Low Temperature Refrigeration Technology

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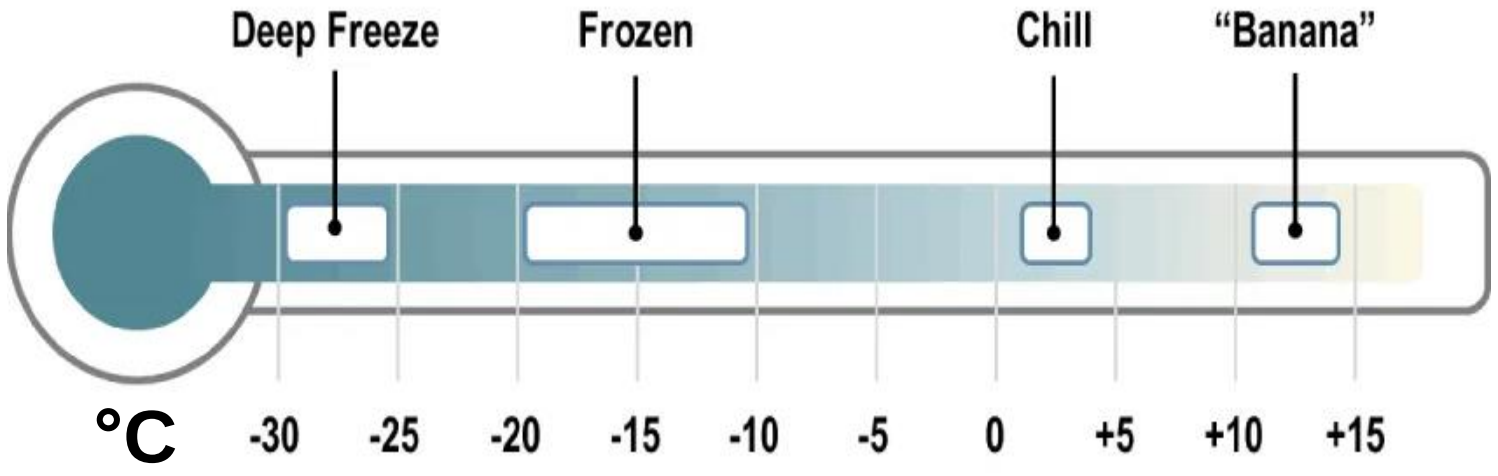
Content

- Introduction and definition of ‘Low Temperature’
- Which working fluids are applicable and energy efficient
- System architecture for low temperature refrigeration units
- Examples from industrial installations
- Summary
- Further work and possibilities (INDEE+, etc.)

Low temperature refrigeration

~ -70°C



°C	°F
100	212
90	194
80	176
70	158
60	140
50	122
40	104
30	86
20	68
10	50
0	32
-10	14
-20	-4
-30	-22
-40	-40
-50	-58
-60	-76
-70	-94
-80	-112

Required evaporation temperature of the system depends:

- **System architecture and product**
- **Freezing time and duration of storage**
- **Expected quality**

Working Fluids / Refrigerants

- McLINDEN [NIST] carried out database screenings to **identify suitable refrigerants**
- Used **PubChem database** (Kim *et al.*, 2016), i.e. more than 60 000 000 chemicals
- **Cycle calculations** (simple performance)→ fluids with low COP and/or volumetric capacity were screened out.
- The **final result** was a list of **27 fluids**; these comprised **hydrocarbons**, HFCs, HFOs, **CO_2, ammonia**, and a total of five compounds with oxygen, nitrogen and/or

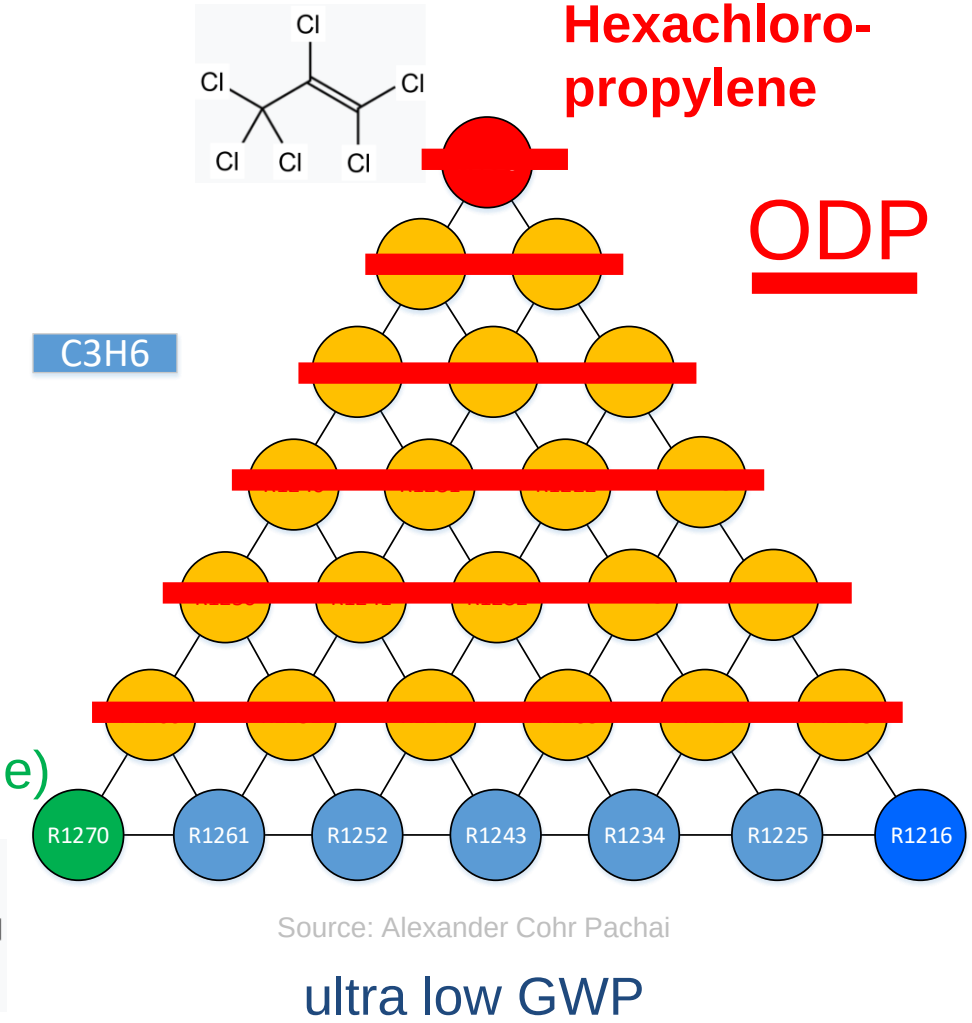
Second Conclusion:

…While a **drop-in replacement** refrigerant requiring no changes to equipment design is appealing, **the properties of low-GWP fluids will generally be different than the refrigerants they are replacing.**

Recognizing and **adapting to these differences will be required** to maximize the safety, efficiency, and reliability of new systems….

Source: Mark O. McLINDEN National Institute of Standards and Technology, Boulder, USA

Working Fluids / Refrigerants



Why focusing on

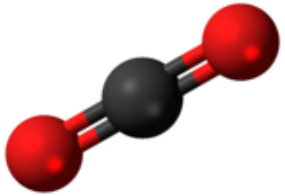
Natural Working Fluids ?

You and your customers will face no risk to invest into technologies being on the **phase out agenda** in the future

Safe & sustainable investment

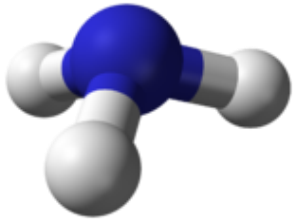
Most relevant natural working fluids

Carbon Dioxide / CO_2 / R744



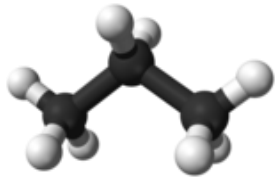
- Hot water heat pumps
- Commercial- / low temp. industrial refrigeration
- Heat pump chillers

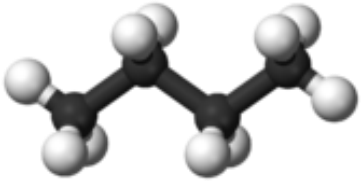
Ammonia NH_3 / R717



- Industrial refrigeration and heat pumps

Hydrocarbons (Propane, Butane, etc.) / R290, R600

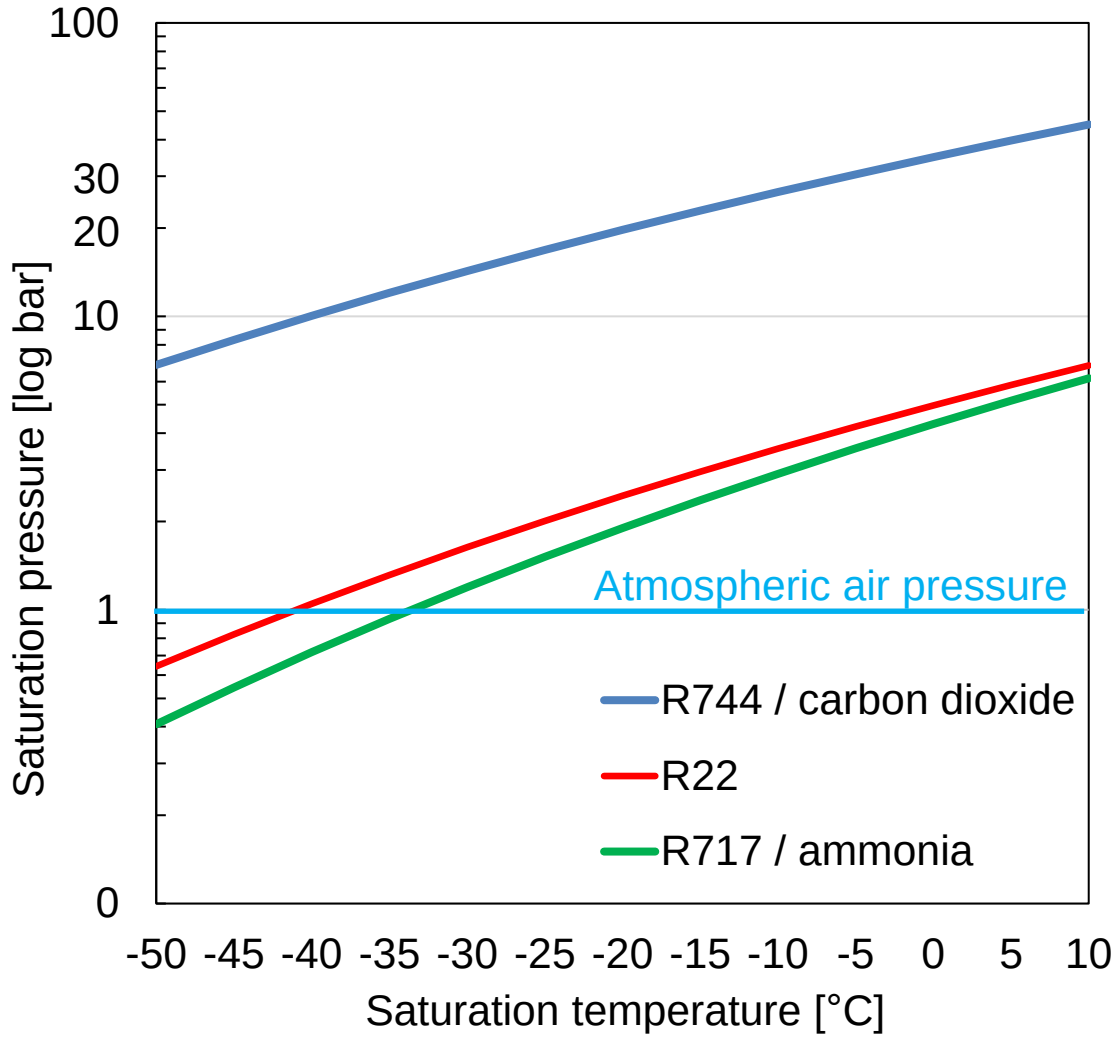




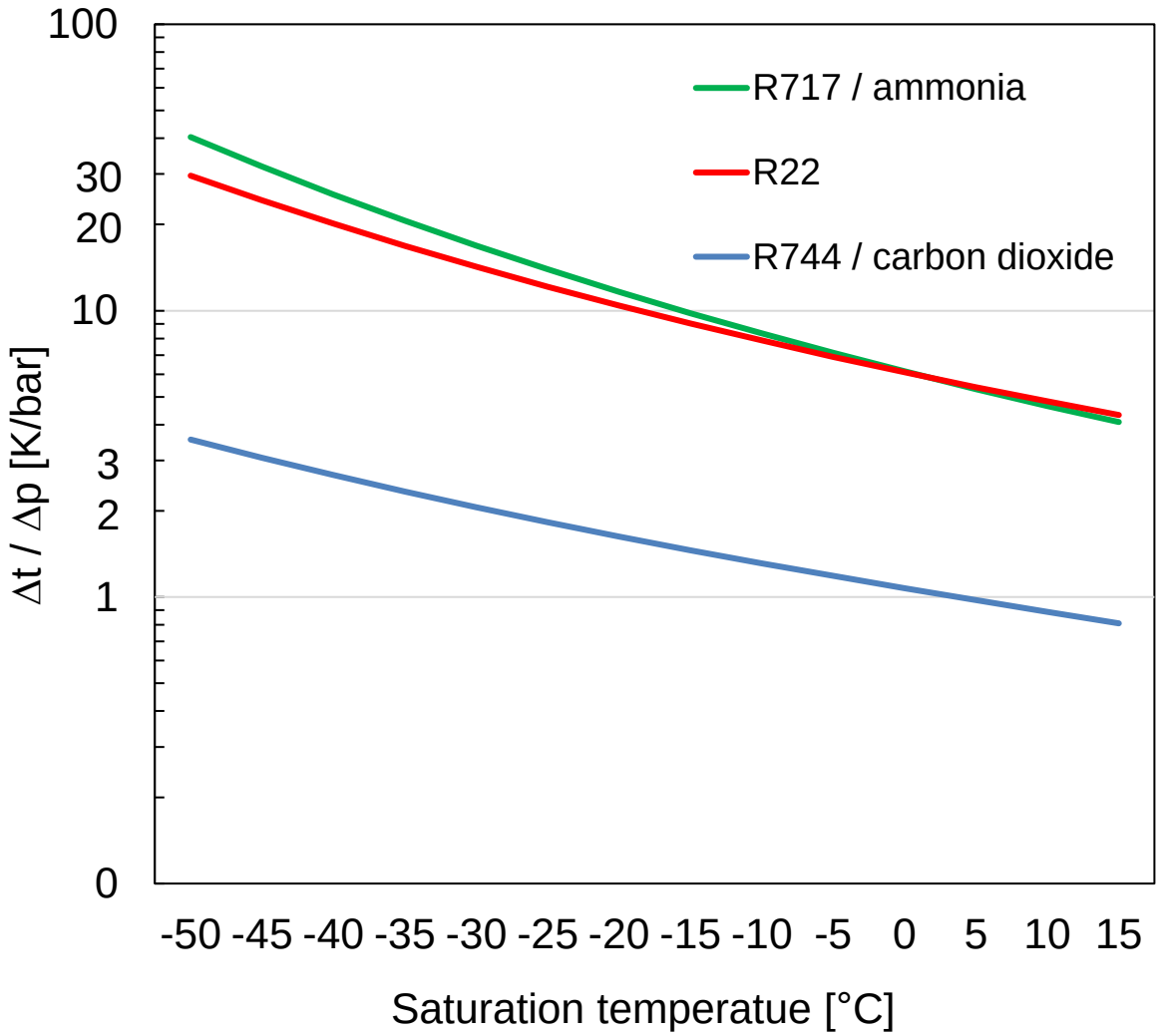
- Residential AC split units
- Light commercial refrigeration
- Home appliances (fridges and freezers)

Properties of working fluids

Evaporation pressure

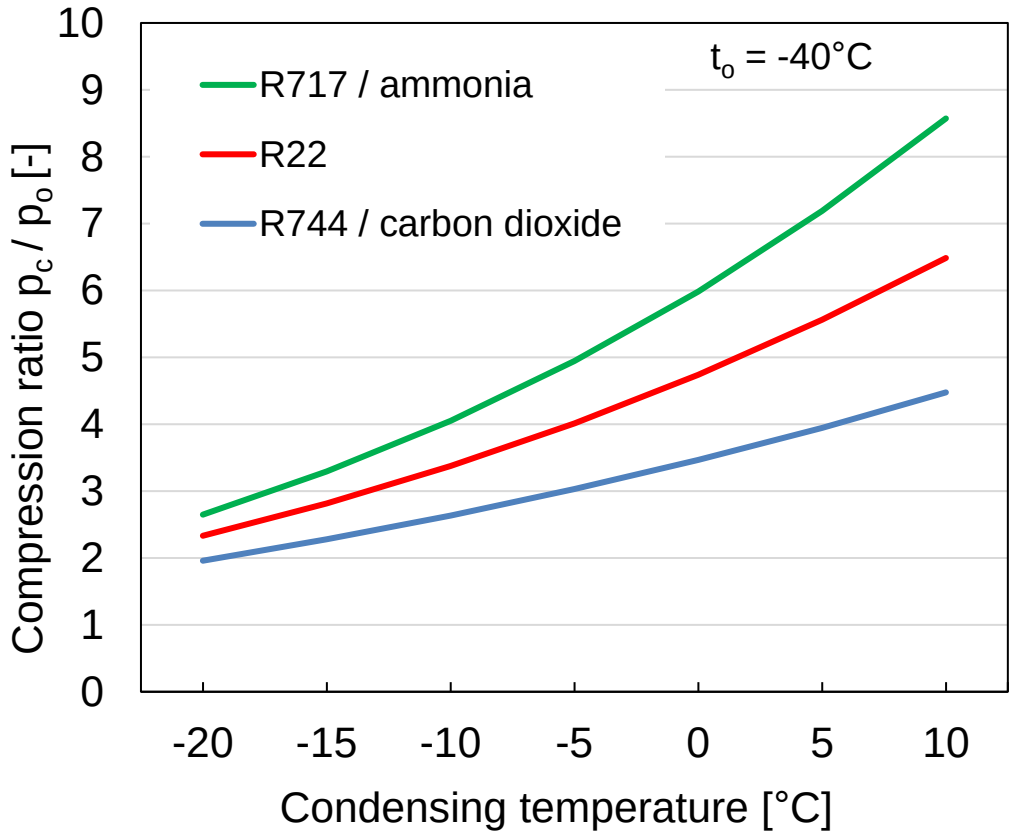


Temperature difference / pressure drop

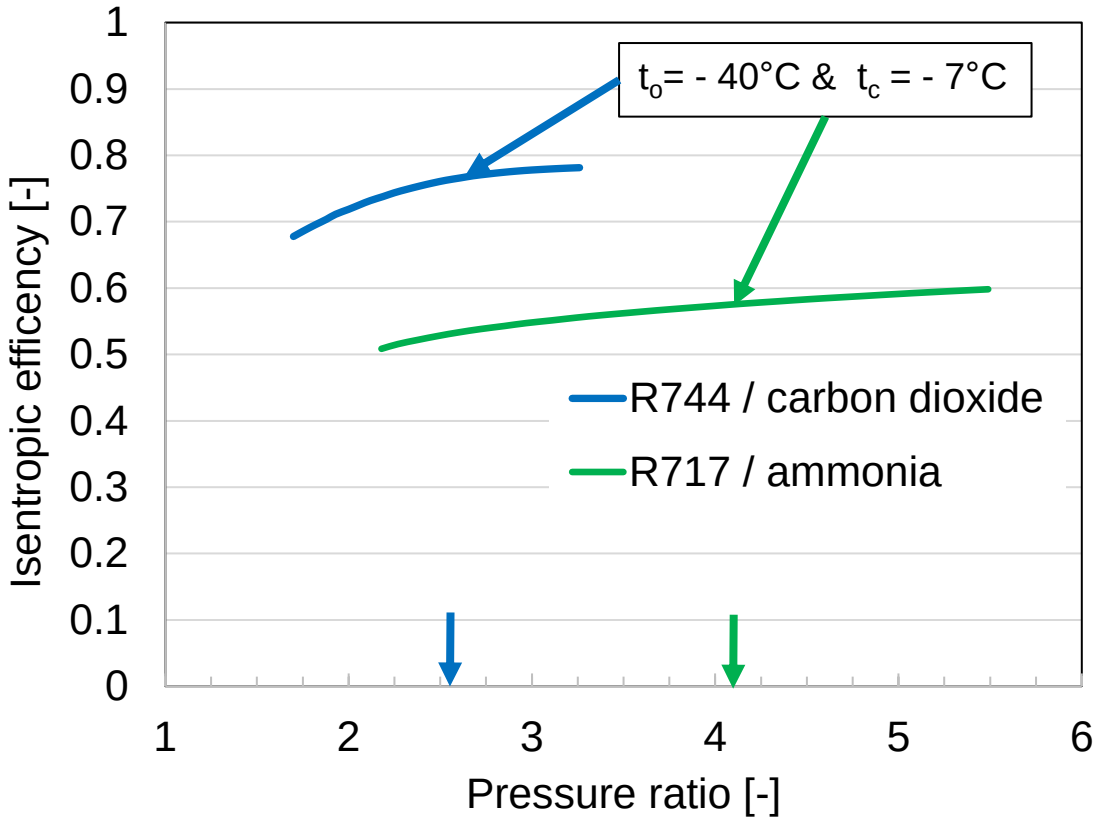


Properties of working fluids

Pressure ratio versus condensing temp.



Isentropic compressor efficiencies

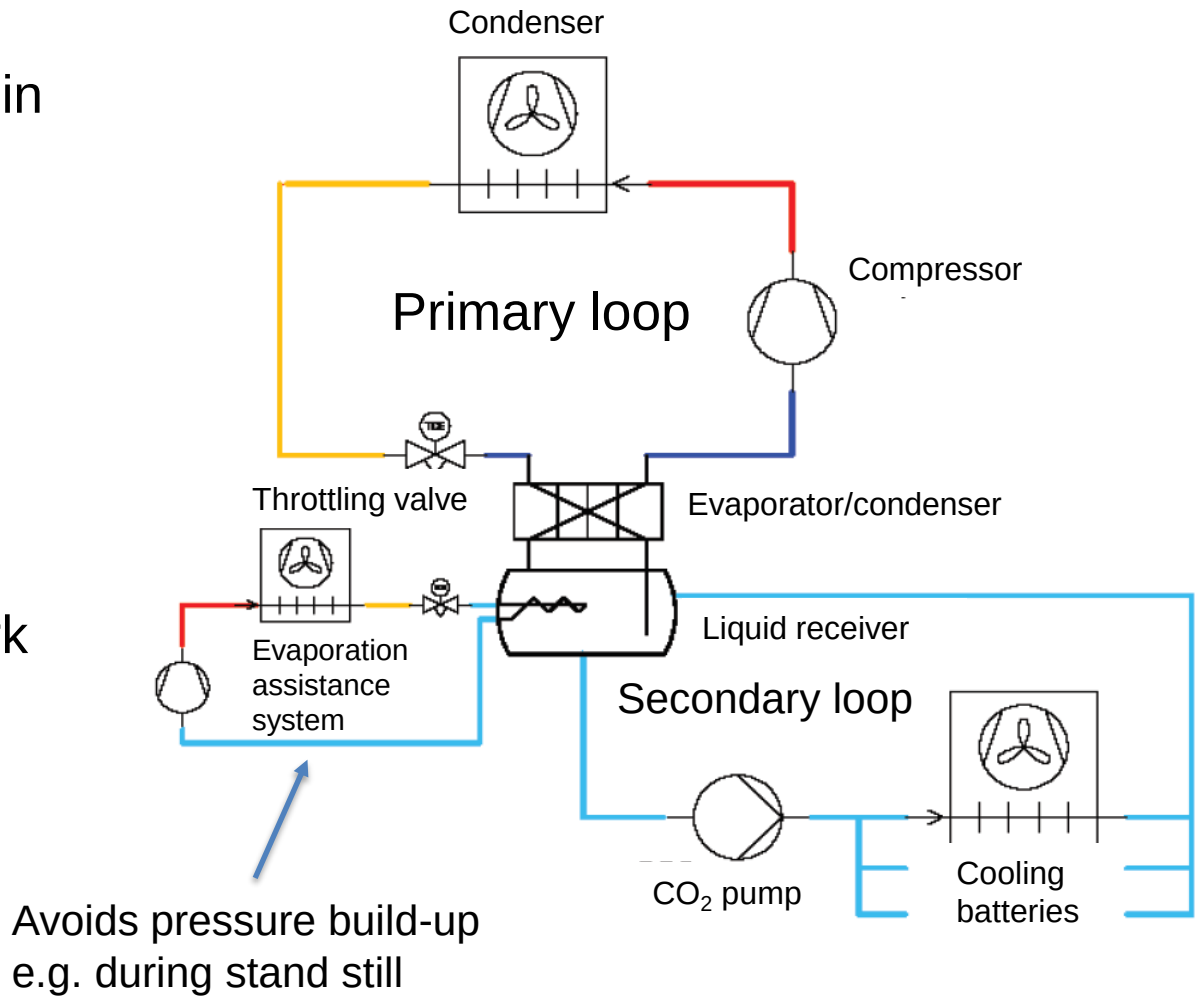


System architecture for low temperature refrigeration units

- CO_2 as an evaporating secondary fluid
- CO_2 in a conventional cooling process
  - cascade systems
- Transcritical two stage compression system
- CO_2 booster system: Two evaporation temperature levels

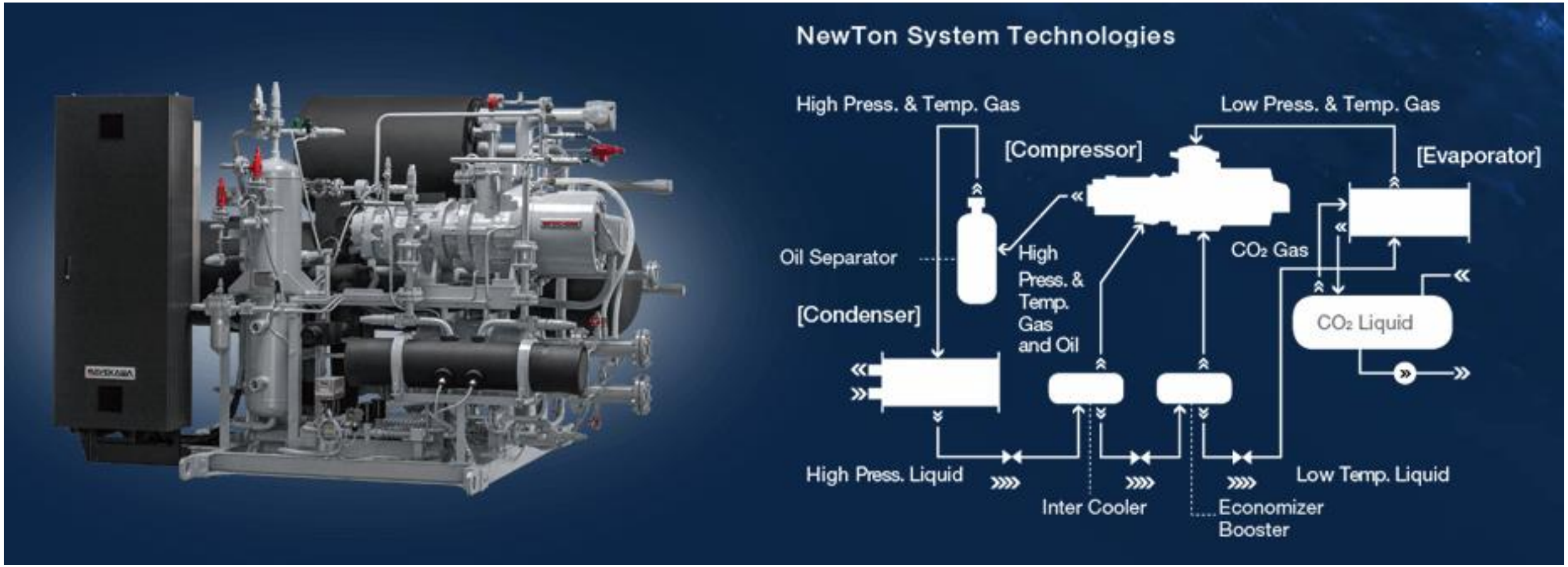
CO_2 as an evaporating secondary fluid

- Application:
  - Subcritical CO_2 system with NH_3 or HC in the primary loop
  - Industrial freezers, ice rinks
- Advantages:
  - Flooded evaporator
  - **Oil free CO_2 loop (Food security)**
  - High chiller efficiency
  - Smaller pipe dimensions and pump work compared to glycol circuits
- Disadvantages:
  - Complicated
  - Expensive



Example:

MAYEKAWA MYCOM



Significant Reduction in NH3 Charge Amount

NH3 Charge

1/38

NH3 charge amount is drastically reduced down to 1/38.

Power consumption

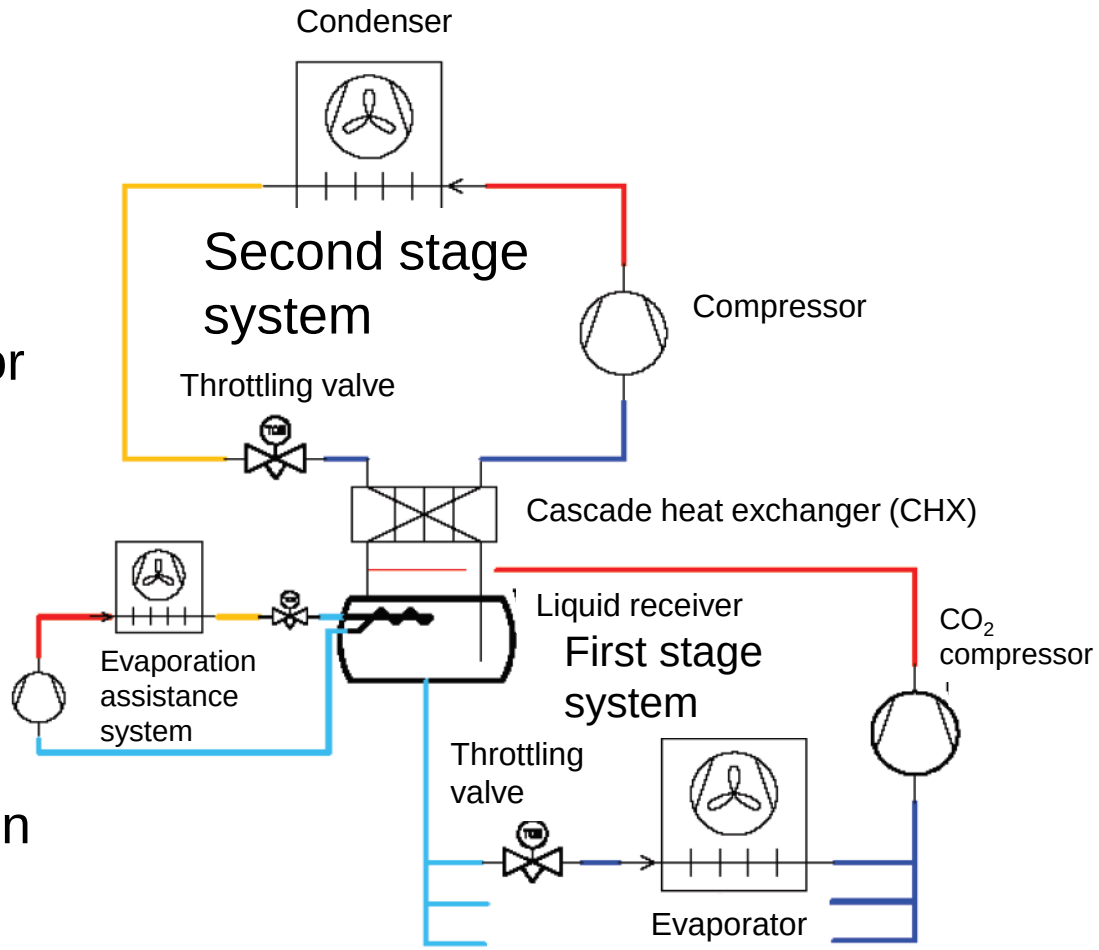
1/2

The annual power consumption on the compressor motor is cut by half.

Source: https://mayekawa.com/lp/newton/index.html

CO_2 in a conventional cooling process - cascade systems

- Application:
  - Two separate refrigeration units
  - First stage subcritical CO_2 system
  - Second stage system with a working fluid suitable for heat rejection (NH_3, propane (R290), etc.)
  - Industrial refrigeration systems
- Advantages:
  - **Energy efficient process**
  - Small operational cost
  - The indirect system provides NH_3 leakage precaution
- Disadvantages:
  - Problematic if the second stage system is inactive
  - Challenging to regulate the CHX at small capacities without variable speed drive



CO_2 in a conventional cooling process - cascade systems EXAMPLE

CO_2 /Ammonia Freeze Package

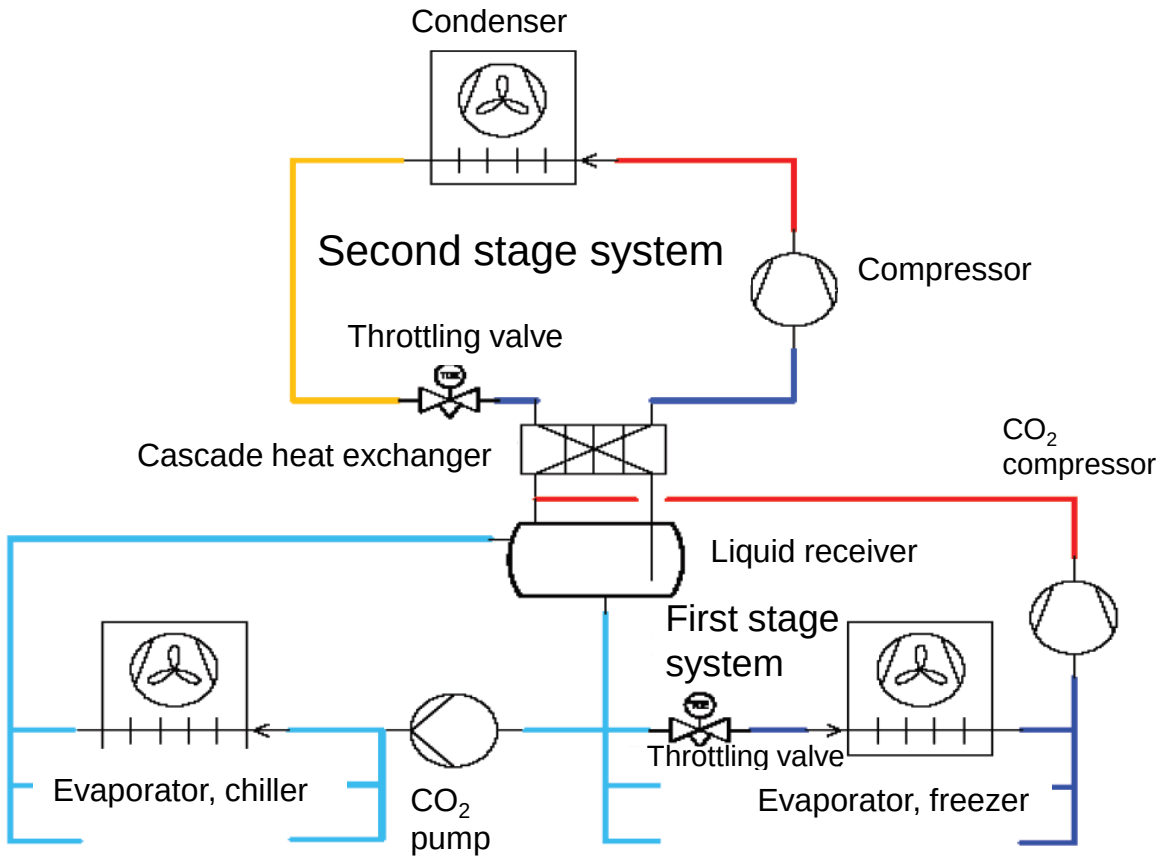
Compact packaged freezer systems using reciprocating compressors, and CO_2 /ammonia as refrigerant

Capacity range: 100–800 kW

Temperature range down to –55 °C

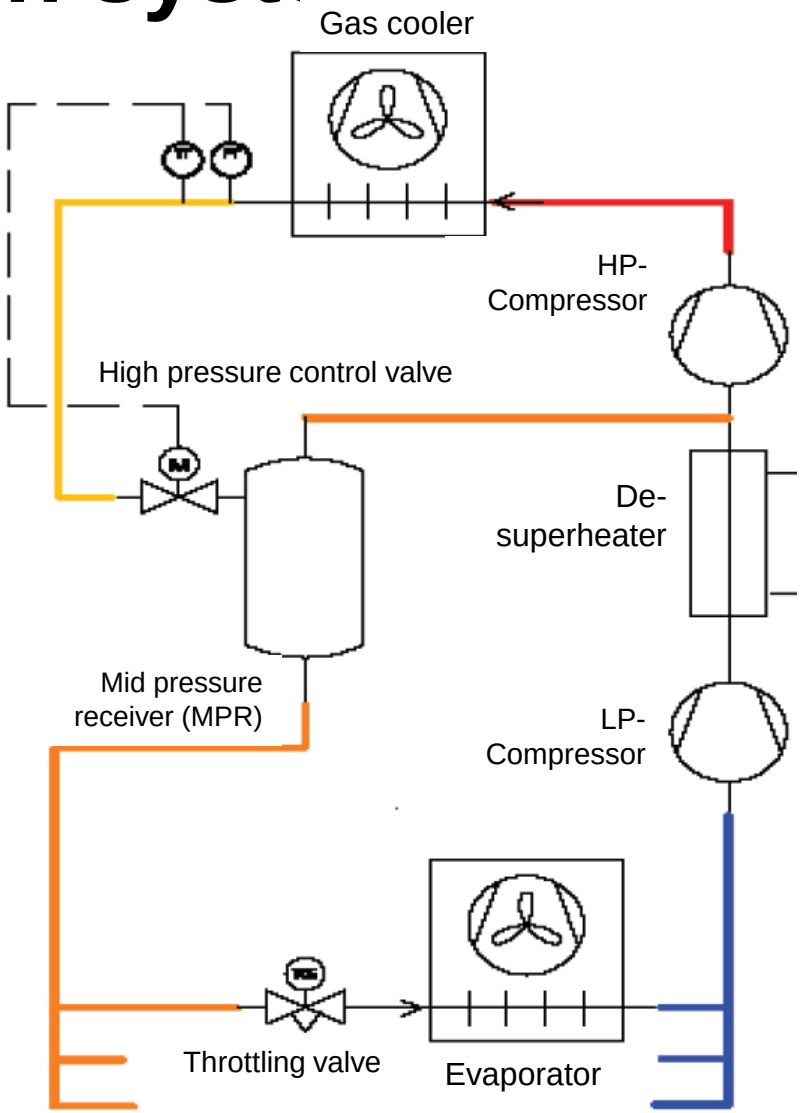
CO_2 in a conventional cooling process - cascade systems

- Application:
  - Large facilities with need for refrigeration at **several temperature levels**
- Advantages:
  - Flooded chiller evaporator
  - Compact
- Disadvantages:
  - Expensive
  - The CO_2 system fully relies on the second stage system for condensation



Transcritical two stage compression system

- Application:
  - Two stage compression and throttling
  - Industrial freezing applications
- Advantages:
  - Robust and well developed
  - Standard components and regulation
  - Strong competitor to NH_3 systems in the industry
  - Well known and applicable all over the world
  - **Utilization of heat recovery potential → 90°C water**
- Disadvantages:
  - Slightly reduced efficiency when gascooler outlet temperature is above 25°C (-> ejector & HR)



Premium quality fish from R744 equipped vessels

CO_2 (R744) DEEP-FREEZING PLANT FOR *M/S ROALDNES*

Helge Hansen & Yves Ladam

KULDE TEKNISK

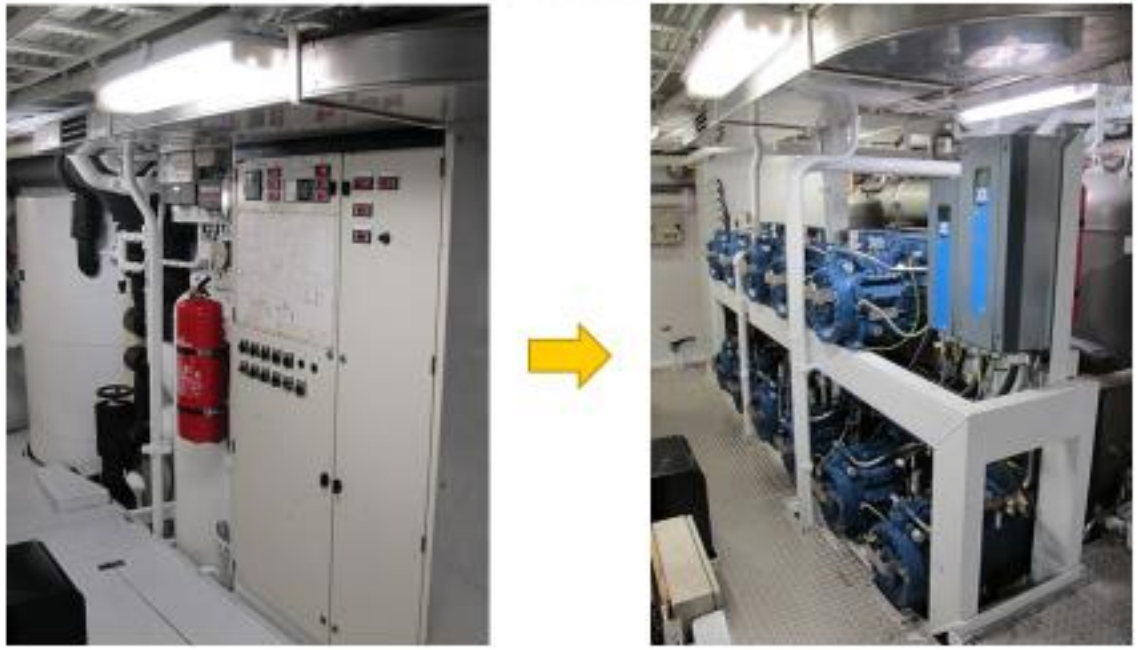
M/T ROALDNES

- Stern trawler
- Length : 33,95 m
- Width : 10,3 m
- Trawling:
  - haddock & pollock
- Capacity:
  - 120 metric tonn

KULDE TEKNISK

Premium quality fish from R744 equipped vessels

CONVERSION FROM HCFC 22 TO CO_2 (R744)



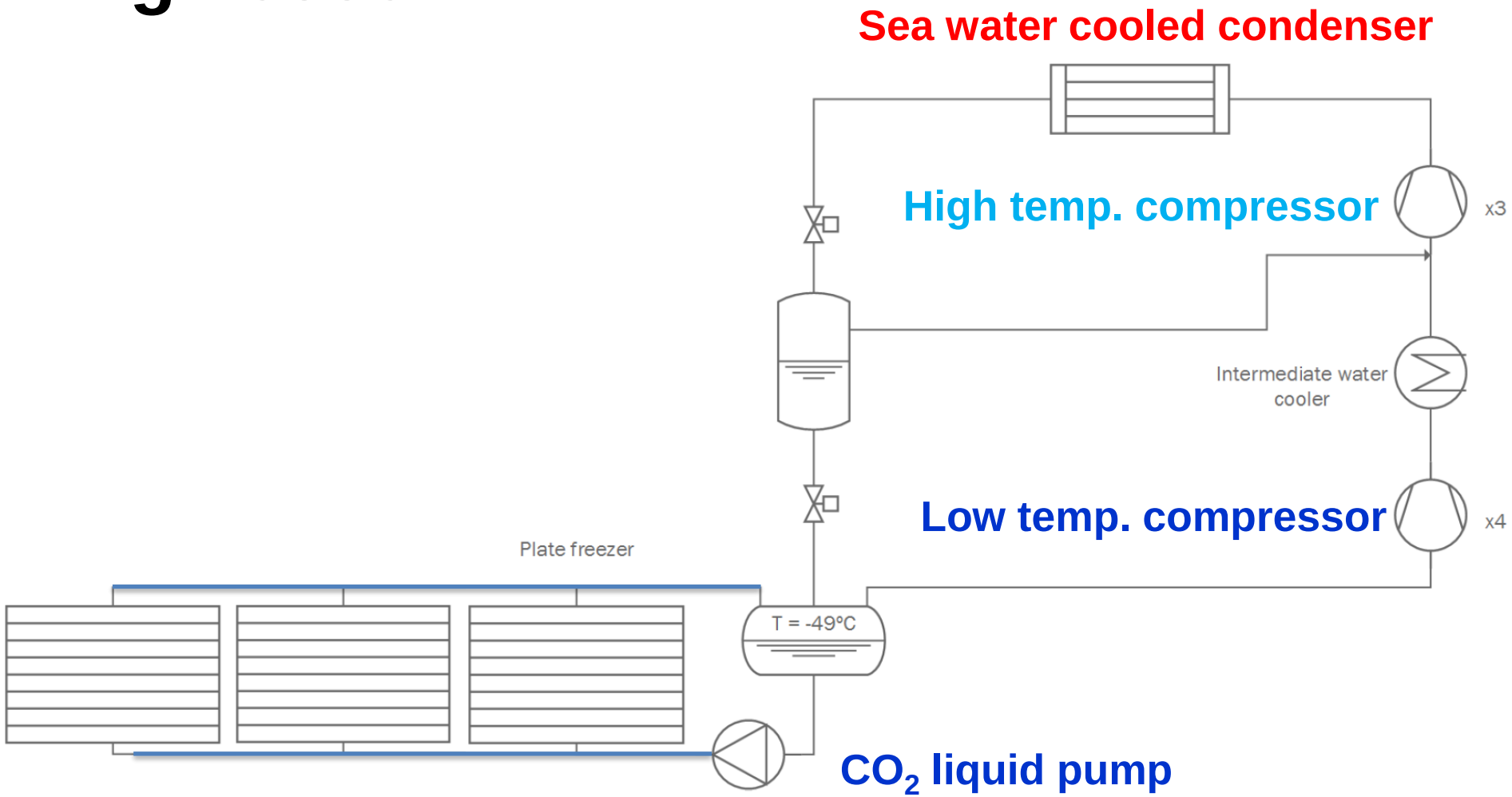
KULDE TEKNISK

DEEP-FREEZING WITH CO_2 VS HCFC 22

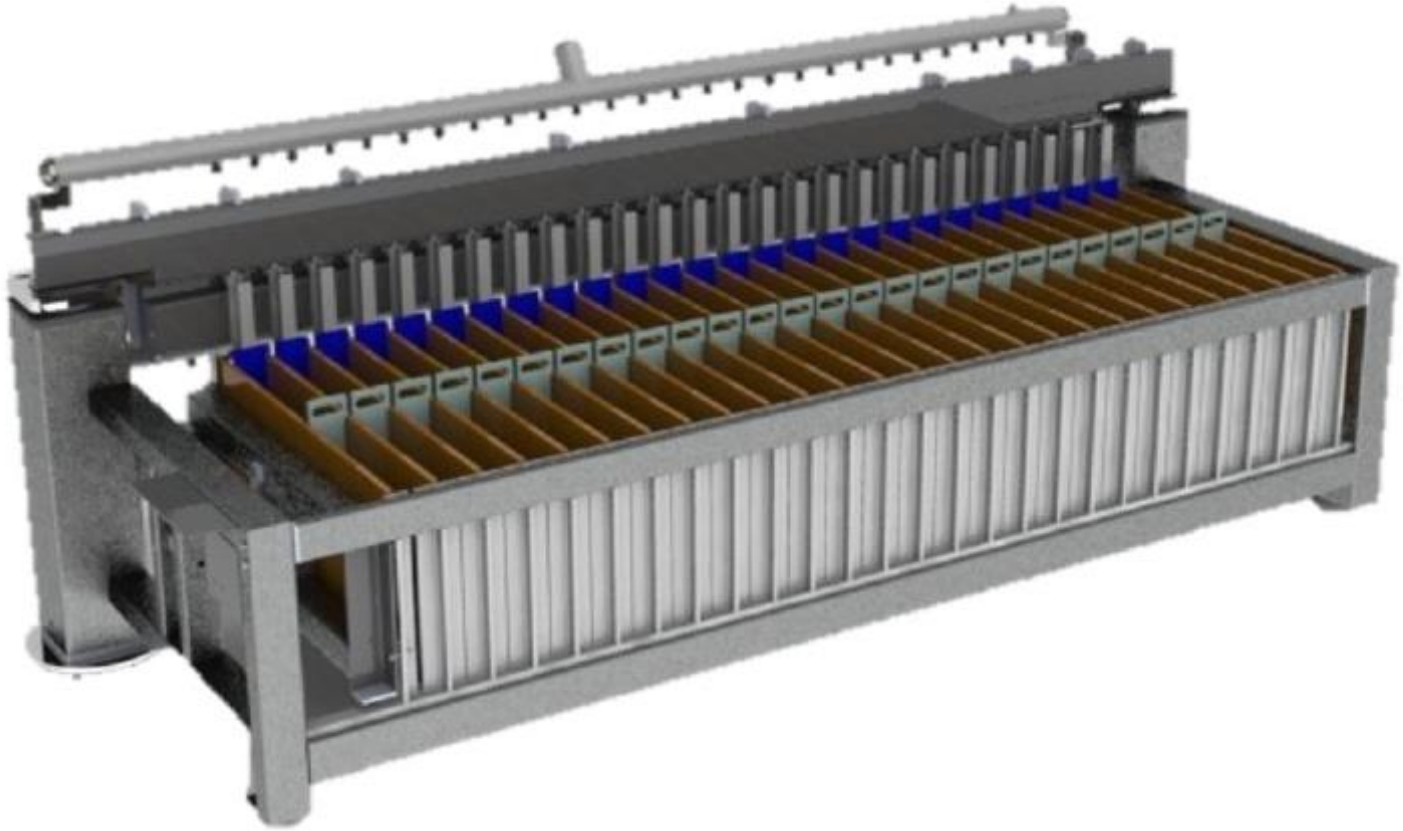
	R 744 /CO_2	HCFC 22
Metric tonn/day	40	30
Freezing time	140 min	190 min
Defrost	faster	

KULDE TEKNISK

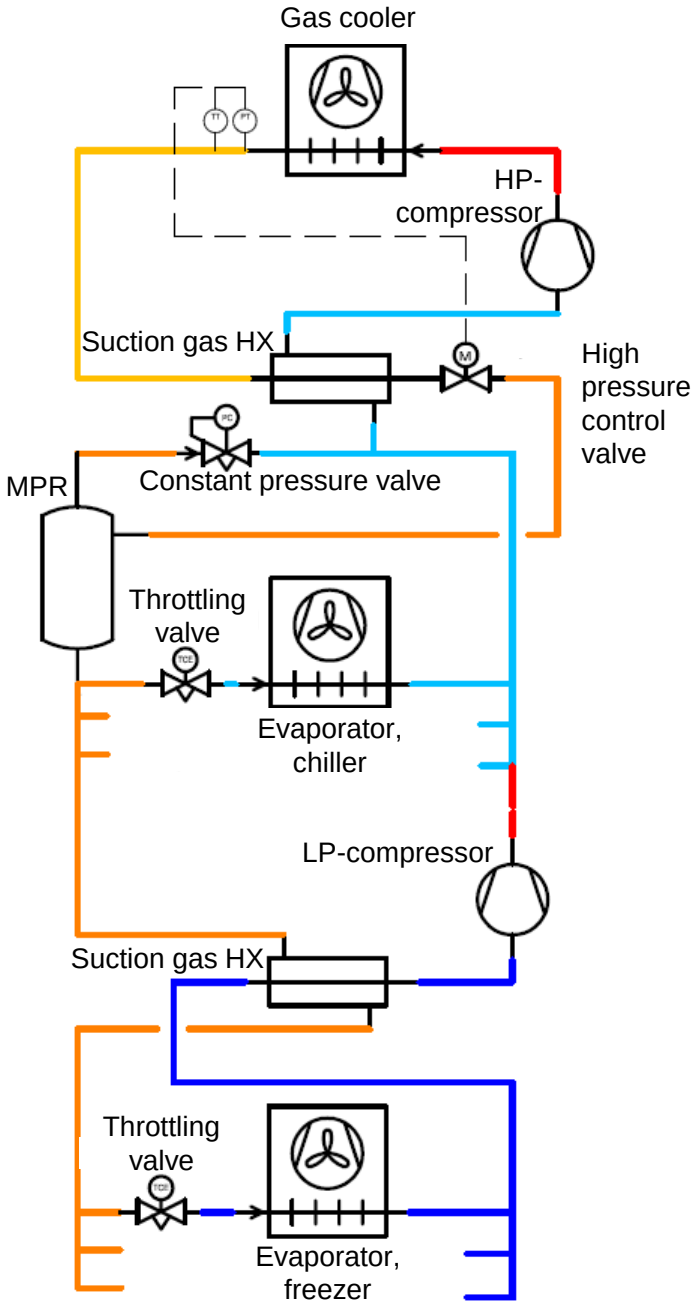
Principle freezing system layout on a fishing vessel



Principle freezing system layout on a fishing vessel, Source: Verpe 2018

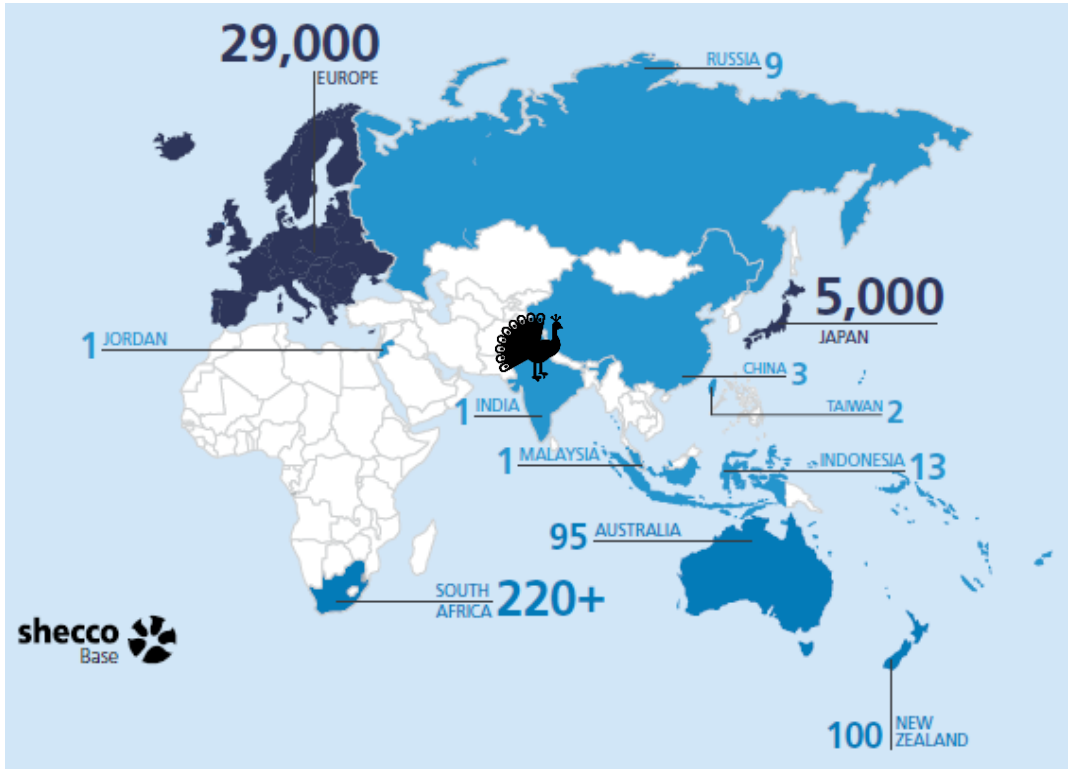


Source: Espen Halvorsen **Verpe**, 2018, Master Thesis NTNU, *Low Temperature Plate Freezing of Fish on boats using R744 as Refrigerant and Cold Thermal Energy Storage*

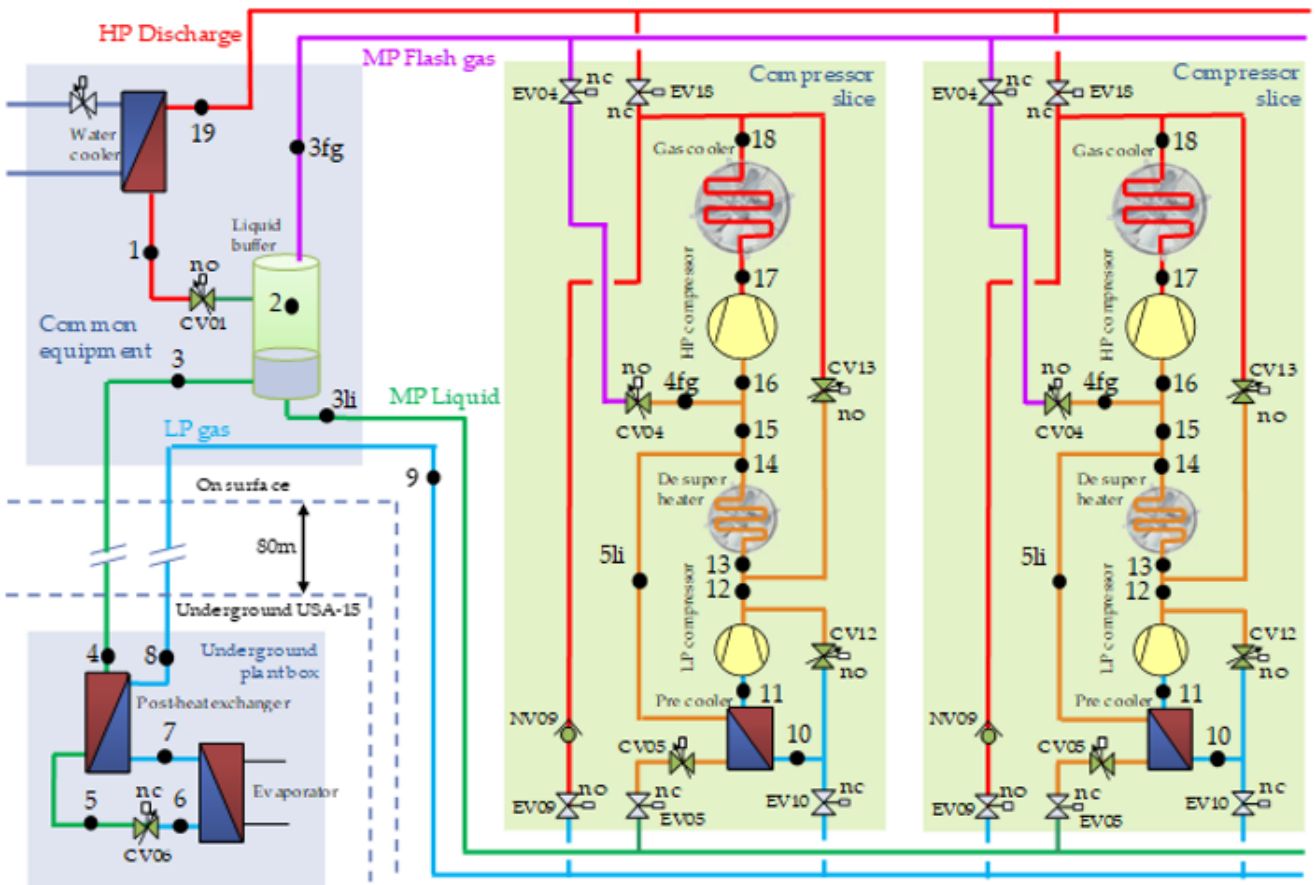


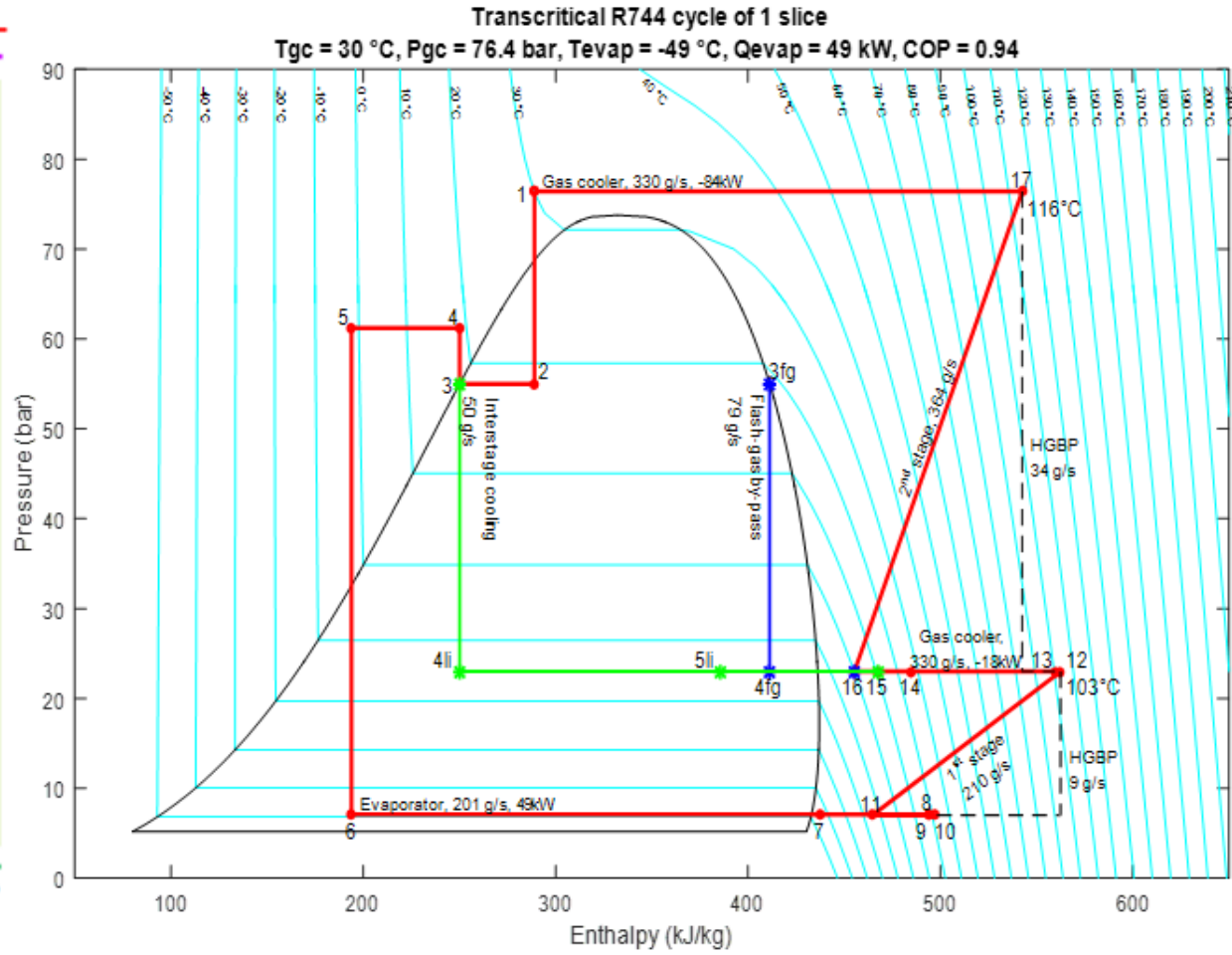
CO_2 booster system
Two evaporation temperature levels:
LowTemp [-30°C] &
MediumTemp [-5°C]

- Smaller investment cost
- Higher efficiency
- Standard solution for supermarkets



Primary R744 refrigeration system @ CERN





Evap. temp: @ -53°C

PTG THE VALUE OF PERFECT TEMPERATURE

CERN

NTNU Norwegian University of Science and Technology

Summary & Conclusion

- **Food is valuable** and essential for humankind

  → safe and reliable refrigeration equipment is needed to reduce food loss

- **Safety at work** is also important for responsible companies
  - Nobody should become sick due to refrigerants
  - Natural refrigerants are a safe choice
- **Environmental impact** of major importance
  - Only **natural working fluids will survive** towards 2050
  - Great energy efficiency improvements can be achieved
- Let's cooperate

Thank you for your attention

Contact:

armin.hafner@ntnu.no

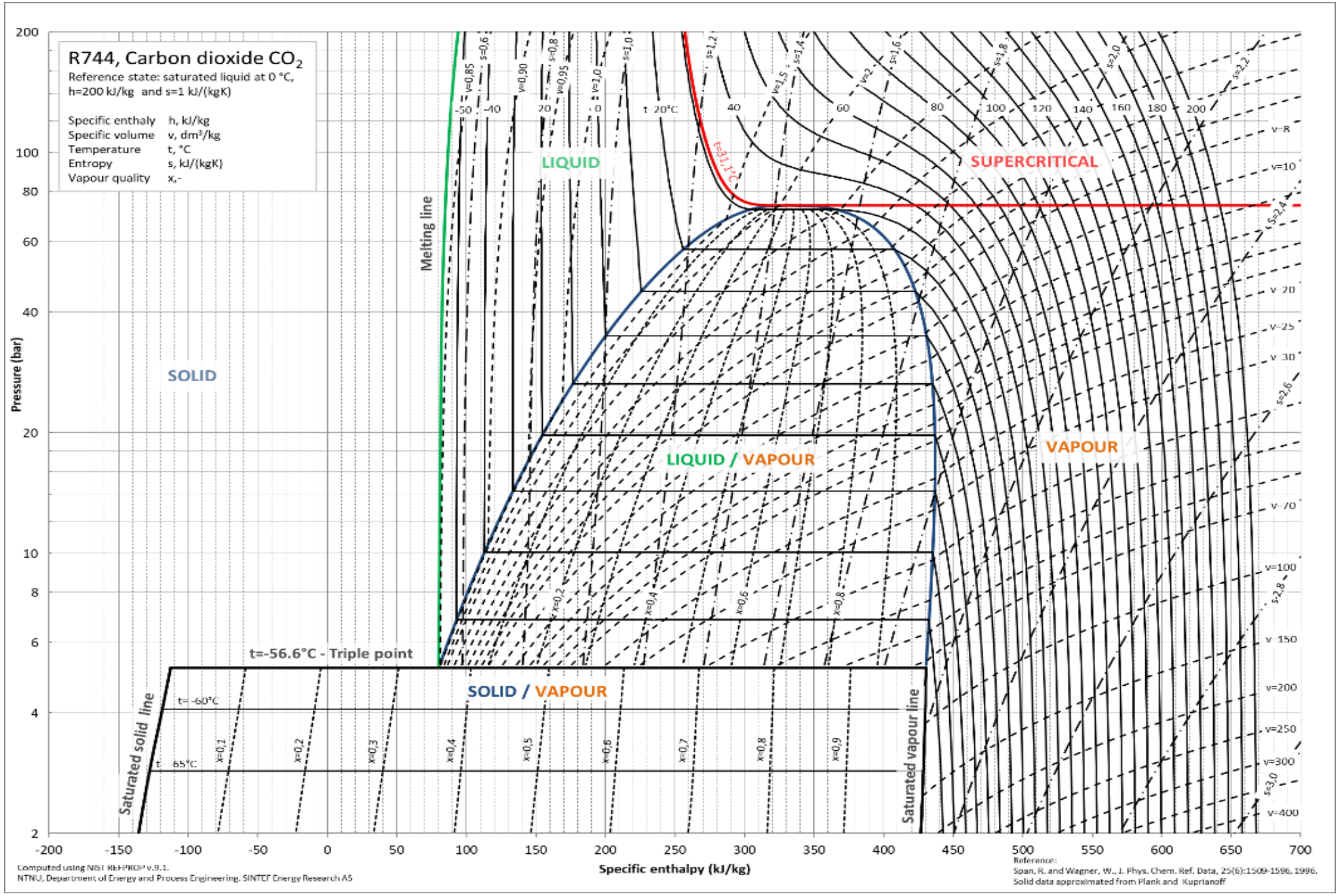
Please visit:

www.ntnu.edu/indee

Please contact us for further cooperation's

Pressure Enthalpy Diagram

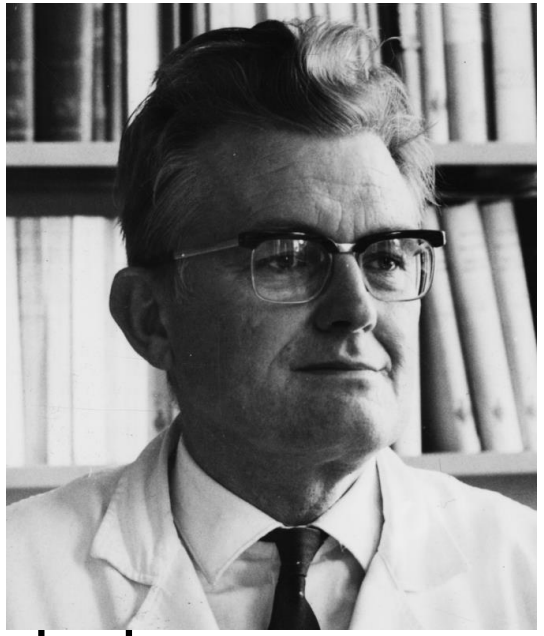
CO_2 / R744



INFLUENCES ON THE HUMAN BODY

PPM	EFFECTS ON HEALTH
410	Average value in the atmosphere
< 800	EN13779: Good indoor air quality
5000 (0.5 Vol-%)	Maximum Workspace Concentration (MAK) Threshold Limit Value, 8 hours, weighted average
10,000	Short Time Exposure Limit (Germany) 60 min, 3 times per shift
20,000	50% increase in breathing rate! Can affect the respiration function & cause excitation followed by depression of the central nervous system
30,000	100% increase in breathing rate after short term exposure
50,000	Immediate Danger to Life or Health (IDLH) “Escape” after exposure time of 30 min without irreversible health effects
100,000	Lowest lethal concentration Few minutes exposure produces unconsciousness
200,000	Death accidents have been reported
300,000	Quick results in unconsciousness & convulsions

1995 Prof. Gustav Lorentzen said:



We have heard a great deal lately of the **harmful effects to the environment when halocarbon refrigerants are lost to the atmosphere**. This should **not really** have come as **a surprise** since similar problems have happened over and over again. Numerous cases are on record where **new chemicals**, believed to be a benefit to man, **have turned out to be environmentally unacceptable**, sometimes even in quite small quantities (DDT, PCB, Pb etc.).

In the present situation, when the CFCs and in a little longer perspective the HCFCs are being banned by international agreement, **it does not seem very logical to try to replace them by another family of related halocarbons, the HFCs, equally foreign to nature**.

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