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iiar®

Design of Evaporator with CO2 Coolant

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Selection of CO2 Evaporators

- The selection process of the evaporators that operate in a system of refrigeration with CO2, is very similar to the selection of evaporators for ammonia. Evaporator manufacturers commonly require the same data for both refrigerants and likewise, performance and selection data will be displayed in the same way.

- Typically, the data to be fed for an adequate selection of evaporators for either CO2 or ammonia, are:

a. Elevation above sea level
b. Air inlet temperature
c. Relative humidity in return air
d. Evaporation temperature
e. Cooling supply type
f. Recirculation radius (recirculated pumps)
g. Liquid pressure and temperature in the expansion valve (Direct Expansion)
h. Required cooling load
i. Type of melting
j. Power supply voltage
k. Construction materials
l. Required MAWP (Maximum Allowable Working Pressure)

Selection of CO2 Evaporators

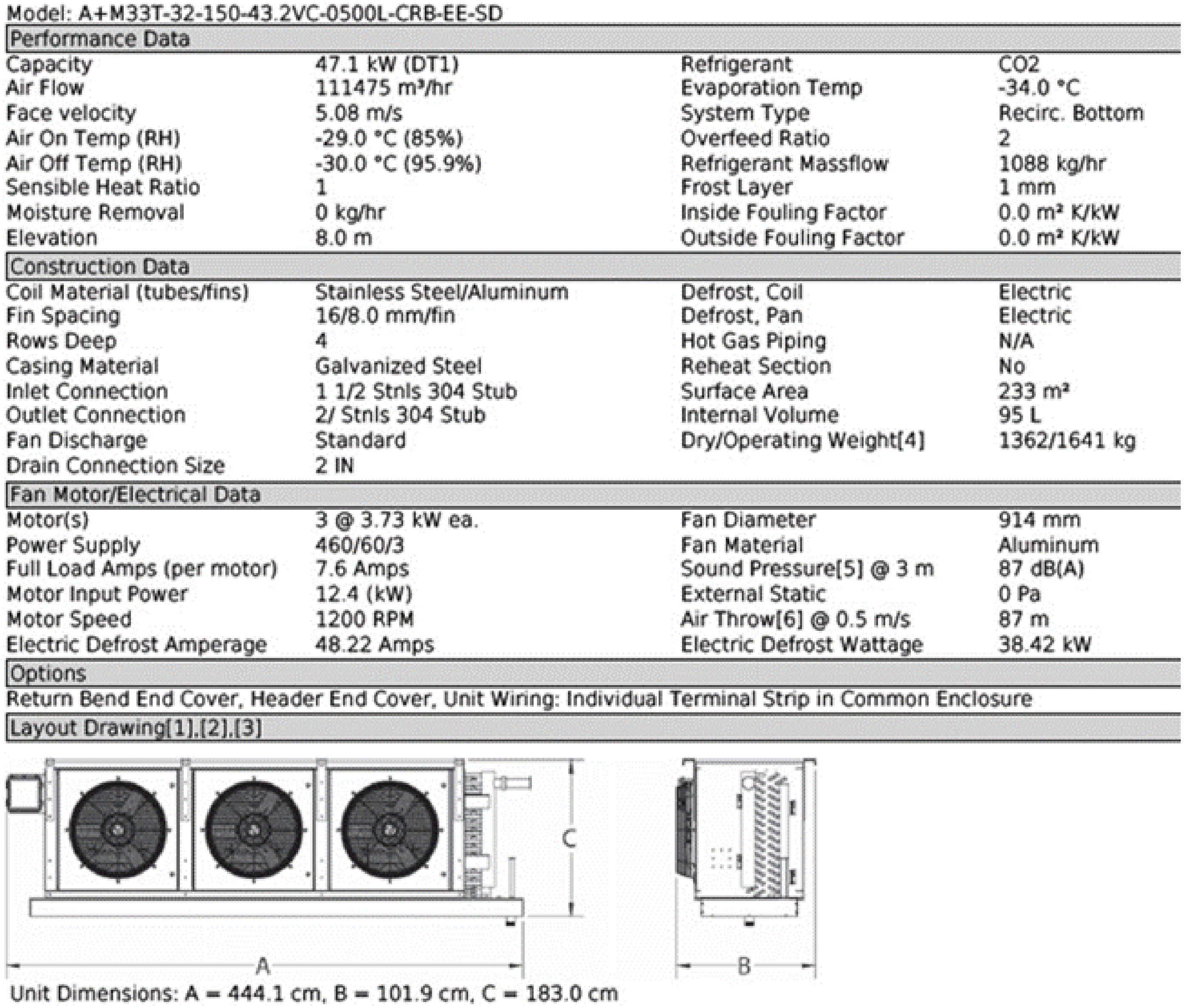
Other important data for selection may be:

a. Maximum air speed allowed
b. Minimum airflow radius
c. Maximum fan speed allowed
d. Maximum sound pressure allowed (commonly in dB (A))
e. Minimum air throw distance
f. Minimum number of fans
g. Dimensional constraints (maximum height or length limitation)

Selection sheets typically include:

a. Current cooling capacity
b. Flow rate and air velocity.
c. Output temperature
d. Output Relative Humidity
e. Noise pressure level
f. Distance of the air shot
g. Characteristic Dimensions
h. LxWxH cabinet
i. Weight
j. Internal volume
k. Electrical Characteristics
l. Number of fans / motors
m. Fan Speed
n. Power to the fan motor brake
o. Amperage at full load and/or power consumed

Selection of CO2 Evaporators



Model: A+M33T-32-150-43.2VC-0500L-CRB-EE-SD

Performance Data			
Capacity	47.1 kW (DT1)	Refrigerant	CO2
Air Flow	111475 m³/hr	Evaporation Temp	-34.0 °C
Face velocity	5.08 m/s	System Type	Recirc. Bottom
Air On Temp (RH)	-29.0 °C (85%)	Overfeed Ratio	2
Air Off Temp (RH)	-30.0 °C (95.9%)	Refrigerant Massflow	1088 kg/hr
Sensible Heat Ratio	1	Frost Layer	1 mm
Moisture Removal	0 kg/hr	Inside Fouling Factor	0.0 m² K/kW
Elevation	8.0 m	Outside Fouling Factor	0.0 m² K/kW

Construction Data			
Coil Material (tubes/fins)	Stainless Steel/Aluminum	Defrost, Coil	Electric
Fin Spacing	16/8.0 mm/fin	Defrost, Pan	Electric
Rows Deep	4	Hot Gas Piping	N/A
Casing Material	Galvanized Steel	Reheat Section	No
Inlet Connection	1 1/2 Stnls 304 Stub	Surface Area	233 m²
Outlet Connection	2/ Stnls 304 Stub	Internal Volume	95 L
Fan Discharge	Standard	Dry/Operating Weight[4]	1362/1641 kg
Drain Connection Size	2 IN		

Fan Motor/Electrical Data			
Motor(s)	3 @ 3.73 kW ea.	Fan Diameter	914 mm
Power Supply	460/60/3	Fan Material	Aluminum
Full Load Amps (per motor)	7.6 Amps	Sound Pressure[5] @ 3 m	87 dB(A)
Motor Input Power	12.4 (kW)	External Static	0 Pa
Motor Speed	1200 RPM	Air Throw[6] @ 0.5 m/s	87 m
Electric Defrost Amperage	48.22 Amps	Electric Defrost Wattage	38.42 kW

Options

Return Bend End Cover, Header End Cover, Unit Wiring: Individual Terminal Strip in Common Enclosure

Layout Drawing[1],[2],[3]

Unit Dimensions: A = 444.1 cm, B = 101.9 cm, C = 183.0 cm

Selection of CO2 Evaporators

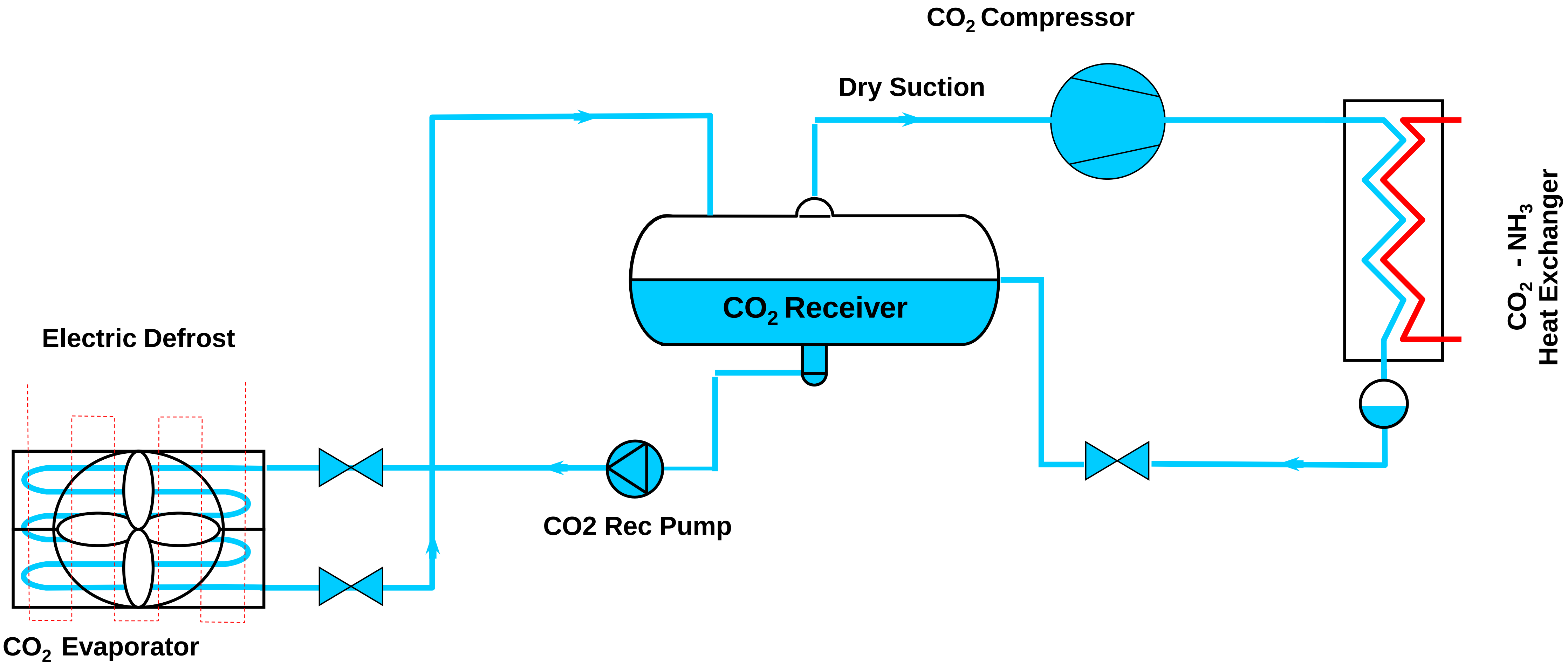
Important Topics:

- System Type
- Materials Compatibility
- Pressures
- Heat transfer
- Defrosting

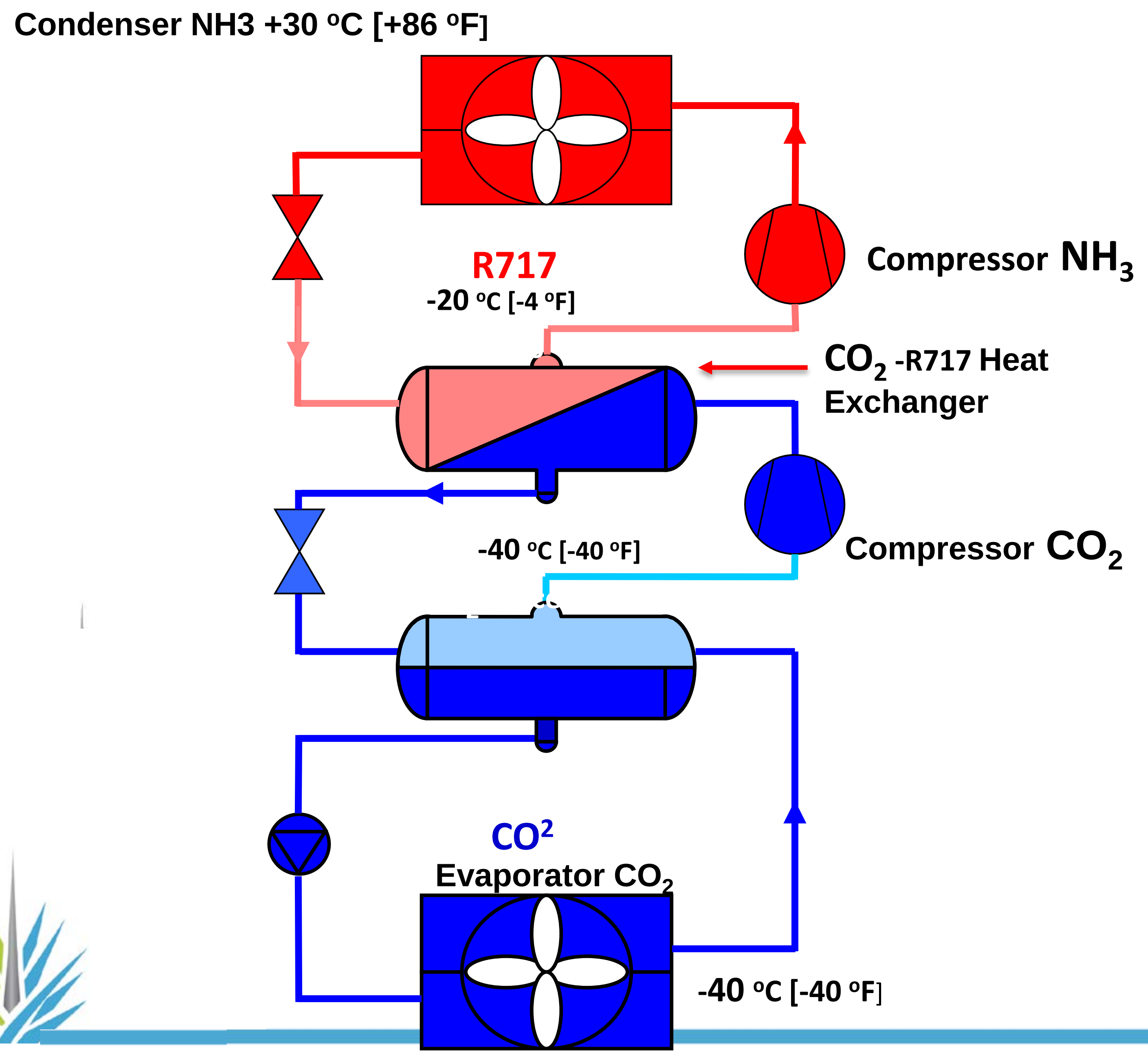
Types of CO2 Systems

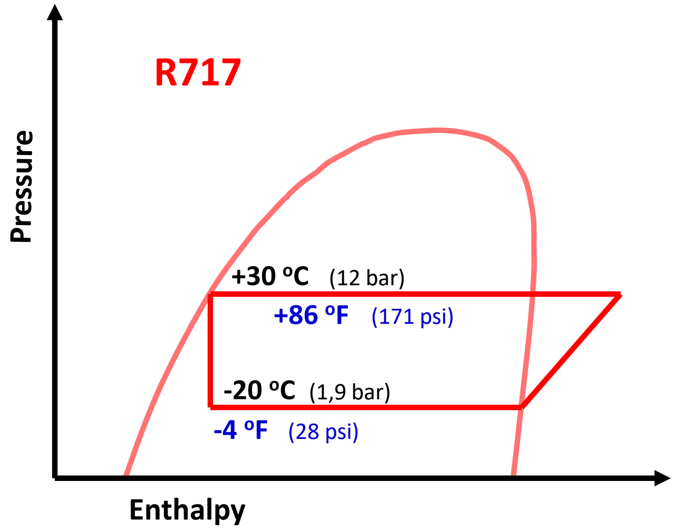
- **More commonly used by their type of feeding, are the following methods:**
  - Recirculated by Pumps, and ...
  - Direct Expansion
- Gravity Inundated are not common with CO2 due to:
  - High density of the liquid causes a high evaporation temperature due to the static height in the feeding leg.
  - Very High Pressure vessel required for the suction tank.
  - Poor performance due to little pressure drop available.
  - Rectification of oil required in the accumulator suction.
- Radio Recirculation Pump
  - Smaller than ammonia (1.5: 1 for chillers, 2: 1 for freezers)

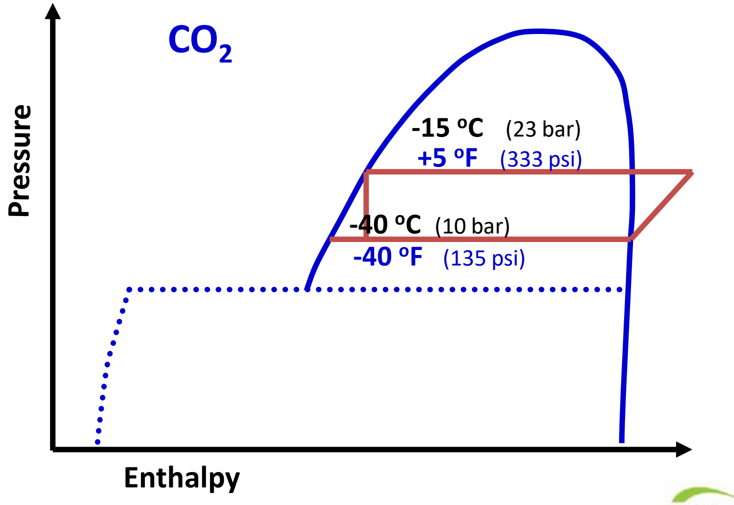
CO2 Cascade Systems



Main Diagram of Cascade CO2 System

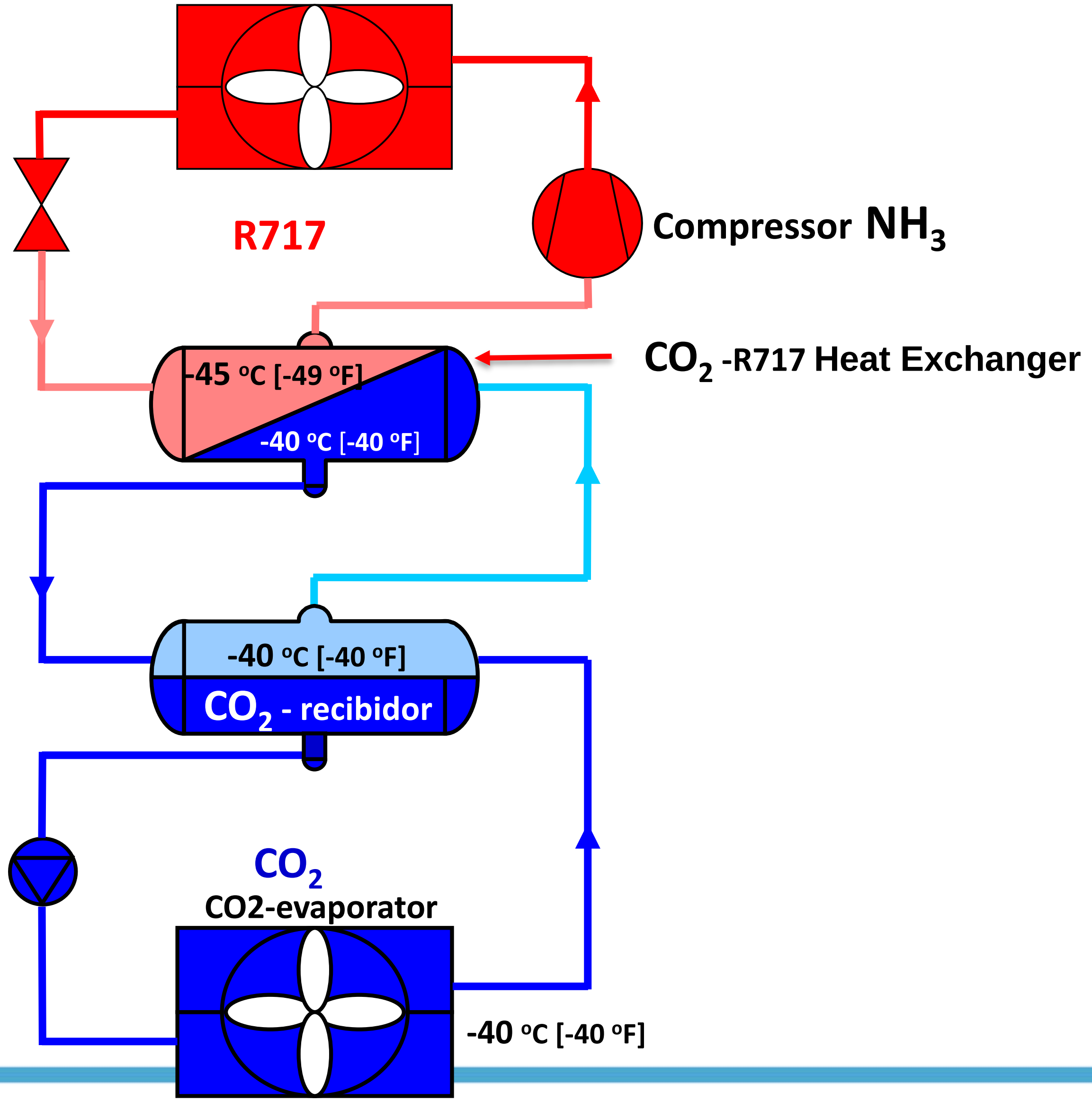


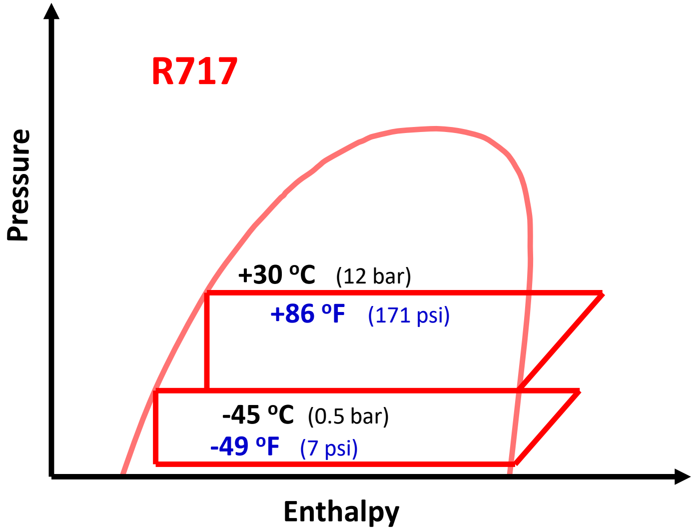


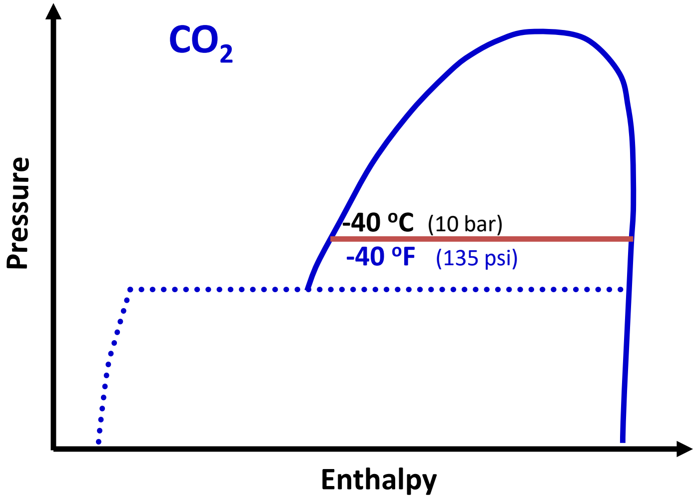


Main Diagram of Brine CO2 System

Condenser NH3 +30 ºC [+86 ºF]







Compatibility of Materials with CO2

Dry CO2 is very inert and compatible with the following materials:

- Copper
- Coal Steel
- Stainless steel
- Aluminum

Compatibility of Materials with CO2

- **Copper**
  - It does not undergo embrittlement even at very low temperatures
  - Some resistance limits (sufficient for applications of 0°F (-17°C) and lower)
  - Resistant to corrosion with mildly aggressive acids
  - It is recommended to use non-phosphorous alloy welding.
- **Coal Steel**
  - The following must be taken into account:
    - High corrosion potential under low aggressive acid conditions.
    - Fragilization at low temperatures
  - Not recommended

Compatibility of Materials with CO2

- **Stainless Steel**
  - **It does not suffer embrittlement even at very low temperatures.**
  - **Resistance is sufficient for all applications**
  - **Resistant to corrosion with all types of acids**
  - **The most recommended for industrial evaporators**
- **Aluminum**
  - **Resistance and stress generally limited by internal dimensions**
  - **The pressure must be handled very carefully**

Comparison of CO2 Materials

MAX. PERMISSIBLE WORKING PRESSURE FOR TUBES UNDER INTERNAL PRESSURE

(CALCULATIONS BASED ON ASME SECCION VIII, 2002 ADDENDA, UG-27)

Tube Diam (in)	Tube Wall (in)	Tube Material	Corrosion Allowed, (in)	Max. Working Pressure Allowed, BAR (P)	Max. Working Pressure Allowed, PSIG (P)	Max. Tension Allowed (PSI) (S)
7/8	0.028	304L SS	0.002	51	738.2	14200
7/8	0.049	SA-179 Carbon	0.002	88	1284.7	13400
7/8	0.065	3003 Alum	0.002	31	443.7	3400

Conclusion: The stainless steel tube is the most suitable to operate with CO2 refrigerant

CO2 Pressure Comparison

Table No 1

Saturation Pressure vs. Temperature							
CO2 vs Ammonia							
			Amonnia			CO2	
Temperature			Pressure			Pressure	
° F	° C		psia	bar		psia	bar
-60	-51.1		6	0.4		95	6.5
-40	-40.0		10	0.7		146	10.0
-20	-28.9		18	1.3		215	14.8
0	-17.8		30	2.1		306	21.1
20	-6.7		48	3.3		422	29.1
40	4.4		73	5.1		568	39.1
60	15.6		108	7.4		748	51.6

CO2 Pressure Comparison

ASHRAE Std 15

- **Section 9.2.6 When a refrigeration system uses Carbon Dioxide refrigerant (R744) as a heat transfer fluid, the minimum design pressure shall comply with the following:**
  - **9.2.6.1 in a non-compressor circuit, the design pressure shall be at least 20% greater than the saturation pressure corresponding to the hottest part of the circuit.**
  - **9.2.6.2 In a cascade system, on the high side the design pressure must be at least 20% greater than the maximum pressure delivered by the pressurizing element, and on the low side the pressure must be at least 20% greater than the saturation pressure corresponding to the hottest part of the circuit.**

CO2 Pressure Comparison

Table No 2

Minimum Design vs. Temperature Pressure					
CO2 Evaporators					
			Minimal Design		
Temperature			Pressure		
° F	° C		psia	psig	bar
-60	-51.1		113	99	7.8
-40	-40.0		175	160	12.1
-20	-28.9		258	243	17.8
0	-17.8		367	352	25.3
20	-6.7		505	492	34.9
40	4.4		681	666	47
60	15.6		897	883	61.9
80	26.7		1070*	1055*	73.8*

*Exceeds the critical pressure of CO2, so pressure of design chosen is equal to the critical pressure

CO2 Pressure Comparison

Table No 3

Minimum Tube Wall Thickness vs Temperature Chamber (ASHRE Std 15)							
CO2 Evaporators							
Room Temperature		**Min. Tube Wall Thickness, in.**					
		Copper Tube SB-75			**Tube Diam. SA-249 304 SS**		
° F	**° C**	**3/8"**	**1/2"**	**5/8"**	**3/8"**	**1/2"**	**5/8"**
-60	-51.1	0.010	0.010	0.010	0.010	0.010	0.010
-40	-40.0	0.010	0.011	0.013	0.010	0.010	0.010
-20	-28.9	0.012	0.015	0.018	0.010	0.010	0.012
0	-17.8	0.016	0.020	0.025	0.011	0.015	0.017
20	-6.7	0.022	0.028	0.034	0.015	0.021	0.024
40	4.4	0.027	0.035	0.043	0.020	0.027	0.032
60	15.6	0.036	0.046	NR	0.026	0.036	0.041
80	26.7	NR	NR	NR	0.031*	0.042*	0.048*

* Critical pressure used to determine Maxima Job Prsesion

CO2 Pressure Comparison Conclusions

- Evaporators with CO2 will operate at a significantly higher pressure than with ammonia.
- ASHRAE Std 15 sets the design pressure required for CO2 systems.
- ASHRAE Std 15 requires that the design pressure of CO2 evaporators "be at least 20% greater than the saturation pressure of the hottest section of the circuit".
- Respect the minimum wall of the pipe shown in Table 3. Remember that the pressure of all coil components, including manifolds, and pipe connections, should be designed correctly.

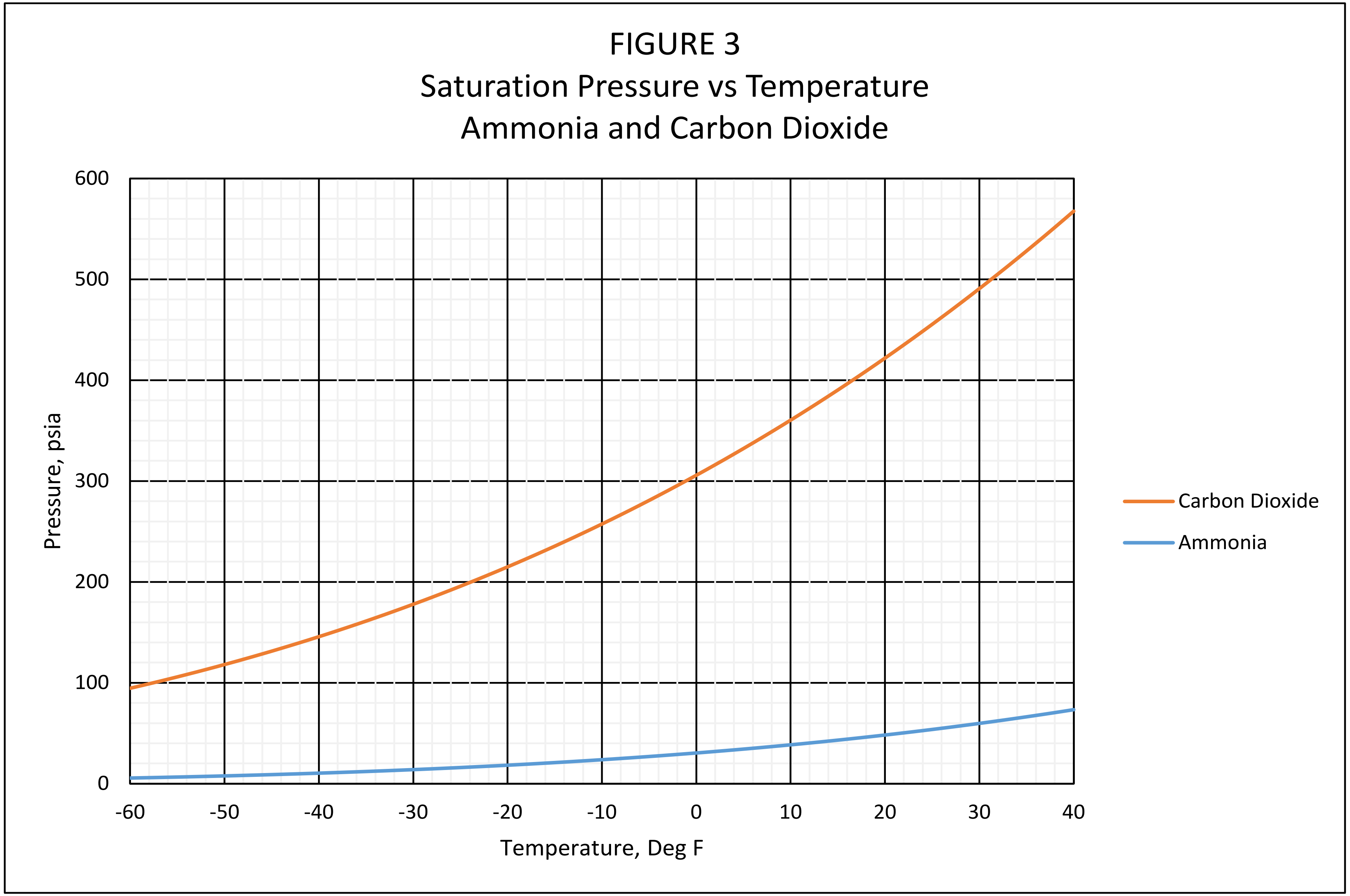
CO2 Pressure Comparison Conclusions

- **The temperature used to establish the design pressure must be carefully selected taking into account conditions, which include:**
  - Starting conditions
  - Peak loads during operation
  - Abnormal loads (process temperature variations)
  - Conditions to frequent states of “Standby”
    - Power outages that can occur frequently
    - Out of operation during cleaning

CO2 Heat Transfer

- For the same mass flow and evaporation temperature, ammonia produces a much higher (200% to 300%) coefficient of heat transfer compared to CO2.
- Fortunately, the steeper slope of the CO2 vapor pressure curve allows circuits to be designed with much greater mass flow (longer circuit length).
- This causes the heat transfer coefficient for the CO2 back to the point that the yield is almost equivalent to ammonia.

CO2 Heat Transfer



CO2 Heat Transfer

Table No 4

Delta P / Delta T vs Saturation Temperature					
		Ammonia		**CO2**	
Temperature		**Delta P/Delta T**		**Delta P/Delta T**	
° F	**° C**	**psi/Gr F**	**kPa/Gr C**	**psi/Gr F**	**kPa/Gr C**
-60	-51.1	0.184	2.3	2.157	26.8
-40	-40.0	0.309	3.8	2.980	37.0
-20	-28.9	0.489	6.1	3.973	49.3
0	-17.8	0.735	9.1	5.143	63.8
20	-6.7	1.059	13.1	6.510	80.8
40	4.4	1.470	18.2	8.100	100.5

CO2 Heat Transfer

- **Typically, manufacturers design the length of the circuit to produce a pressure drop corresponding to about 1.8°F at the evaporation temperature.**
- **Using the pressure drop in the curve from Table 4 to -20°F:**
  - **Ammonia Delta P = 1.8 °F x 0.489 psi /° F = 0.88 psi**
  - **CO2 Delta P = 1.8° F x 3.973 psi / °F = 7.15 psi**

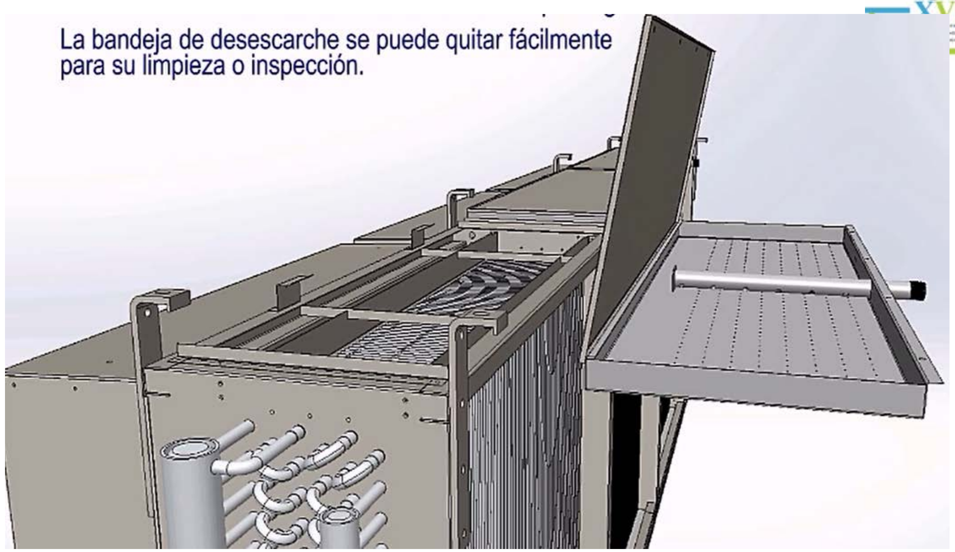
CO2 Heat Transfer Conclusions

- CO2 evaporators should be designed for greater mass flow and pressure drop compared to ammonia. This is reflected in more circuits in the coil.
- If properly circuited, an evaporator operating with CO2 will have the cooling capacity equivalent to that of ammonia, i.e. CO2 does not penalize performance.

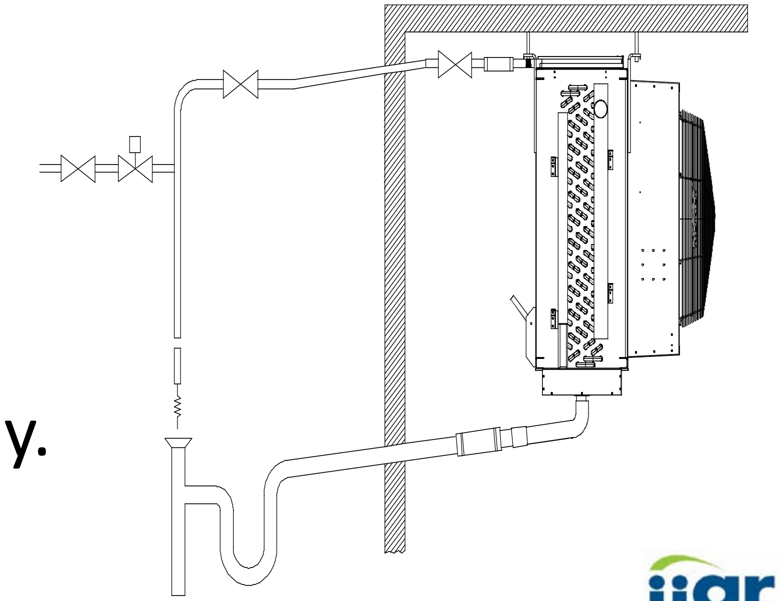
Defrosting CO2 Evaporators

- The most commonly used methods for defrosting evaporators are:
  - Air
  - Water
  - Electric
  - Warm Glycol Circuit
- Hot Gas is not used because of the very high pressures required (50 bar / 710 psig)

Defrosting CO2 Evaporators

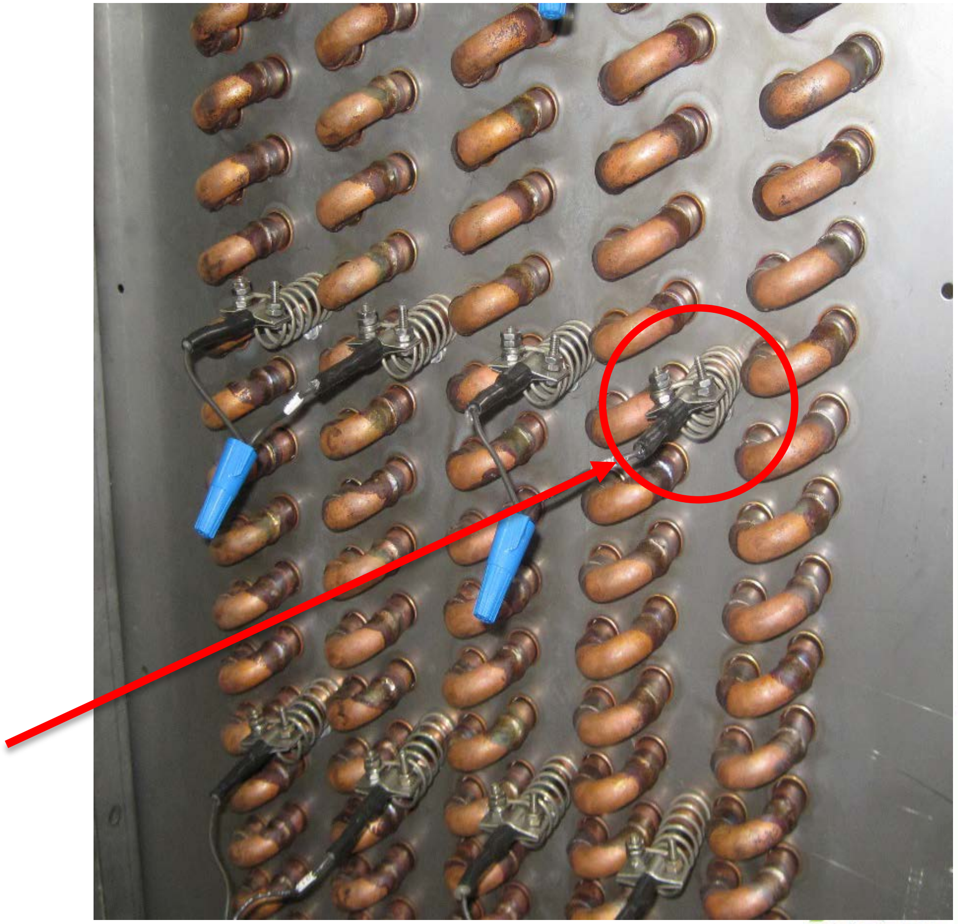


- **Water**
- **The most used method**
  - – Simple
  - – Operates at any temperature
  - – Very fast
  - – Cabinet design and coil tray to mop up splashing
  - – Use of motorized ball valves!
  - – Common use of water from the condenser tray.



Defrosting CO2 Evaporators

- **Electric**
  - Simple to apply and install
  - Wiring can be expensive
  - Higher cost operation
  - Longer thawing
  - Caution to prevent overheating of the coil tubes.
  - The position of the heaters in the coil is transcendental
  - Alerts with elongation of the heating rods



Defrosting CO2 Evaporators

- **Warm Glycol Circuit**
  - Initial cost high by including an independent circuit in the coil.
  - It involves the installation of a glycol circuit to the whole system, including pumps and tanks.
  - Careful maintenance and high cost of glycol.
  - Prolonged thaw cycles.

Thank You!