NTNU
Norwegian University of Science and Technology

CoolFish Workshop

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Natural Refrigerants

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Working fluids - history

1930 * Use of natural working fluids – ethyl ether, SO_2, methyl chloride, ammonia, propane, isobutane, **CO_2** etc.

1930-50 * Introduction of synthetic working fluids, among others **CFC12** and **HCFC22**

1987 * *Montreal protocol* established, CFC and HCFC ozone depletion due to chloride/bromine. Phasing out CFC (1995) and HCFC (2010) in Europe

1987 * Hydrogen-Fluor-Carbons (**HFC**) introduced

1997 * *Kyoto protocol* established, HFC regulated due to high GWP factor

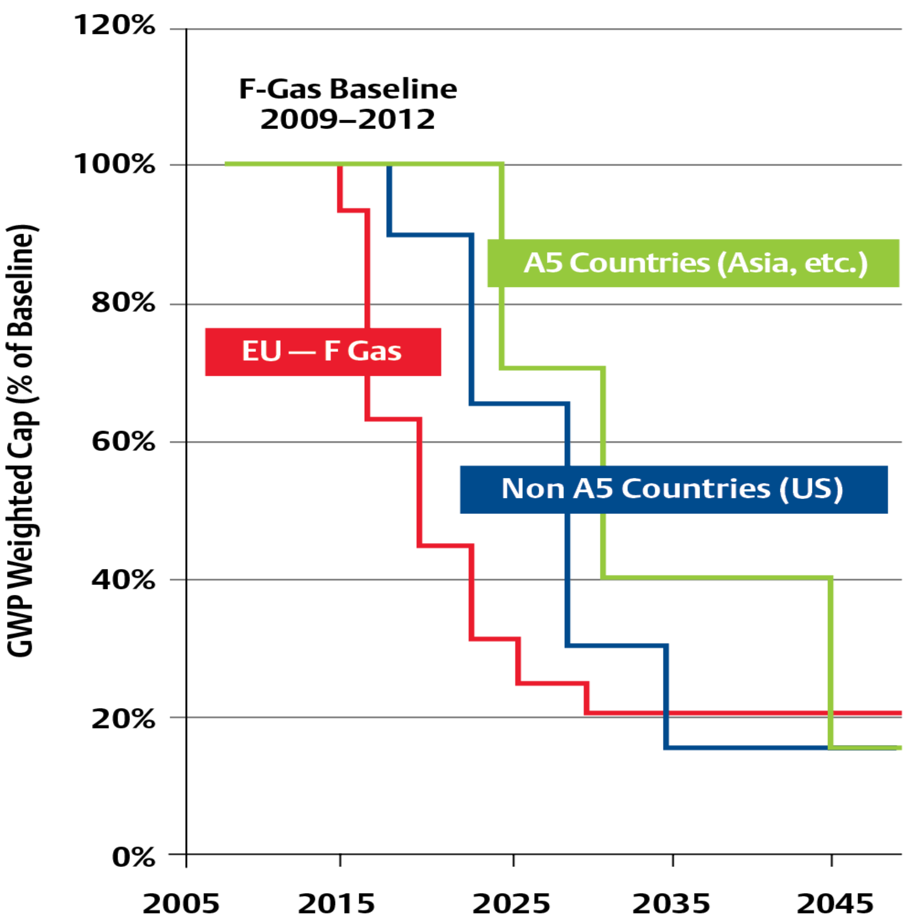
2006/2007 * EUs F-gas directive – Phase down of high GWP fluids

2016 * Kigali amendment to the Montreal protocol, global HFC phase down

1990-now * Increasing focus on use of natural working fluids, especially ammonia, hydrocarbons and **CO_2**

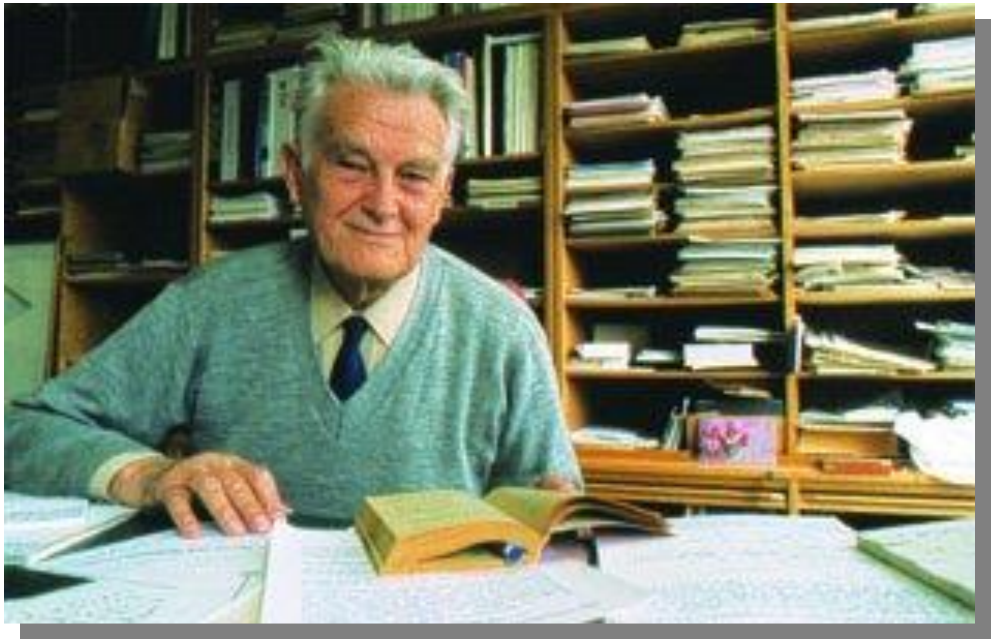
EU – F-Gas Regulation

Limitation of the amount of fluorinated greenhouse gases emitted to atmosphere



Service and maintenance bans	GWP	Timing
HFC's	2,500	Jan. 2020
'Placing on the market' (new equipment) bans		
Domestic refrigerators and freezers	150	Jan. 2015
Refrigerators and freezers for commercial use (hermetically sealed systems)	2,500	Jan. 2020
Refrigerators and freezers for commercial use (hermetically sealed systems)	150	Jan. 2022
Stationary refrigeration equipment (except equipment for temperatures below -50 °C)	2,500	Jan. 2020
Multipack centralized refrigeration systems for commercial use with a capacity of ≥ 40 kW (140 kBTU/hr) (except in the primary refrigerant circuit of cascade systems, where fluorinated greenhouse gases with a GWP of less than 1,500 may be used)	150	Jan. 2022
Movable room air-conditioning appliances (hermetically sealed equipment which is movable between rooms by the end user)	150	Jan. 2020
Single split air-conditioning systems containing < 3 kg	770	Jan. 2025

Professor Gustav Lorentzen (1915-1995)



"In the present situation, when the CFCs and in a little longer time perspective the HCFCs are being banned by international agreement, **it does not seem very logical to replace them by another family of related hydrocarbons, the HFCs,** equally foreign to nature. In any case **it must obviously** be much preferable **to use natural compounds**, which are already circulating in quantity in the biosphere and are **known to be harmless**"

(statement from 1987)

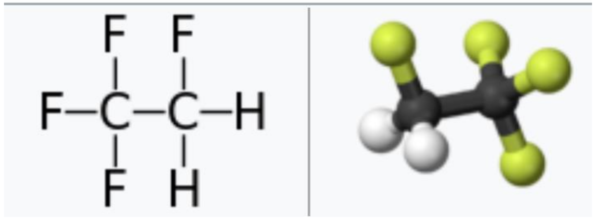
New synthetic low-GWP refrigerants (short life-time)

* **They are HFCs**, even if the chemical companies composed another name for it (**HFO**).
* **Real** Environmental **Impact**: What are the by-products when producing these fluids nowadays?
* Are these 'A2L' fluids **harmless**?
  - Short atmospheric lifetime means: <u>decomposition wherever applied</u>
  - Decomposition products?
    - Will always react with water (H_2O)

Its all about H, F and C

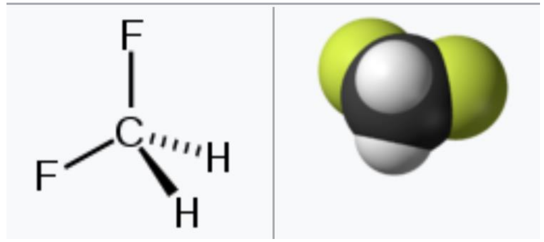
R-134a

1,1,1,2-Tetrafluoroethane



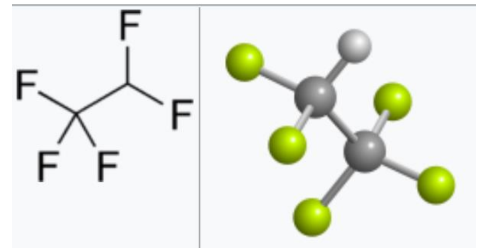
R-32

Difluoromethane



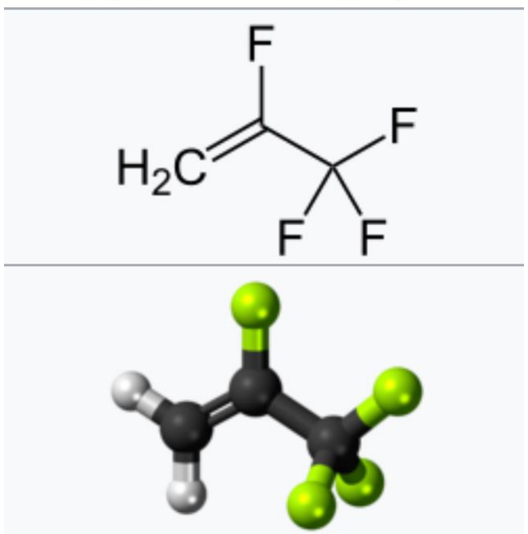
R-125

Pentafluoroethane



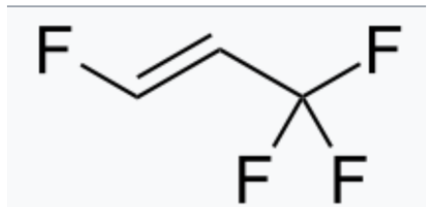
R-1234yf

2,3,3,3-Tetrafluoropropene



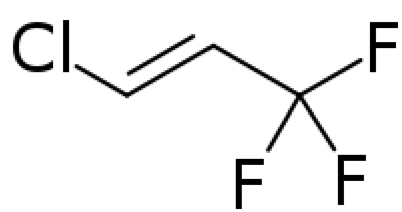
R-1234ze

1,3,3,3-Tetrafluoropropene



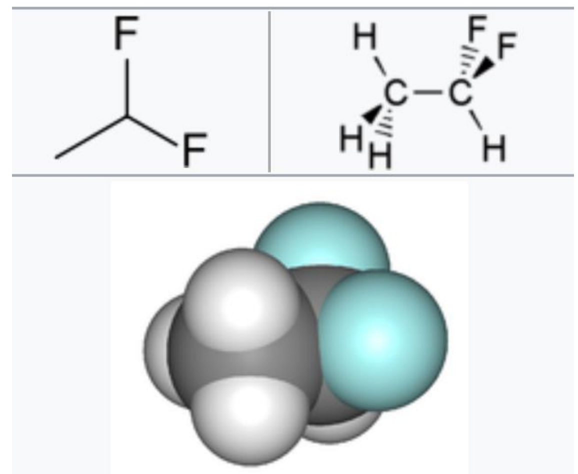
R-1233zd

1-Chloro-3,3,3-trifluoropropene



R-152a

1,1-Difluoroethane[1]

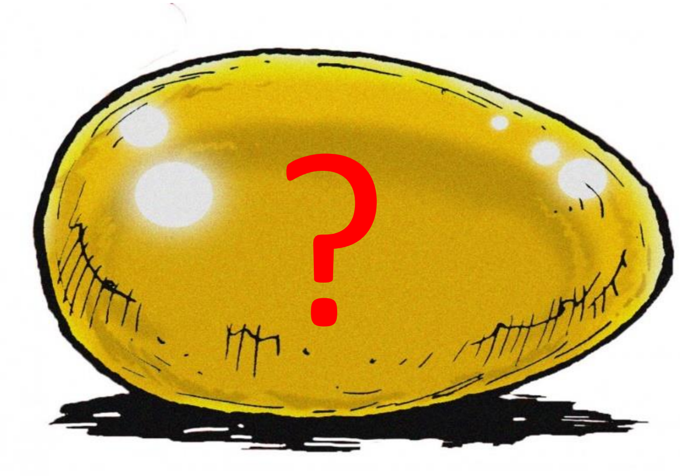


Source: Wikipedia

New synthetic working fluids with ultra low GWP due to short life span

Safety / SHE / Responsibility

* Flammability
* End user
* Service people
* Rescue people
* What is in the SHE data sheet?



New synthetic working fluids
With ultra low GWP due to short life span

What happens when the gas leaks out:

* in the machine room?
* in the workshop?
* in the service car?
* during service or installation?

Who will have the responsibility for injured people during operation and work with these fluids?

* ?

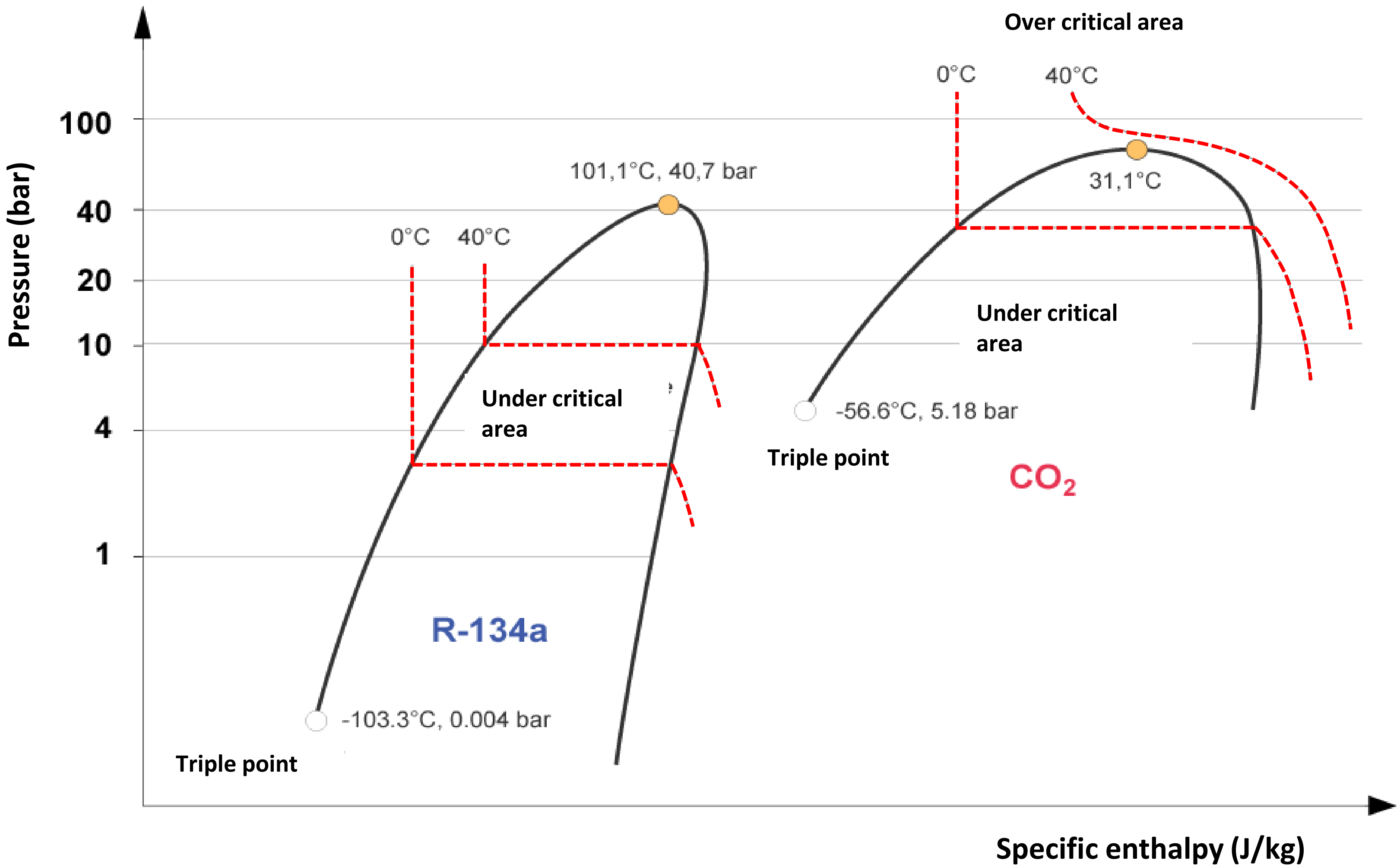
Natural Working Fluid

Natural five

* Ammonia – NH3
* Carbon dioxide – CO_2
* Hydrocarbons – HC (R290, R1270……)
* Water – (high temperatures)
* Air – (low temperatures systems)

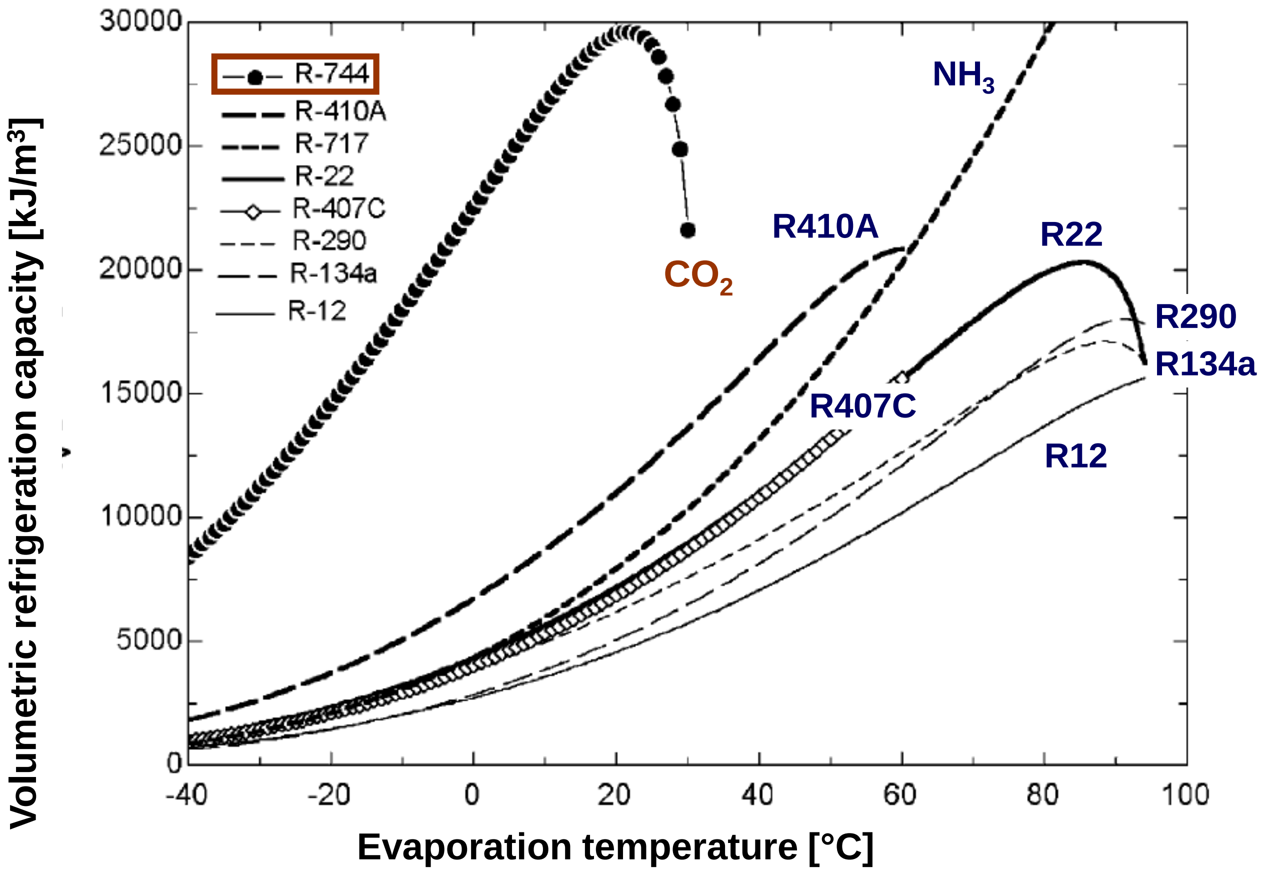
Low critical temperature

Comparing of pressure – enthalpy diagram for R134a and CO_2



Compressor stroke volume

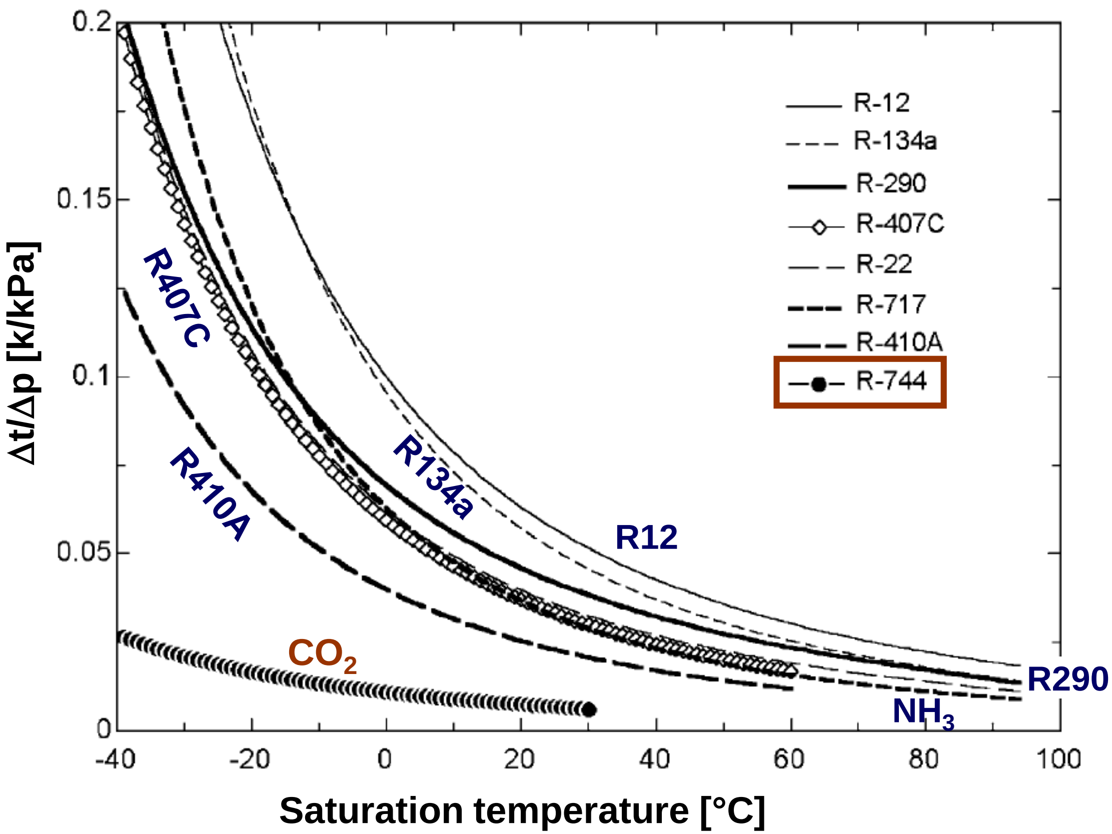
Volumetric refrigeration capacity (VRC) for different working fluids [kJ/m³]



- VRC for CO_2 is 4 to 10 times higher than for HFC and ammonia
- Use of CO_2 as working fluid gives significant lower compressor volume
- The difference in compressor volume is largest at low evaporation temperatures
- Pressure ratio is smaller resulting in higher isentropic efficiency

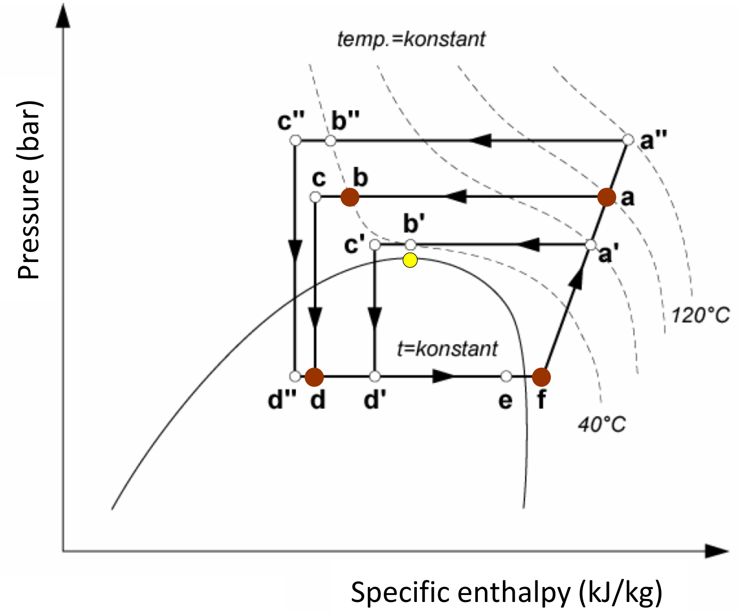
Temperature drop vs. pressure drop

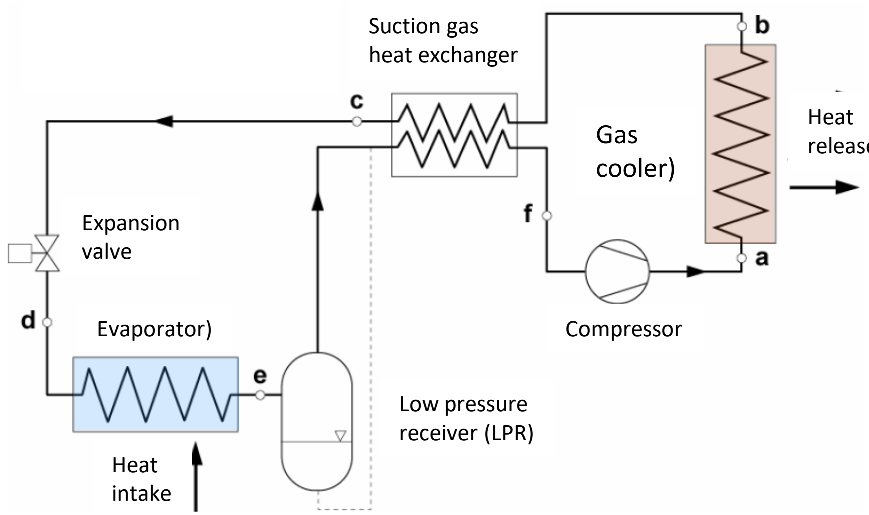
Boiling point curve *as basis – Δt/Δp [K/Pa]*



- Drop in saturation temperature at a given pressure drop (Δt/Δp) for CO_2 are 5 to 10 times lower than for HFC and ammonia
- Heat exchanger designs for a relative high pressure drop – gives high heat transfer conditions
- Pipes can be designed for giving high temperature loss relatively high velocities without

CO2 system for transcritical operation



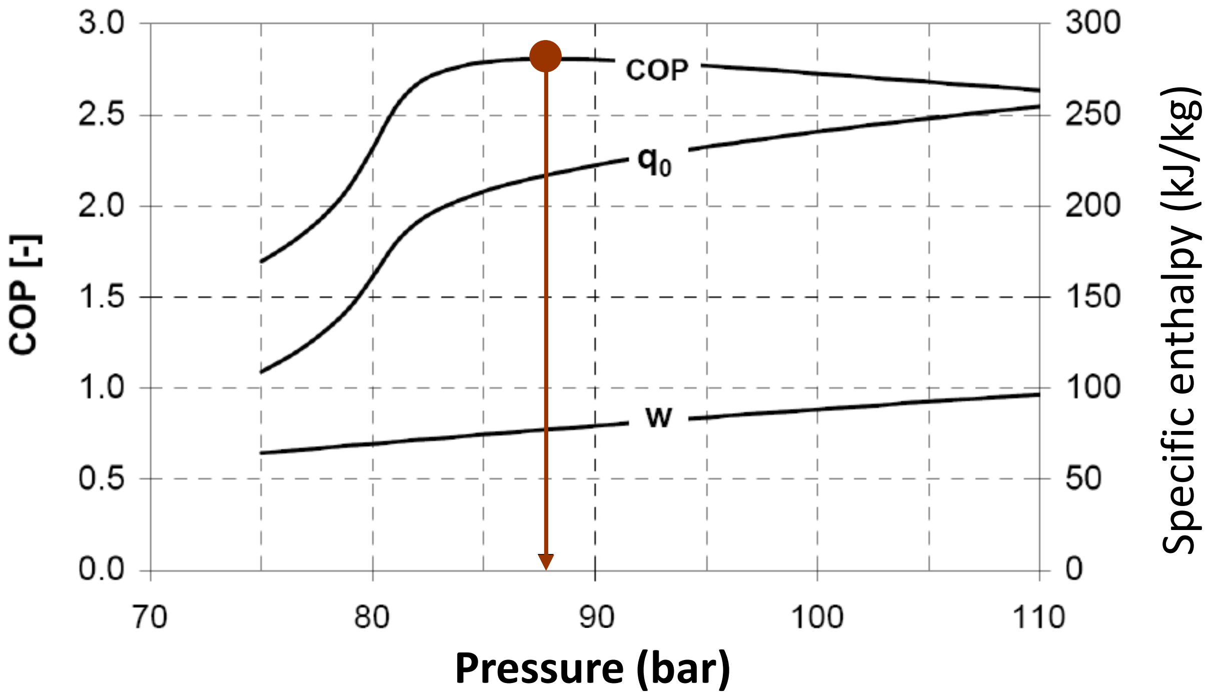


- * Process points in pressure/enthalpy diagram

  Evaporator **d-e** Compressor f-a Gas cooler **a-b** Suction gas heat exchanger **b-c** and **e-f**
- * Pressure regulation with expansion valve (open/close) and low pressure receiver (filling/emptying)
- * Suction gas heat exchanger will evaporate oil containing CO_2 liquid and secure dry condition at the entrance of compressor

Gas cooler pressure and power factor

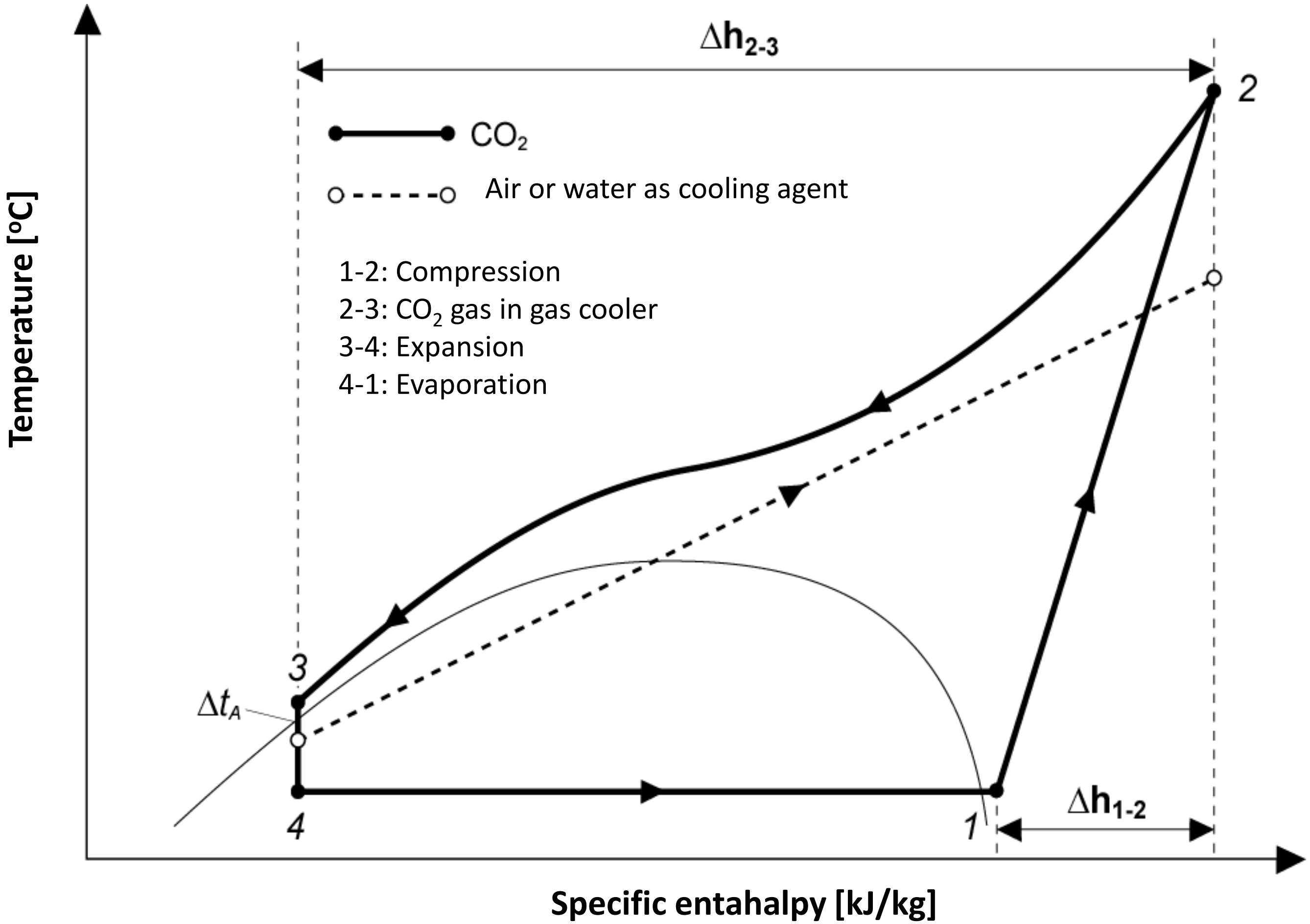
Example – optimal gas cooler pressure for CO_2 refrigeration process



- Power consumption for the compressor increases relatively linear with increasing pressure
- *The increase in refrigeration capacity will be smaller with increasing pressure*
- The CO_2 system has a optimal gas cooler pressure that gives maximum power factor (COP)

Heat release at over critical pressure

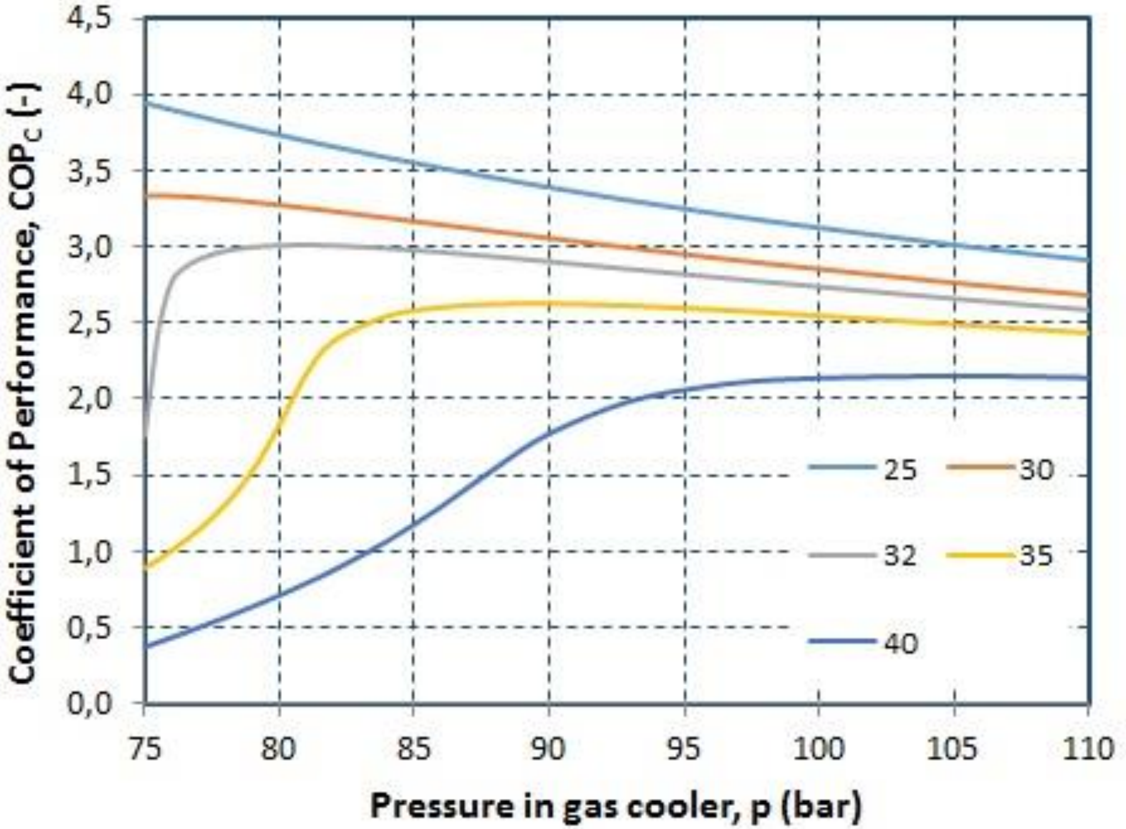
Cooling of the high pressure CO_2 gas in a gas cooler



1) Inlet compressor 2) Inlet gas cooler 3) Outlet gas cooler 4) Inlet evaporator

Gas cooler pressure and power factor

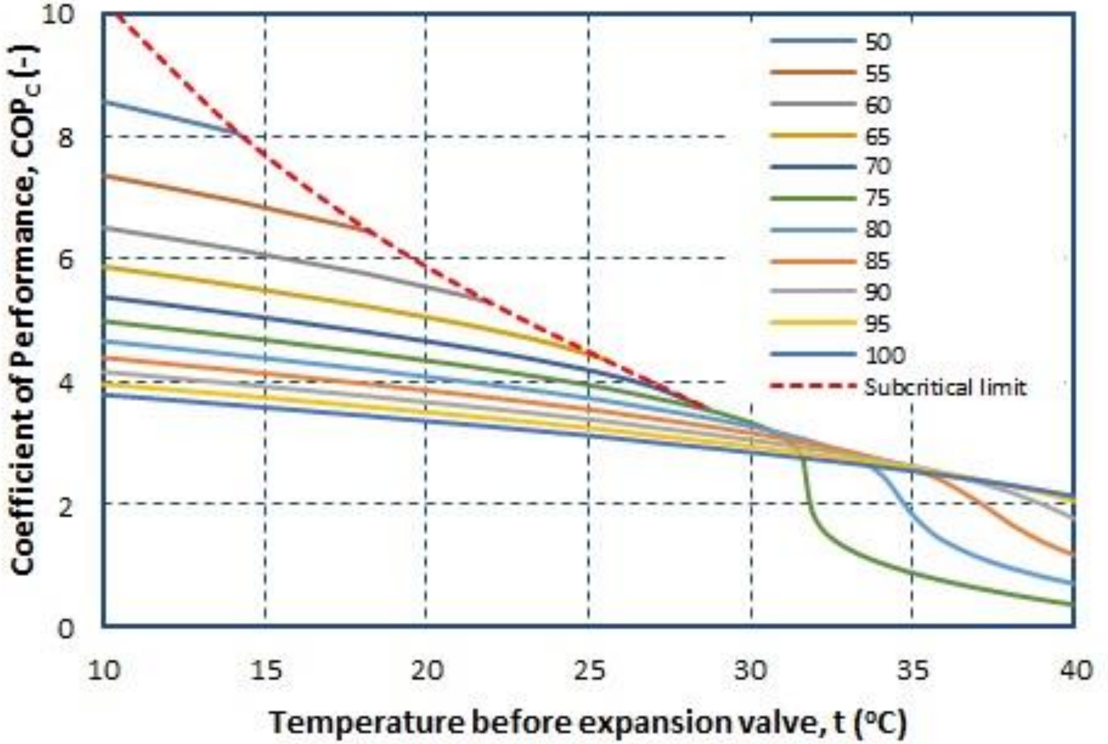
Example – power factor for a theoretical CO_2 process, t_0=-10°C



- Optimal gas cooler pressure for a theoretical process
  - Approx. 100 bar and 75 bar at respectively 40°C and 30°C CO_2 temperature after the gas cooler
- Optimal gas cooler pressure will be somewhat lower for the real CO_2 process (incl. η_{is} and λ)

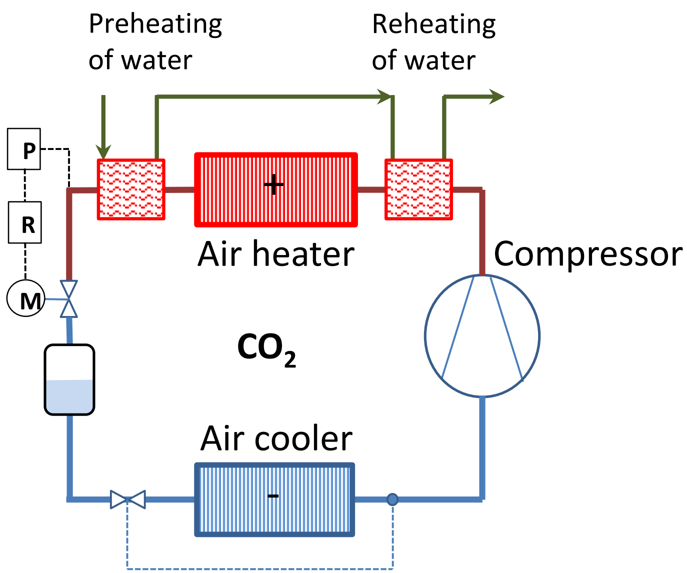
High pressure control of CO_2 systems

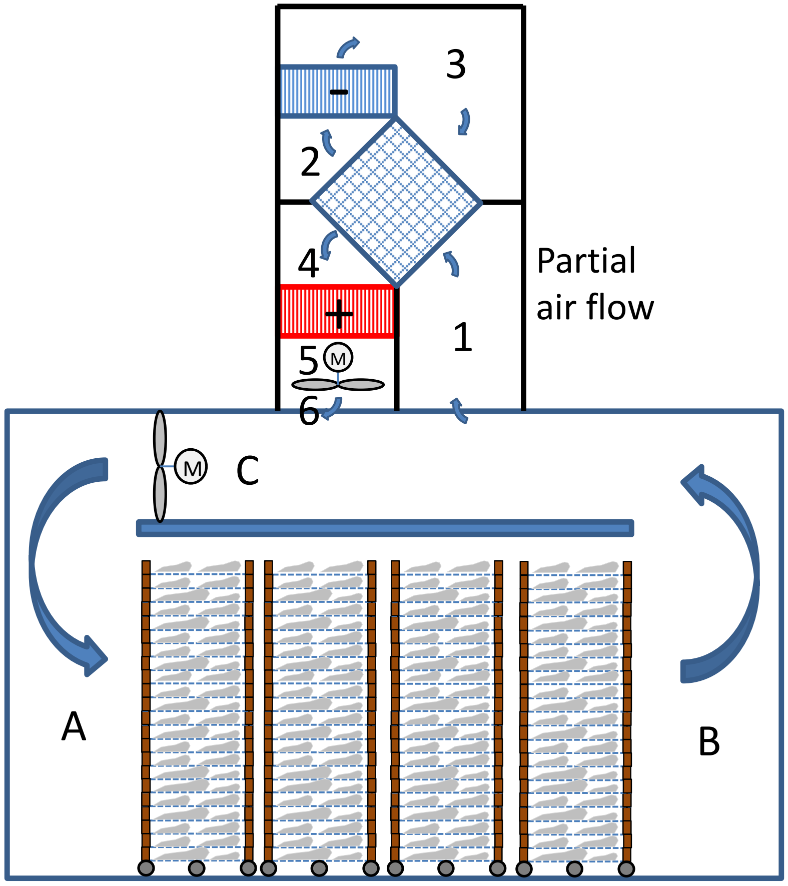
Theoretical power factor, t_0=-10°C



- Operation under sub critical pressure (condensation)
  - Dotted line – power factor at condensation without sub cooling (p_{gc}< ca. 74 bar)
  - Unbroken line – power factor at condensation and with sub cooling
- Operation at over critical pressure (gas cooler) – unbroken line at pressures > ca. 74 bar

Example: Clip fish - tunnel dryer with partial air flow conditioning and heat recovery





Drying tunnel

Conclusions

* Natural working fluids can be implemented in all applications in food/fish handling and processing
* Energy efficient CO_2 systems have been introduced in the market
* Adapted ejector technology offer high system performances and COP's in warm climate.
* Refrigeration and Heat Pumps system – energy efficient processing

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Thank you for your attention!