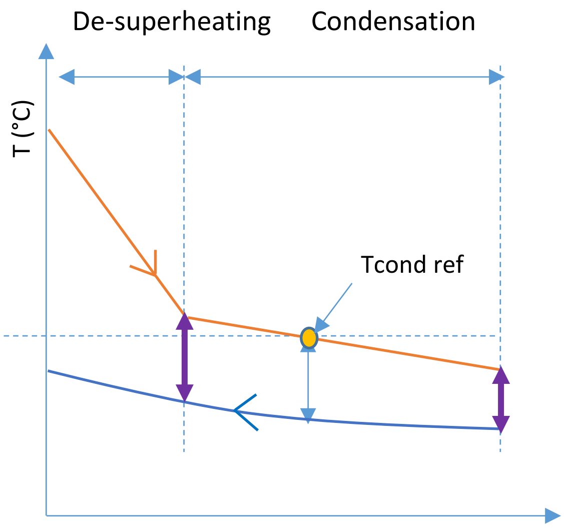
5.1.2 Condenser selection from medium condensation temperature

The condenser is counterflow type.

<table>
<tr><td>For a single substance refrigerant and an azeotropic mixture:</td><td>Zeotropic mixture (with glide)</td></tr>
<tr><td>



DT= - T average cond - Tinlet air condenser
With T reference cond = T dew cond
= Taverage cond.</td><td>



DT= T average cond - Tinlet air condenser
With reference condensation Temperature = average Temperature.</td></tr>
</table>

Fig 7.

- ➔ The use of the 'Medium' condensation Temperature as a reference reflects the actual DT along the heat transfer.
- ➔ The heat exchanger will be properly sized.

5.2. Glide impact on DT and on evaporator capacity

The refrigerant temperature increases along the heat transfer.
The average temperature difference, commonly known as DT average, is therefore greater thanks to the glide.

5.2.1. Viewing DT from a dew selection Temperature

The evaporator is counterflow type.

The area between refrigerant temperature curves allows us to compare theoretical exchange abilities with a reference to the dew evaporation point (Dew)

Single substance refrigerant	Zeotropic mix (with glide)

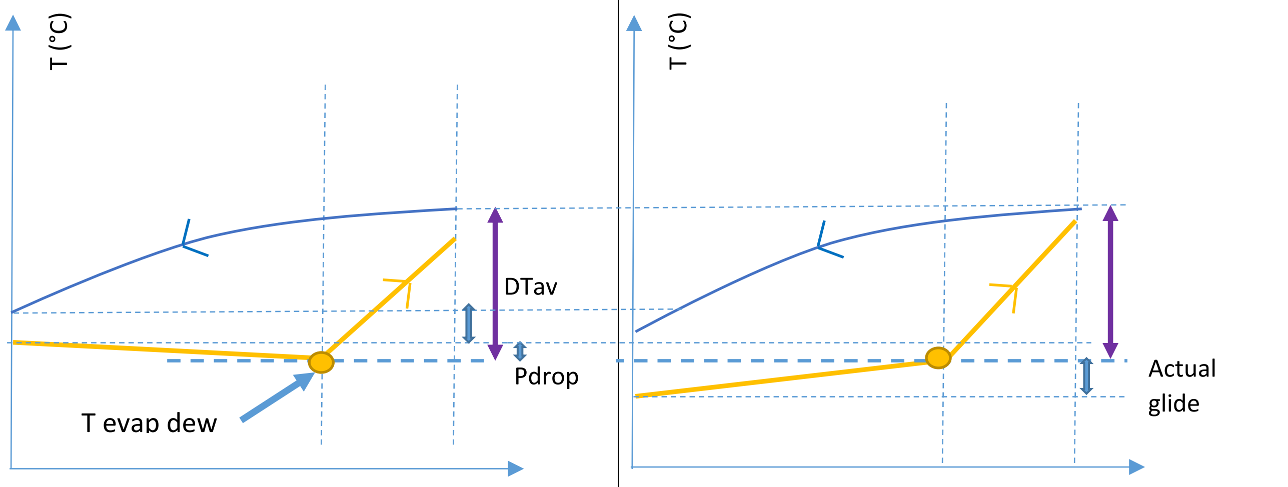


Fig 8.

The heat exchanger selection based on the dew point leads to an increase in the area between the curves and reflects a theoretical increase in exchange capacity.

- ➔ The increase in latent heat over sensitive heat will have to be taken into account.
- ➔ The icing and the glide of the refrigerant will impact this result.

5.2.2. Viewing Temperatures difference (DT) from a 'Medium' selection Temperature

The evaporator is counterflow type.

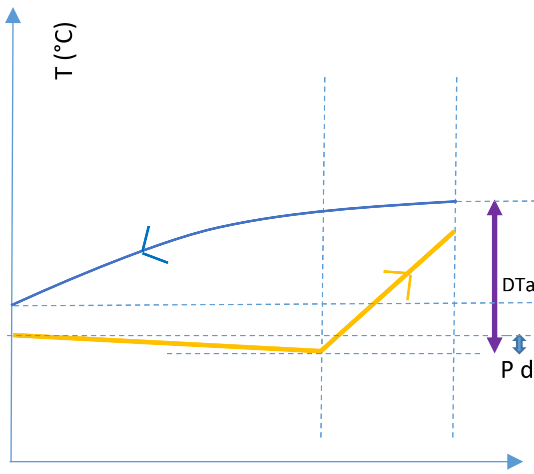
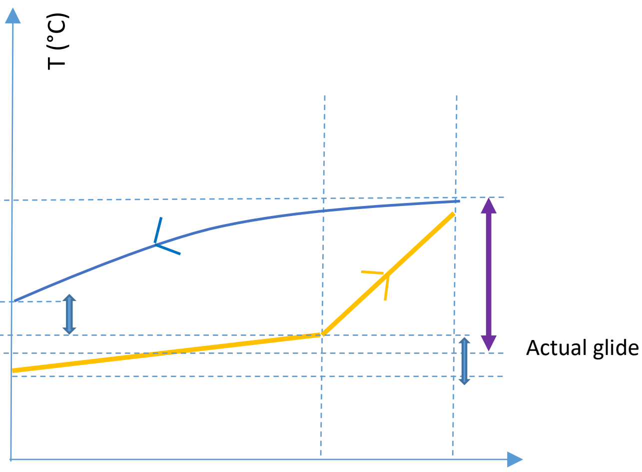
Single substance refrigerant	Zeotropic mix (with glide)
	

Fig 9.

- ➔ The 'Medium' selection point as a reference point reflects the actual DT along the heat exchanges.
- ➔ The heat exchanger will be properly sized.

Dehumidification and icing:

The inlet evaporator refrigerant temperature is 2 to 3K lower than the Medium exchange temperature.

- ➔ It contributes to an increase in air dehydration and faster icing.

6. Impact of Evaporation Temperature on Cooling Capacity Announcement

If this temperature is an average (Mid) temperature:

- ➔ T°evap $_{dew}$ seen by the compressor is therefore greater than the T°evap $_{mid}$: Delta Temp will be between 1/4 and 1/3 of glide.

	T° $_{evap\ Dew}$	
	R454C	R455A
T° $_{evap\ Mid}$ = -15°C	-12.6°C	-11.4°C
T° $_{evap\ Mid}$ = -30°C	-27.9°C	-26.9°C

- ➔ Because of these differences, a compressor selection with a dew evaporation temperature leads to oversizing.

Dew vs Mid	R454C	R455A
LBP - Δ Pf (%)	≈ + 14%	≈ + 21%
HBP - Δ Pf (%)	≈ + 10%	≈ + 11%

It is therefore strongly recommended to make the selection in Medium condition 'Mid' (available in our selection software), for these new refrigerants.
It should be noted that this 'Mid' condition does not change (R134a), or very little (R404A), the performances of products with traditional refrigerants.

7. Cooling capacities and Efficiencies (COP)

7.1. Comparison of performances at standard points EN12900 – EN13215

The standards require the publication of refrigerated performances at dew points.
The total superheat corresponding to the compressor suction temperature of 20°C is taken into account.
It adds to the latent heat of each refrigerant, and therefore impacts the cooling capacities and the corresponding efficiencies.

These results do not impact refrigeration systems due to the useful superheat typically lower than 10K.

A review of the EN12900 – EN13215 standards is in progress and will incorporate the Mid/Mid conditions for performances publication. This change will bring it closer to the actual conditions of use.

7.2. Refrigerant R1234yf versus R134a

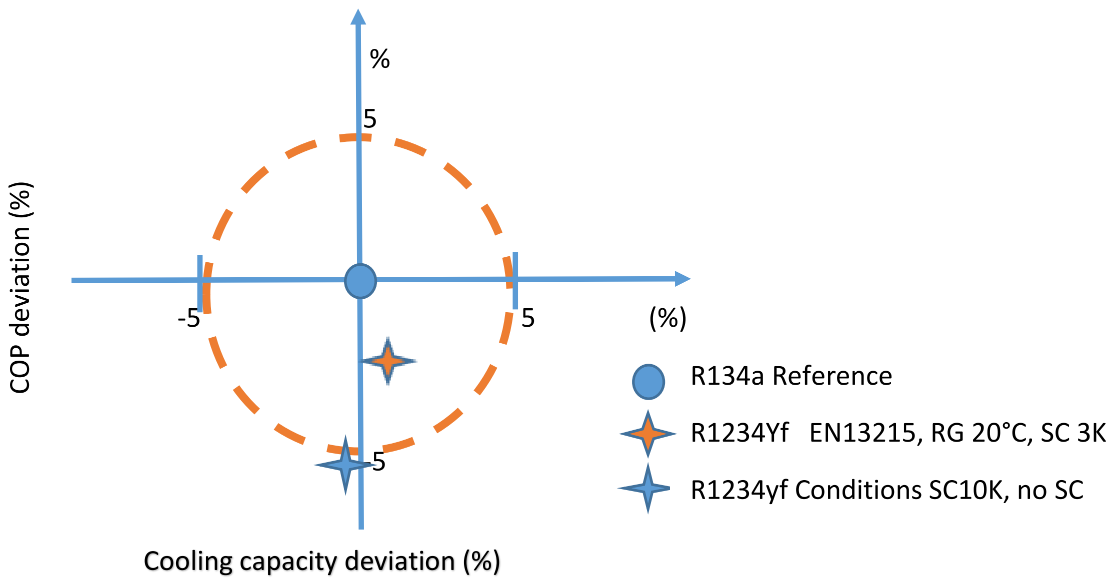


Fig 10.

Reference = performances with R134a:

Comparison R1234yf vs R134a (%)	Qo (Watt)	COP (W/W)
EN13215, To/Tc=-10/45°C, RG=20°C, SC 3K	1.00	-2.30
To/Tc = -10/45°C,SH10K , no SC	-0.85	-5.69

➔ Refrigeration performances are in the +- 5% deviations circle, commonly accepted in the performances measures of refrigeration systems.

7.3. Refrigerants R455A and R454C versus R404A

7.3.1. Medium and High Pressure Applications (MHBP): refrigeration performances deviations

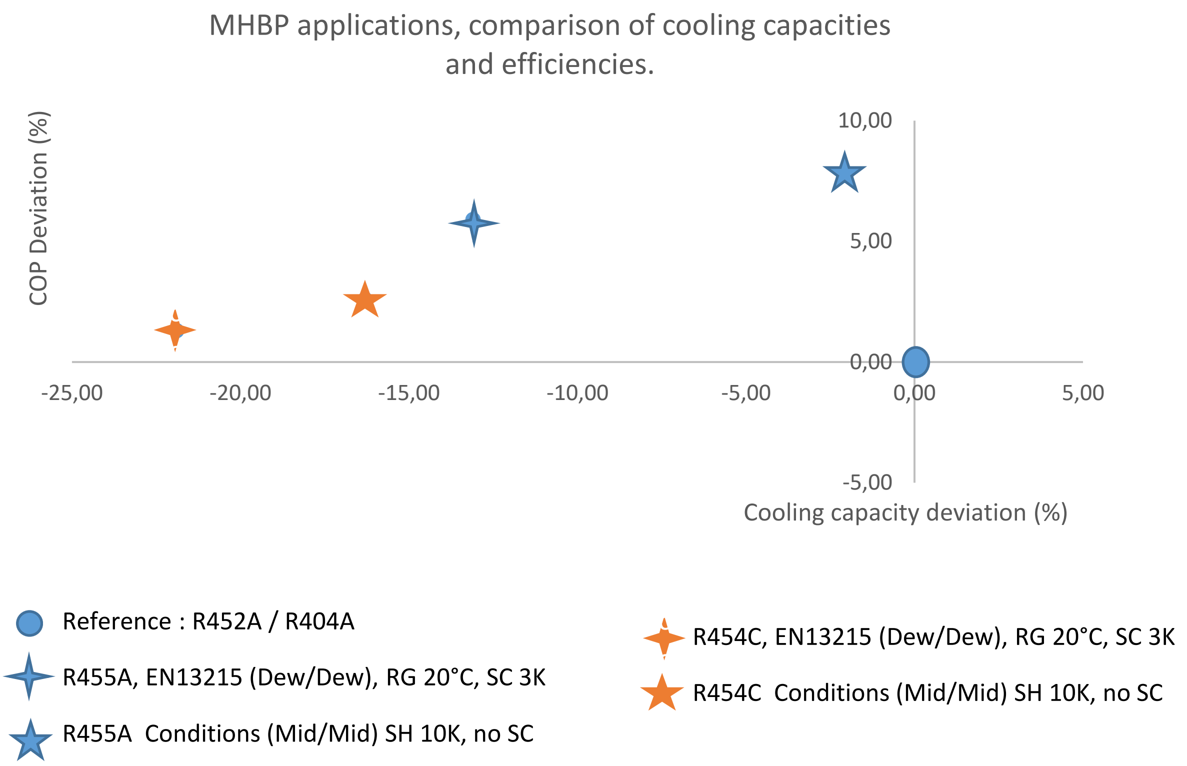


Fig. 11

- ➔ Standard conditions are largely unfavourable to the cooling capacity announcements.
- ➔ Under real-world conditions, the R455A performs similarly to R452A/R404A refrigerants.

Comparison R455A vs R404A	Qo (%)	COP (%)
EN13215, dew point, To/Tc=-10/45°C, RG=20°C, SC 3K	-13.1	5.9
Conditions Mid, To/Tc = -10/45°C,SH10K , no SC	-2.1	7.8

Comparison R454C vs R404A	Qo (%)	COP (%)
EN13215, dew point, To/Tc=-10/45°C, RG=20°C, SC 3K	-21.9	1.3
Conditions Mid, To/Tc = -10/45°C,SH10K , no SC	-16.3	2.6

This average data relates to the AJ compressor platform. They are likely to evolve for the FH and AG platforms.

7.3.2. Low Back Pressure Applications (LBP): refrigeration performances deviations observed on the 'AJ' compressor platform.

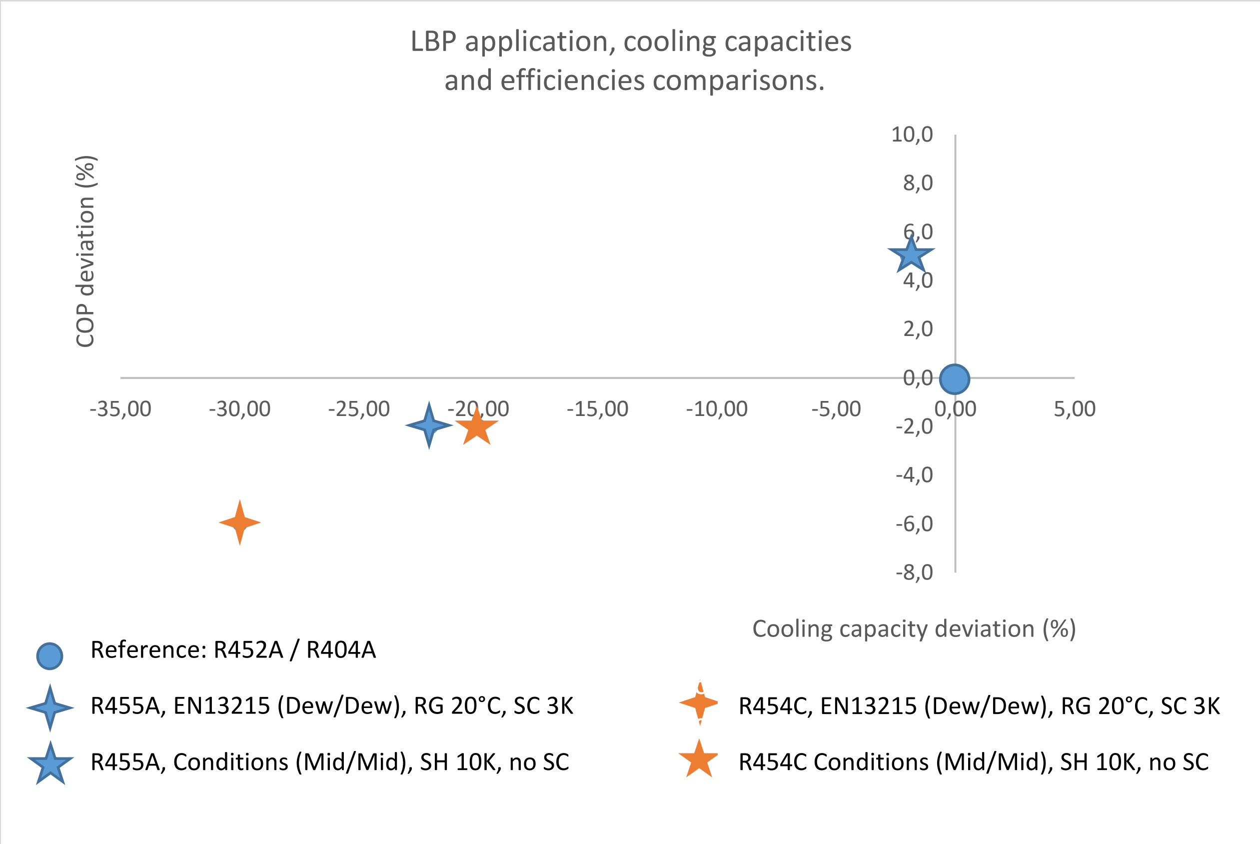


Fig 12.

Comparison R455A vs R404A	Qo (%)	COP (%)
EN13215, Dew Point, To/Tc=-35/40°C, RG=20°C, no SC	-22	-2
Conditions Mid, To/Tc = -30/40°C, SH10K , no SC	-2	5

Comparison R454C vs R404A	Qo (%)	COP (%)
EN13215, Dew Point, To/Tc=-35/40°C, RG=20°C, no SC	-30	-6
Conditions Mid, To/Tc = -30/40°C, SH10K, no SC	-20	-2

This average preliminary data relates to the AJ compressor platform.

8. Refrigerant and Oil Chemical compatibility

8.1. Refrigerant R12343yf

Tecumseh MHBP compressors and condensing units, qualified with R1234yf refrigerant, use a POE type oil of the same viscosity as that used with R134a and R513A refrigerants.

8.2. Refrigerants R454C and R455A

The Tecumseh MHBP and LBP compressors and condensing units, qualified with R455A/R454C refrigerants, use a POE type oil of the same viscosity as that used with R452A/R404A/R449A/R448A refrigerants.

Refer to the Spare Parts Selection tool for the selection of corresponding codes.

9. Reliability and operating window

9.1. Comparison of discharge gas temperatures with R452A/R404A refrigerants.

Example with a Low Back Pressure compressor, FH² platform.

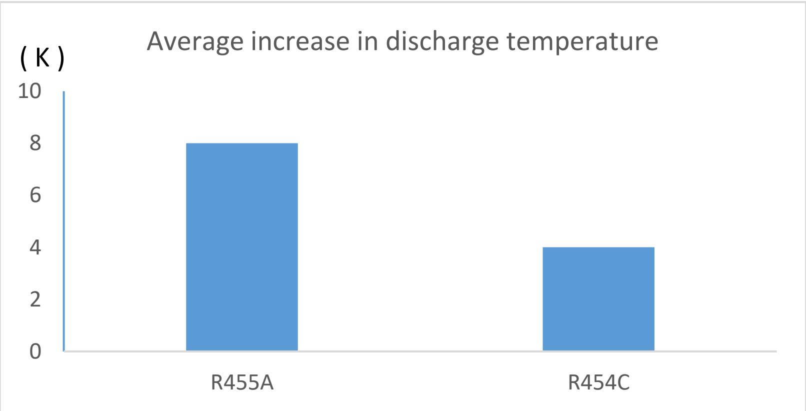


Fig. 13.

The use of HFC/HFO, R455A or R454C blends, implies an average increase of 8 or 4K depending on the refrigerant.
In order to not damage the oil, and to not lower the lubrication ability of the compressor, Tecumseh recommends not exceeding the peak of 135°C.

- ➔ Unlike R448A/R449A refrigerants, R455A and R454C refrigerants do not impact the compressor's operating window.

The compressors operating windows related to the superheat at the compressor inlet, are readable below.

9.2. Compressor operating window

9.2.1. R1234yf refrigerant

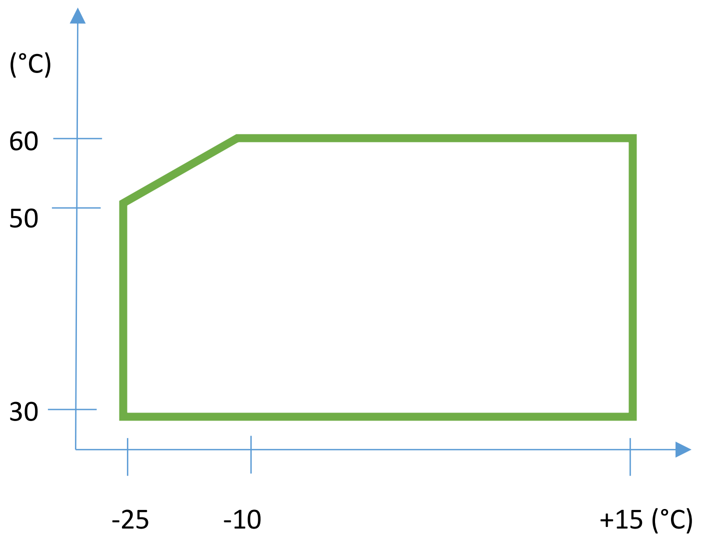
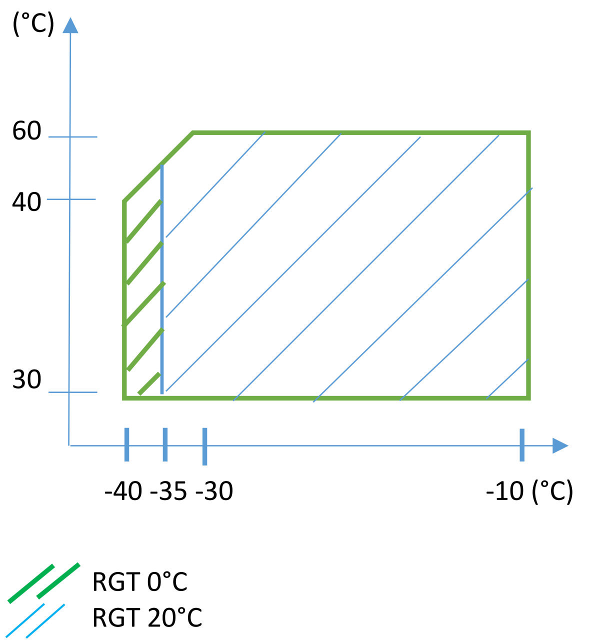
MHBP application, Return Gas Temp = 20°C


Fig 14.

➔ The High and Medium Pressure compressors (MHBP) have the same application window with R134a and R1234yf refrigerants.

9.2.2. Refrigerants R454C - R455A

LBP application Temperatures expressed in Mid condition	MHBP application Temperatures expressed in Mid condition



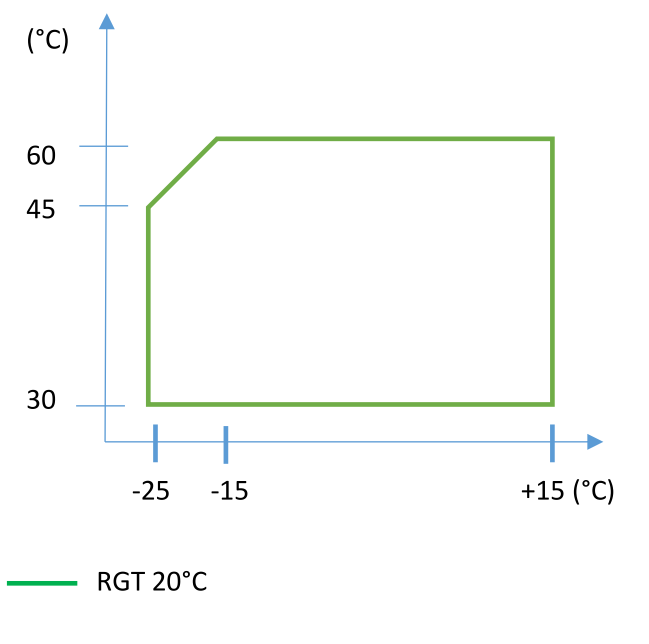


Fig15.

10. Acoustic impact

10.1. Acoustic comparison with the R1234yf

For a given cooling capacity, the acoustic power is almost identical with R134a and R1224yf.

10.2. Acoustic comparison with R455A, R454C

The expected acoustic power is almost identical to the one emitted with HFC Mid GWP refrigerants.

11. Refrigerant charge impact in the refrigerating systems

11.1. Refrigerant densities comparisons

	R1234yf	R134a
Liquid density (kg/m^3), T bubble=45°C	1007	1126
Vapour density (kg/m^3), Tsat dew = -10°C	12.6	10

	R404A	R455A	R454C
Tsat bubble corresponding to To mid= 45°C Liquid density (kg/m^3)	45 935	40.4 951	41.8 909
Tsat dew corresponding to To mid= -10°C Vapour density (kg/m^3)	/ 22.1	-6.5 16.8	-7.7 15.8

- ➔ Liquid density change is the main criteria, it is included in the range -2 / +10%.

11.2. Refrigerant charge estimation

For a given cooling capacity, the R1234yf expected refrigerant charge will be the same + - 5%, as the one obtained with R134a.

For a given cooling capacity, the R455A/R454C expected refrigerant charge will be the same + - 5%, as the one obtained with R404A.

Pre-charge the system at 90% of the estimated total charge, then adjust it through the low pressure circuit to ensure a liquid refrigerant state at the expansion device inlet, and an appropriate superheat.

12. Mass flow Impact – expansion device

12.1. R1234yf refrigerant:

Example of mass flows: running conditions To/Tc=-10/45, SH10K
Compressor: CAJ4513N-FZ

	R1234yf	R134a
Flow (kg/h)	47.8	38.8

- ➔ The increase in mass flow compared to the R134a, leads to an increase in pressure drops in the refrigeration system.
- ➔ The expansion device will be less resistant.

Refer to manufacturers data.

12.2. R455A and R454C refrigerants

MHBP application.

Running conditions: Medium Point, To/Tc=10/45, SH10K

	R455A - R454C	R452A - R404A
Compressor	AJ4519P-FZ	CAJ4519Z-FZ
Flow (kg/h)	60.4 – 58.3	83.9 – 85.4

- ➔ With R455A/R454C refrigerants mass flows are reduced by more than 25%.

Refer to manufacturer data.

13. Pressure Impact – Pressostats Settings

The low and high pressure setting values of the safety pressure switch must be lower or equal to the design pressure (PS) of any component of the refrigeration system.
The compressor and liquid receiver design pressure (PS) are readable on their nameplate.

13.1. Settings with the R1234yf

	R1234yf	R134a
Low Pressure Switch	To=-25°C , P=1,23 b abs To=-15°C, P= 1,84 b abs	To=-25°C , P=1,06 b abs To=-15°C, P= 1,64 b abs
High Pressure Switch	PS = P(Tc=64°C Bubble) = 17 b relative	PS = P(Tc=64°C Bubble) = 17.5 b relative

Due to the very similar evaporation and condensation pressures of R134a and R1234yf, the safety pressure switches will be adjusted to almost the same values.

13.2. Settings with R454C or R455A refrigerants

Cut out settings of the HP safety pressure switch, will be based on the bubble temperatures defined by the designed specified Temperatures.

	R454C	R455A
Low Pressure Switch	To dew=-40°C, P= 0.91 b abs To dew=-25°C, P= 1.78 b abs To dew=-15°C, P= 2.63 b abs	To dew=-40°C, P= 0.97 b abs To dew=-25°C , P= 1.89 b abs To dew=-15°C, P= 2.81 b abs
High Pressure Switch	PS = P(Tc=64°C Bubble) = 27.5b relative	PS = P(Tc=64°C Bubble) = 31.5 b relative

14. Leakage test

The standard NF EN 14624 version June 2012, “Performance of portable leak detectors and of room monitors for halogenated refrigerants" defines a minimum 5g/year leak sensitivity of detectors and atmosphere controllers designed to detect halogenated gases of type CFC, HCFC, HFC, PFC.

EN378 Part 2 defines the leakage test conditions.
Electronic detection by heated diode or ionisation is possible for HFC/HFO refrigerant blends.

Other systems such as infrared cell detection are available and allow more accurate detection.

15. Temperatures and Pressures of R1234yf, R454C and R455A

R1234yf				R454C				R455A	
Temp (°C)	Pressure abs (pa)		Tdew (°C)	Tbubble (calculation)	Pressure abs (pa)		Tdew (°C)	Tbubble (calculation)	Pressure abs (pa)
-25	123049		-40	-48.1	91240		-40	-52.4	97180
-20	151157		-35	-43.1	115167		-35	-47.3	122663
-15	184016		-30	-38.1	143761		-30	-42.3	153124
-10	222132		-25	-33.0	177611		-25	-37.2	189203
-5	266030		-20	-28.0	217339		-20	-32.1	231577
0	316255		-15	-23.0	263601		-15	-27.0	280964
5	373369		-10	-18.0	317085		-10	-21.9	338125
10	437954		-5	-12.9	378517		-5	-16.8	403864
15	510610		0	-7.9	448660		0	-11.7	479035
20	591961		5	-2.8	528322		5	-6.6	564544
25	682655		10	2.2	618359		10	-1.5	661357
30	783368		15	7.3	719685		15	3.7	770507
35	894810		20	12.4	833279		20	8.9	893103
40	1017727		25	17.6	960191		25	14.1	1030339
45	1152910		30	22.7	1101563		30	19.4	1183508
50	1301200		35	27.9	1258634		35	24.7	1354013
55	1463498		40	33.2	1432759		40	30.0	1543383
60	1640772		45	38.5	1625427		45	35.4	1753293
65	1834067		50	43.8	1838281		50	40.9	1985581
70	2044519		55	49.2	2073137		55	46.5	2242269
			60	54.7	2332017		60	52.2	2525591
			65	60.3	2617170		65	58.0	2838019
			70	66.0	2931111		70	63.9	3182297