“Two World-First Projects, Application of Evaporative Condenser/Gas Cooler at Windsor for NSW Department of Justice & Kuala Lumpur for Asia Marine Products”

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Figure 1 – Relative Volumetric Efficiencies of a Reciprocating Compressor Comparing CO_2, R22 and NH_3.

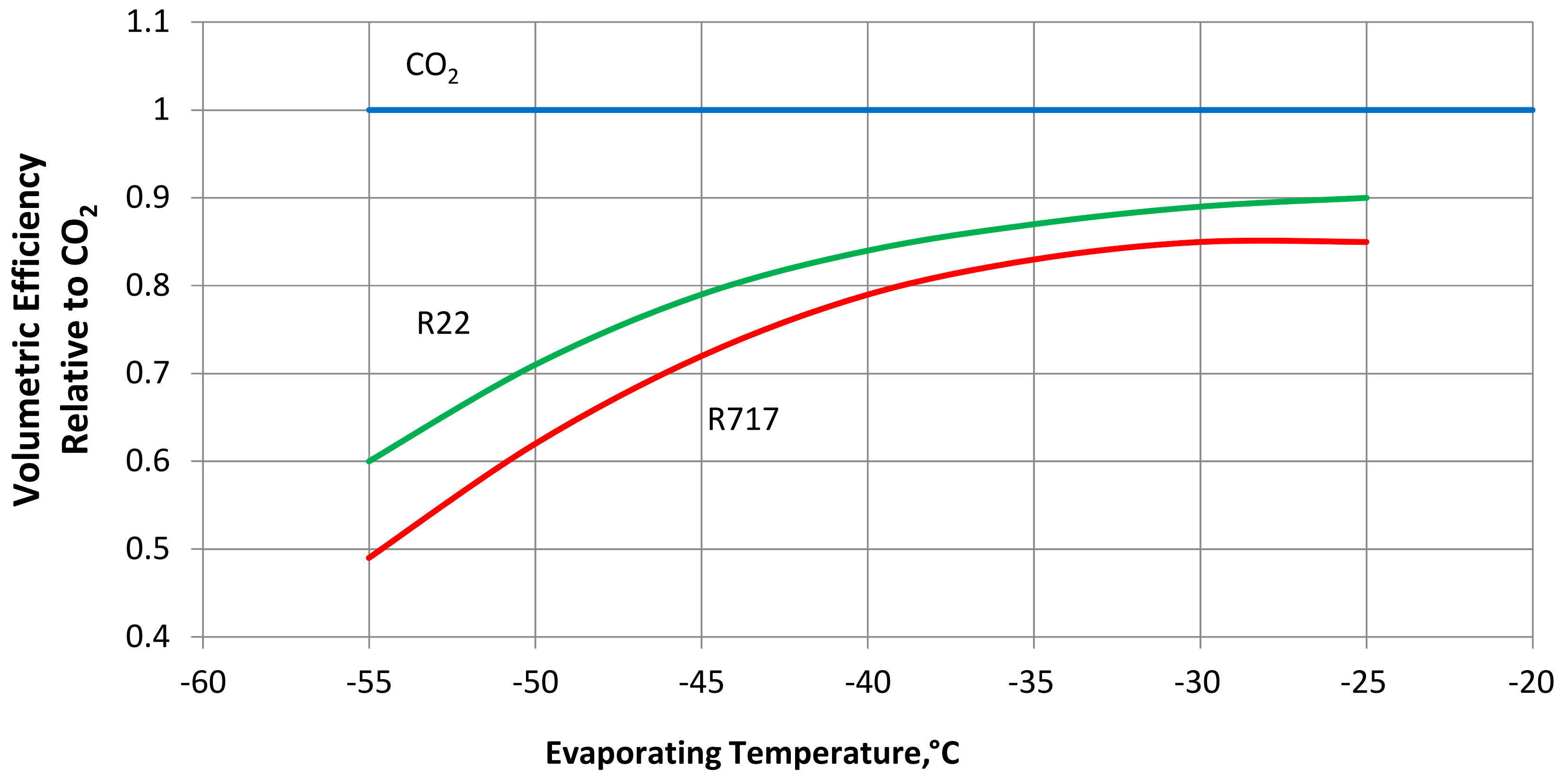

Figure 2 – Relative Isentropic Efficiencies of a Reciprocating Compressor Comparing CO_2, R22 and NH_3.

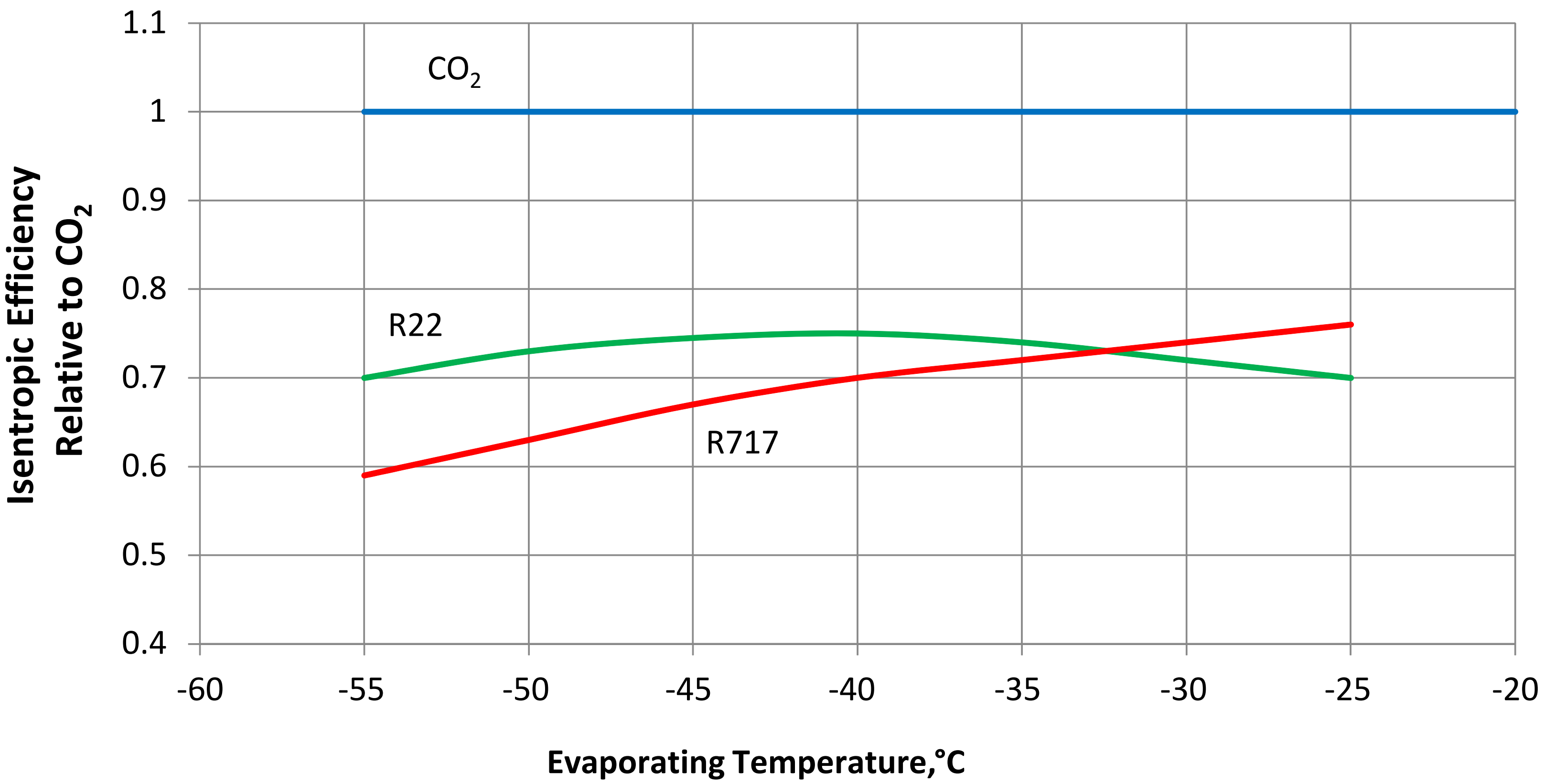

Figure 3 – Overall Heat-Transfer Coefficient of an Air-Cooling Evaporator Operating with R22 and CO_2.

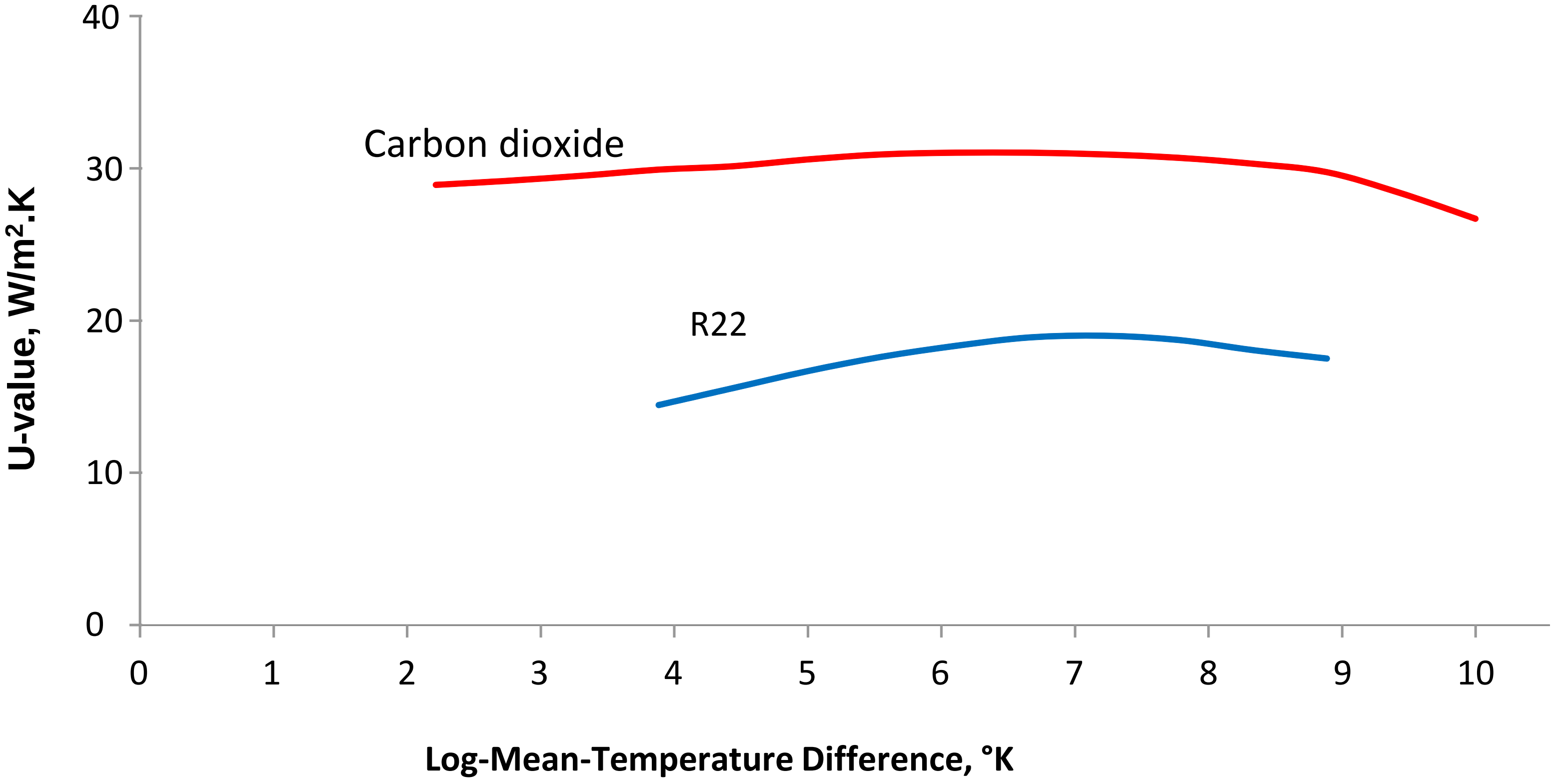

Figure 4 – Raw COP and Discharge Temperature Variation with Gas Cooler Exit Temperature at 0°C SST & 10 K SSH at 75 to 120 Bar Discharge.

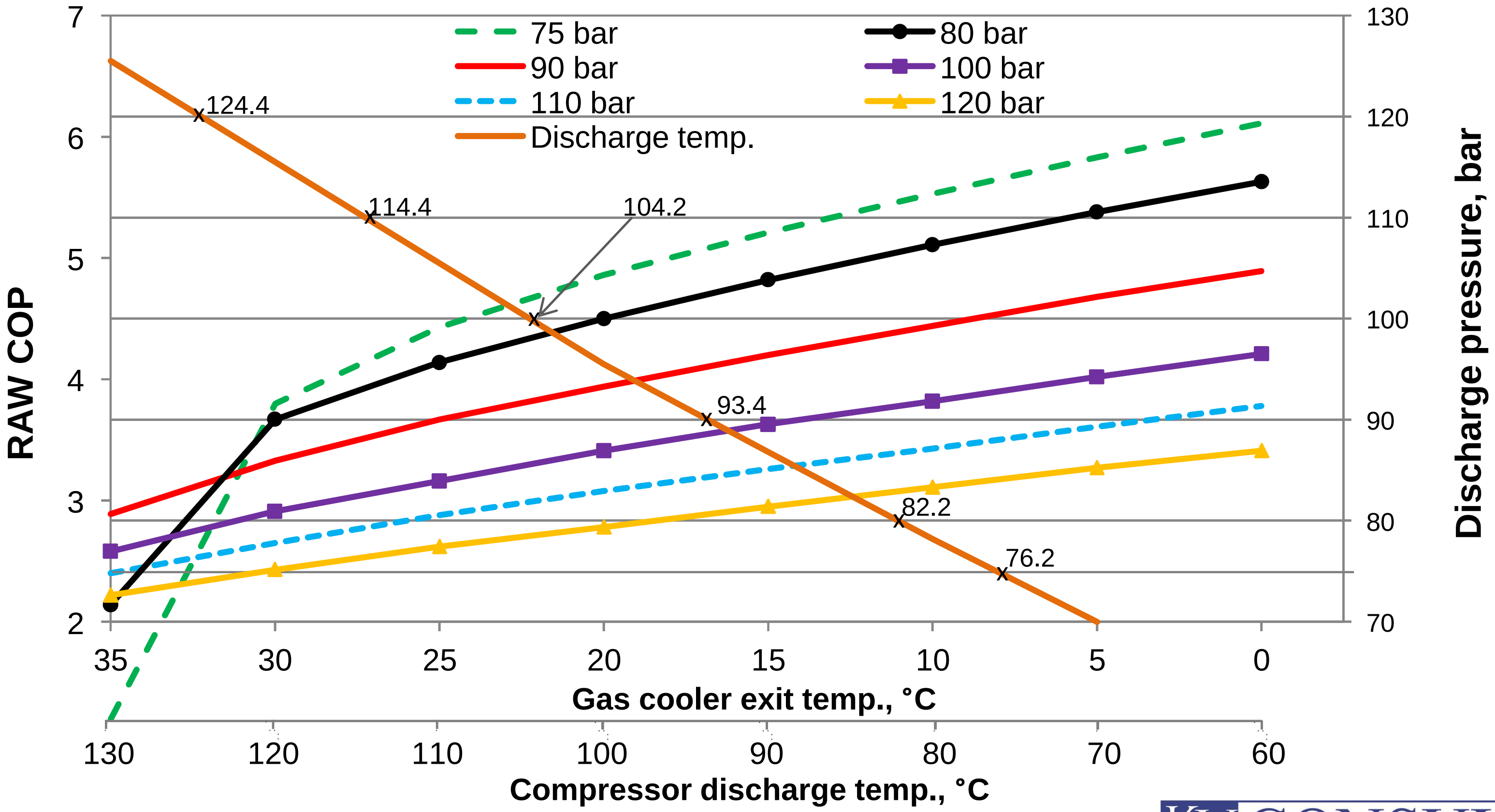

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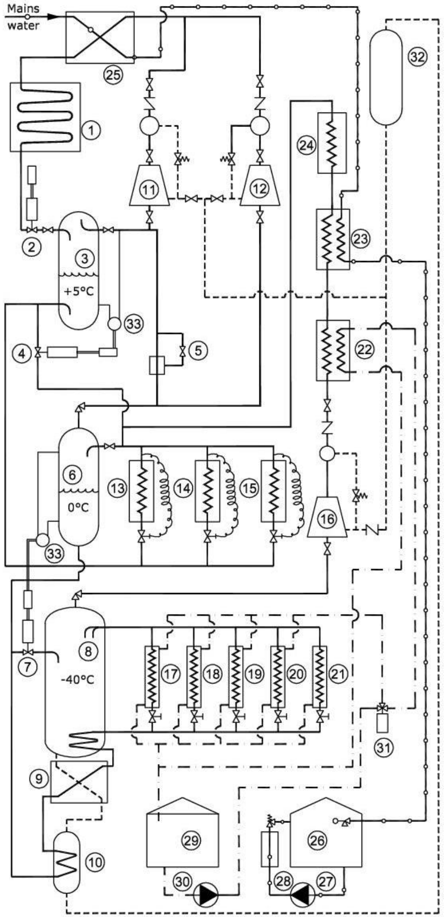
Figure 5 - Simplified CO_2 Refrigerating System



Legend	
1	Hybrid CO_2 gas cooler/evaporative condenser
2	Compressor discharge pressure regulator
3	+5°C 1st stage expansion vessel
4	2nd stage expansion to interstage
5	Back pressure regulator
6	0°C intercooler/Hi stage suction trap
7	3rd stage expansion from 0 to −40°C
8	−40°C suction trap
9	Oil still heat exchanger
10	Oil drain vessel
11	Parallel compressors
12	High stage compressors
13	Work Area evaporators
14	Fresh make-up air coolers
15	Process Area and AC evaporators
16	Booster compressors
17-19	Cold Store evaporators
20	Blast freezer evaporator
21	Transfer Area evaporator
22	Defrost glycol heater in booster discharge
23	2nd stage water heater in booster discharge
24	Transfer Area reheat in booster discharge
25	1st stage water heater
26	Potable hot water tank
27	Hot water circulating pump
28	Hot water consumers
29	Defrost fluid tank
30	Defrost fluid circulating pump
31	Glycol diverting valve to heating or evaporator defrost
32	Compressor oil reservoir
———	CO_2 lines
–◦–◦–	Potable water from main to storage tank
– – –	Temper −55 defrost fluid
-------	Compressor oil recovery & re-use

Guidelines for Industrial Two Stage Transcritical CO_2 Refrigerating Systems with Water Heating

.1 Operating Conditions

.1 75 – 100 bar discharge pressure.

.2 1st expansion stage to +5°C for 0°C DX operation and parallel compression @ +5°C suction.

.3 2nd expansion stage +5 to 0°C for −5°C chiller DX operation/pumped liquid – high stage compressors.

.4 3rd expansion stage from 0°C to −30°C to −40°C for cold store DX and pumped freezing systems.

.2 Compression Stages

.1 Parallel compression @ +5°C suction to gas cooler.

.2 High stage compression @ −5°C suction to gas cooler, including load from 0°C suction evaporators via back pressure regulator.

.3 Low stage compression @ −30 to −40°C suction to −5°C intercooler/chilling accumulator suction trap.

Refrigerant Control

.1 From Gas Cooler Exit to +5°c Expansion Vessel

- .1 Maintain pre-set discharge pressure when heating water on demand.
- .2 Allow discharge pressure to float in combination with parallel compressor suction.
- .3 Feed 0°C suction DX evaporators.
- .4 Maintain constant liquid level in +5°C expansion vessel by overflow to −5°C vessel.

.2 .1 **In the case of all DX systems** the −5°C vessel is the low pressure receiver (LPR) supplying −5°C liquid to the low temperature evaporators.

- .2 In the case of −5°C suction pumped CO_2 systems the −5°C LPR is also the −5°C pump accumulator.
- .3 In the case of pumped CO_2 for blast or plate freezing maintain a constant level in −5°C by letting excess flow to the low temp. pump accumulator and then the low temp. accumulator becomes the low pressure receiver.

Compressor & Booster Selection

.1 Simple exercise once heat loads are known.

.2 Heat water and defrost fluid by booster discharge to reduce high stage heat load.

.3 Adhere to compressor manufacturer’s operating conditions.

.4 Parallel compressors are rated at SST and desirable super heat and discharge pressure/gas cooler exit temperature.

.5 High stage machines rated at SST and desirable super heat at desirable discharge pressure. The gas cooler exit temperature is the liquid feed temperature to the parallel compressor.

.6 Unless heating water, allow discharge pressure to reduce to the lowest possible level allowed by manufacturer.

.7 Presently only limited size compressors are available.

Pipe & Pressure Vessel Sizing

Pipe Sizing

.1 Suction and wet return piping diameters area bout 50% of the diameter of ammonia piping at the same temperature and the same capacity.

.2 Liquid piping is more complicated. Once CO_2 mass flows are established it is easy to determine the volume flows. When flows are known pipe sizes may be determined using water pipe pressure loss tables.

Pressure Vessel Sizing – Separation Velocities and Surge Volumes

.1 Medium temperature vertical suction separators @ +5°C to −5°C
0.12 to 0.15 metres/second separation velocities.

.2 Low temperature vertical suction separators @ −30°C to −40°C
0.18 to 0.23 metres/second separation velocities.

.3 Suction traps on DX systems 0.23 to 0.3 metres/second plus impingement and change of direction.

.4 Surge and free volumes – each requires 50% of operating charge volume.

.5 Liquid receivers – 80% of volume must hold entire CO_2 system charge.

Air Cooler Evaporators

DX Operations Preferred

.1 Long refrigeration circuits possible.

.2 Resulting high CO_2 mass velocities at low boiling point suppression.

.3 High U-factors.

.4 Reduced depth in direction of air flow.

.5 Saves fan energy and resulting parasitic refrigeration loads.

.6 Easy to multi-circuit with highly variable refrigeration loads; beef chillers, pressure cooling.

.7 Easy, reliable oil separation and recycling back to compressors.

Oil Recovery

.1 Employ the best oil separation technology on all compression stages. Prevention is much better than curing.

.2 In multi-stage systems oil will finish up in the suction of the Low Temperature (LT) suction trap.

.3 In the case of all DX systems the oil is trapped in the LT suction trap installed at a high level.

.4 The oil is drained into an oil collection vessel via a Plate Heat Exchanger heated by interstage CO_2 liquid. Oil is transferred automatically to an oil storage vessel.

.5 In the case of pumped CO2 system an oil still is required by evaporating low temperature liquid heater by +5°C liquid flowing to the −5°C high stage.

BENEFIT – Liquid subcooling between +5°C & −5°C .

DISADVANTAGE – Increased evaporator load on boosters. Therefore, ensure to evaporate only enough low temperature liquid to ensure a balanced oil content in the system.

Liquid Pump Selection

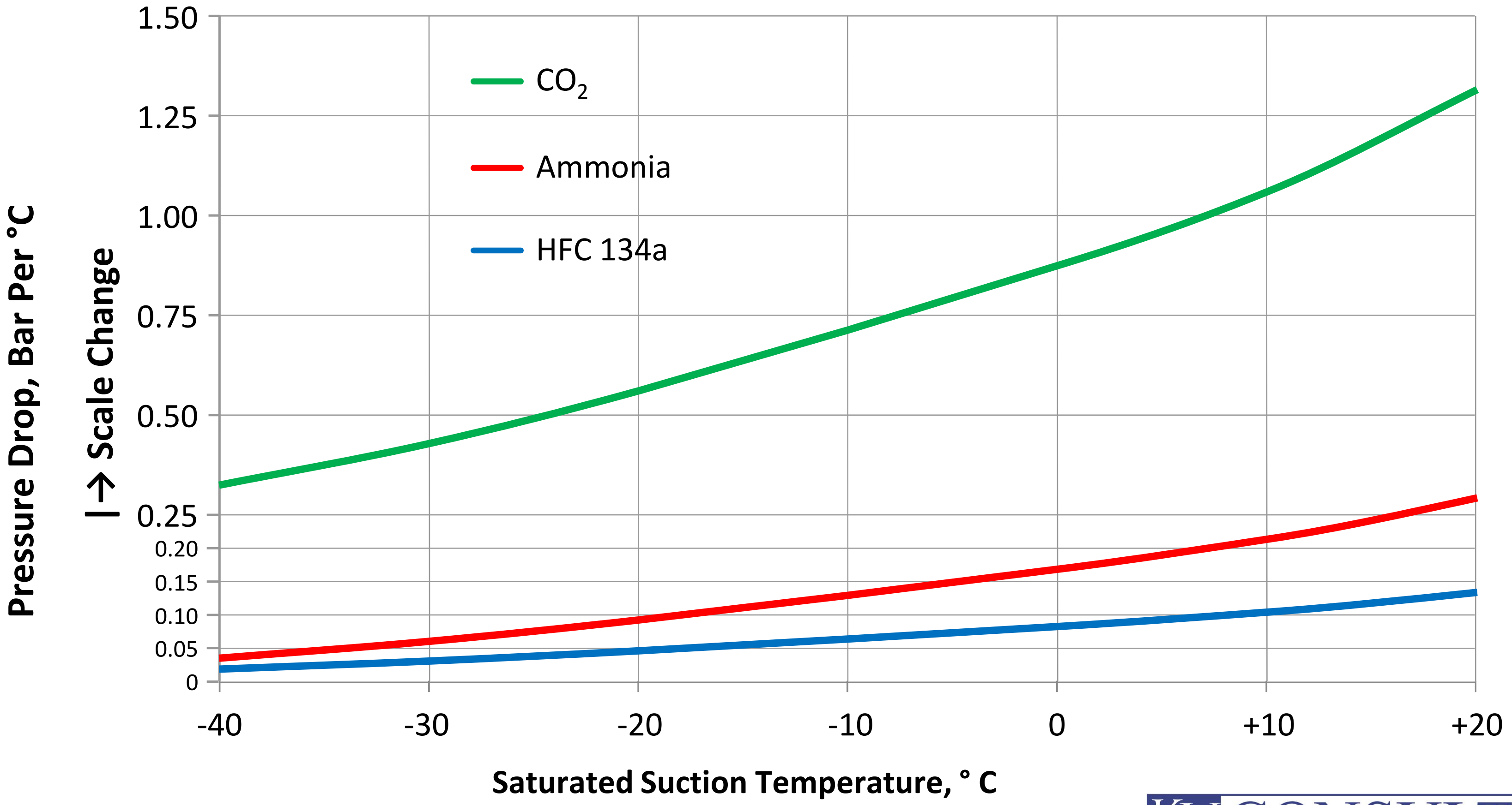
.1 Limited to plate freezing only for preference.

.2 Should be avoided where back pressure regulators are used because of the high pressure drop per degree Celsius lift in evaporating temperature.

.3 Low latent heat capacity requires high to very high pumping rates requiring large piping, even at moderate overfeed rates.

.4 Items .2 and .3 above result in high liquid pump energy consumption and thus a high parasitic refrigeration load.

Figure 6 - Pressure Drop Per °C Boiling Point Suppression for CO_2, Ammonia and R134a.



Defrosting

Basically Three Methods

.1 Hot gas from high pressure boosters condensing at 45 to 51 bar (+10 to + 15°C SCT.

.2 Conventional electric defrost – highly energy intensive.

.3 Warm heat transfer fluid (glycol, Temper, Tyfoxit 1.25) circulated through a tubular circuit installed in lieu of electric heating elements. Very rapid defrost and highly energy efficient.

Defrost fluid must be compatible with food in food processing plants.

Conclusions

.1 CO_2 refrigeration is applicable to all refrigeration duties from refrigerators, through cold storage and food processing plants to AC cooling & heating up to and including District Cooling and Heating systems.

.2 Further development depends on successful demonstration of technology and the availability of large compressors. Easiest source converted high pressure multi-stage compressed natural gas (CNG) compressors.

.3 Combined heating and cooling enhances energy efficiency in the built environment – homes, hospitals, hotels, office buildings, supermarkets – AC, heating, hot water.

Evaporative Condenser Manufacture for Sydney Project.

Figure 7 - Assembly of Condensing Tube Bundle. Twelve/Condenser.

Figure 8 - Welding CO_2 Inlet Connection

Evaporative Condenser Manufacture for Sydney Project.

Figure 9 - Condenser Housings

Figure 10 - Testing Condensing Tube Bundle @ 170bar with Dry Nitrogen.

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Questions?

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Thank you very much!