4. Examples of CO_2 systems

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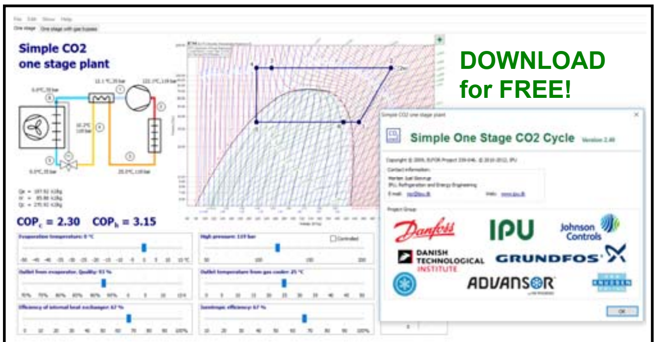
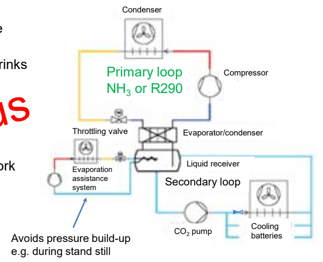
Content

- CO_2 as an evaporating secondary fluid
- CO_2 in a conventional cooling process (cascade system)
- Transcritical CO_2 process with low-pressure receiver
- Transcritical CO_2 process with mid-pressure receiver
- Transcritical CO_2 process with low and mid-pressure receivers
- Transcritical CO_2 booster system



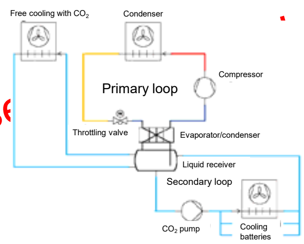
CO_2 as an evaporating secondary fluid

- Application:
  - Subcritical CO_2 system with NH_3 in the primary loop
  - Supermarkets, industrial freezers, ice rinks
- Advantages:
  - Flooded evaporator
  - Oil free CO_2 loop
  - High chiller efficiency
  - Smaller pipe dimensions and pump work compared to glycol circuits
- Disadvantages:
  - Complicated
  - Expensive



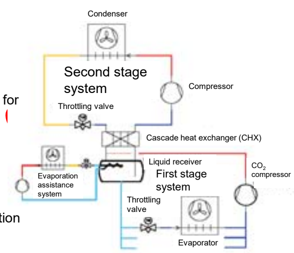
CO_2 as an evaporating secondary fluid

- Free cooling loop included (Cold climates)
- System must be dimensioned for standstill pressure (→ No evaporation assistance system!)



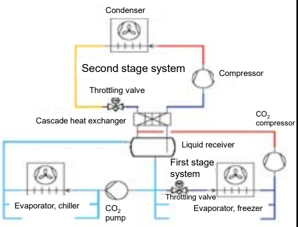
CO_2 in a conventional cooling process - cascade systems

- 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.)
  - Utilized in supermarkets pre-transcritical cycle
- 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



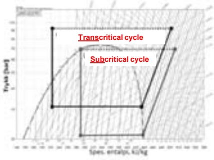
CO_2 in a conventional cooling process - cascade systems

- 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



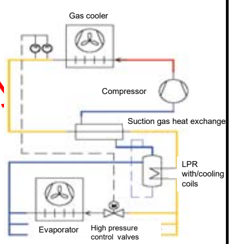
Transcritical CO_2 process: Important considerations

- Gas cooler pressure
- Placement of receivers
- Single vs. several throttling steps
- Mid pressure control
  - Dual throttling steps



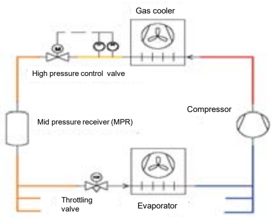
Transcritical CO_2 process with mid-pressure receiver

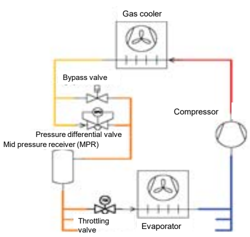
- Application:
  - Single throttling step
  - Small capacity installations
  - Norild, Sonyo, Denso
- Advantages:
  - LRP enables flooded evaporators
  - High suction pressure than with TEV
  - Lower vapour quality before throttling due to the suction gas heat exchanger
- Challenges:
  - Single evaporator
  - Oil boil-off
  - Slow start-up due to liquid accumulation in LPR
  - High pressure control with several devices



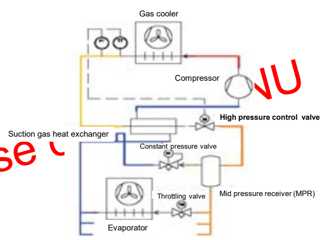
Transcritical CO_2 process with mid-pressure receiver

- Application:
  - Two throttling steps (no flash gas bypass)
  - Simple regulated systems
- Advantages:
  - Uncomplicated transcritical process
  - No connection between gas cooler pressure and feed to evaporator
- Challenges:
  - Superheat at evaporator outlet
  - Oil boil-off
  - Slow start-up due to liquid accumulation in MPR





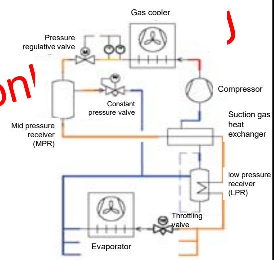
Regulation of gas cooler pressure by constant pressure difference – Passive mid pressure regulation



Active regulation of receiver pressure with flash gas bypass through constant pressure valve

Transcritical CO_2 process with low and mid-pressure receivers

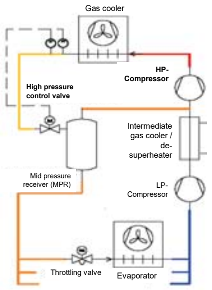
- Benefits from both LPR and MPR
  - Flooded evaporator
  - Enables higher suction pressure
  - No connection between gas cooler pressure control and feed to evaporator

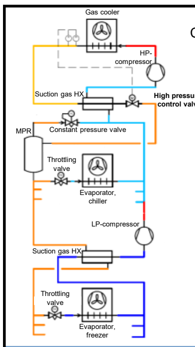


Transcritical CO_2 booster system

Freezing only applications

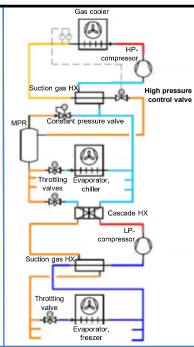
- Application:
  - Two stage compression and throttling
  - Leading solution in larger systems
- Advantages:
  - Robust and well developed
  - Standard components and regulation
  - Strong competitor to NH_3 systems in the industry
  - Well known and applicable all over the world
- Disadvantages:
  - Gas cooler outlet temperature in the range of 25-35℃





CO_2 booster system

- Smaller investment cost
- Higher efficiency



Cascade CO_2 booster system

- Avoid problems due to oil return
- Possible to utilize oil of different viscosities for chiller and freezer evaporators

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Part B

5. Techniques for process improvements
6. Heat recovery from CO_2 systems
7. Applications of CO_2 systems
8. Practical relations of CO_2
9. Safety consideration when dealing with CO_2 systems

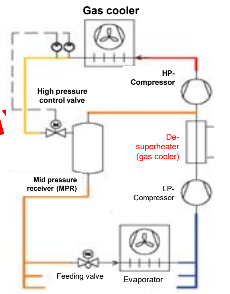
5. Techniques for process improvements

Content

- Intermediate gas cooler (de-superheater)
- Parallel compression
- Subcooling
- Expansion work recovery

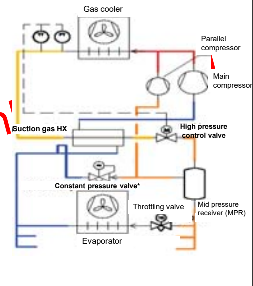
Intermediate gas cooler (de-superheater)

- Advantages:
  - Reduces HP-compressor suction gas temperature
  - Reduction in HP-compression work: Increase in compressor capacity of **0.5 % per K** reduction in suction gas temperature
- Challenges:
  - Extra gas cooler/cycle necessary
  - Suitable temperature level of heat sink



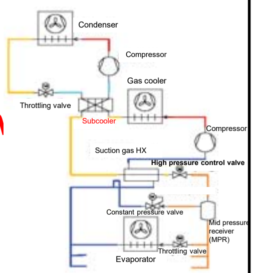
Parallel compression

- Direct compression of flash gas from the MPR instead of flashing vapour to the main compressor suction group
- Advantages:
  - 10-15 % increase in COP
  - Seasonal deployment of parallel compressor
- Challenges:
  - Slightly higher investment costs
  - Slightly higher degree of complexity



Subcooling

- Mechanical subcooling unit (R290 or NH_3)
- Advantages:
  - 1-2 % increase in COP per K internal subcooling
  - 2-4 % increase in COP per K with external subcooling
  - Can handle high return temperatures
- Disadvantages:
  - Extra investment costs
  - Higher degree of complexity
  - Risk of failure in sub cooling heat exchanger

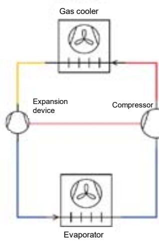


Expansion work recovery

- High CO_2 gas cooler outlet temperature results in large throttling losses
- Great advantage to utilize expansion work to reduce compression work

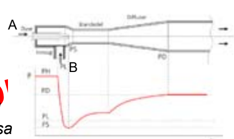
Challenges with Expanders

- Complexity
- Cost
- Reliability
- Two phase expanders, etc.



Expansion work recovery with ejector

- "Jet pump"
- No work required – "Free" pressure lift
- No moving parts: easy to install, operate and maintain
- Bernoulli's Principle: *When the speed of a fluid increases its pressure decreases and vice versa*

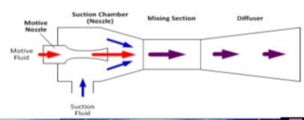


- Mass entrainment ratio: $\Phi_m = \frac{\dot{m}_{sn}}{\dot{m}_{mn}}$
- Suction pressure ratio: $\Pi_s = \frac{P_{diff,out}}{P_{sn,in}}$
- Pressure lift: $P_{lift} = P_{diff,out} - P_{sn,in}$

$$\eta_{ejec} = \Phi_m \left(\frac{h_{mn,in} - h(P_{diff,out}, s_{mn,in})}{h(P_{diff,out}, s_{sn,in}) - h_{sn,in}} \right) = \frac{\dot{W}_{rec}}{\dot{W}_{rec,max}}$$

Two-phase Ejector for Expansion Work Recovery

- High-energetic motive stream accelerated in motive nozzle (low static pressure, high kinetic energy)
- Suction flow pre-accelerated in suction nozzle to reduce mixing losses caused by shearing
- Low-energy suction stream is entrained, accelerated by momentum transfer; velocities equalize during mixing, pressure rise in mixing chamber (possibility of shocks)
- Deceleration in subsonic diffuser; further increase of static pressure



Prof. S. Elbel

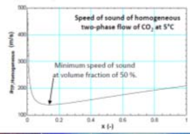
Two-phase Ejector Flow Fundamentals

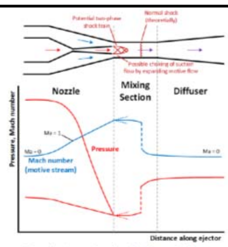
→ Two-phase speed of sound depends on flow regime – each phase has a different speed of sound and possibly a different velocity.

$$Ma = \frac{u}{a} \qquad a = \text{speed of sound} = \left(\frac{\partial P}{\partial \rho}\right)_s^{0.5}$$

$$a_{TP,Homogeneous} = \left[(\alpha\rho_v + (1-\alpha)\rho_l)\left(\frac{\alpha}{\rho_v a_v^2} + \frac{1-\alpha}{\rho_l a_l^2}\right)\right]^{0.5}$$

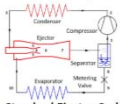
a_v, a_l = speed of sound of vapor, liquid phase
α = vapor volume fraction



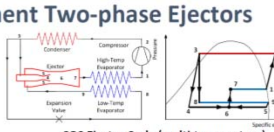


→ Complex, two-phase shock train possible at nozzle outlet if motive flow is over-expanded.
→ Suction flow can become choked by motive flow as it expands into the mixing section.
→ Additional shock often observed in mixing section or diffuser.

Different Ways to Implement Two-phase Ejectors

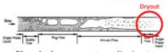


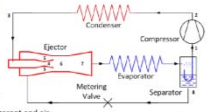
Standard Ejector Cycle



COS Ejector Cycle (multi-temperature)

Liquid recirculation cycle

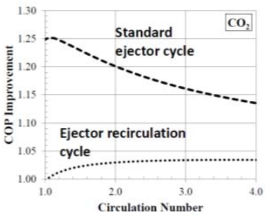




- Flooded evaporator eliminates dryout:
  - Improved heat transfer coefficient at end of evaporator
  - Elimination of superheat and reduced ΔT between refrigerant and air

Standard Ejector Cycle is Best for CO_2

- CO_2 ejectors can achieve very large P_{lift} (due to very large work recovery)
- Trade-off between evaporator improvement and P_{lift} results in a maximum COP.
  - A slight amount of overfeed is still beneficial to just eliminate dryout



- Fluids that have large throttling loss but gain little benefit from overfeed should use standard ejector cycle.

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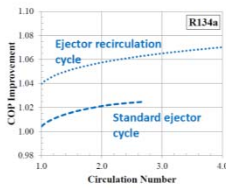
Ejector Recirculation Cycle is More Favorable for Low-pressure Fluids

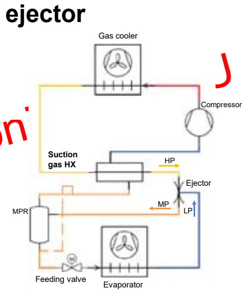
- P_{lift} of low-pressure fluids (R134a, NH_3, etc.) is very small
- Far better to use ejector to pump liquid and improve the evaporator
  - R134a gains benefit from liquid overfeed because it is very sensitive to evaporator ΔP
- Ejector in recirculation cycle can operate over larger range of flow rates because it pumps only liquid



- Low pressure fluids should use the ejector to recirculate liquid and improve evaporator performance

Expansion work recovery with ejector
Standard Ejector Cycle

- Pressure lift from 'LP' to 'MP'
- Ensures continuous fluid stream through evaporator



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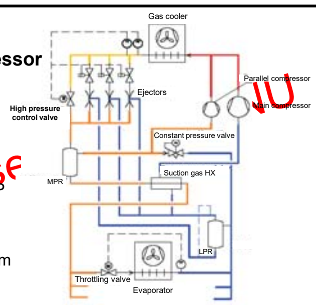
Ejector systems:
ejector supports parallel compressor

- **Multi Ejectors**
  - Liquid (→ flooded evaporators all year)
  - Vapour (→ boost parallel compressors)
- Always flooded evaps. → +10% in COP
- Pressure lift: 10-15 bar
- COP increase of up 17%
- Ejector efficiency of 30% under optimum operational conditions



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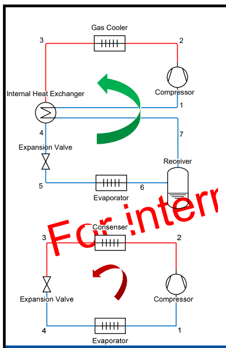
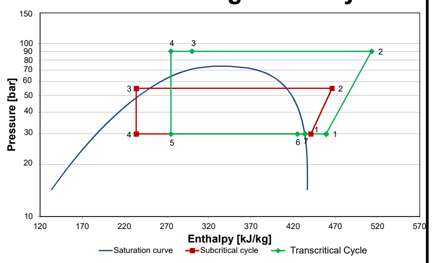
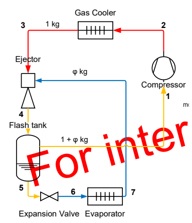
Short review / Summary

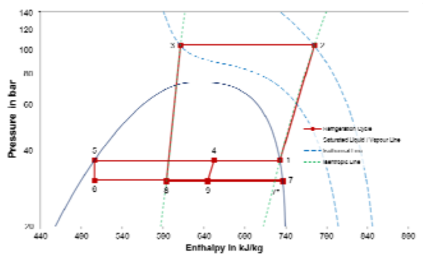
Refrigeration cycle





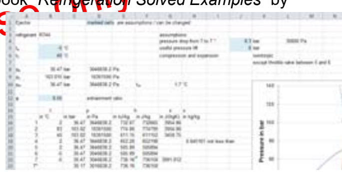
Ejector cycle



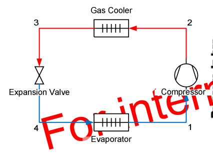


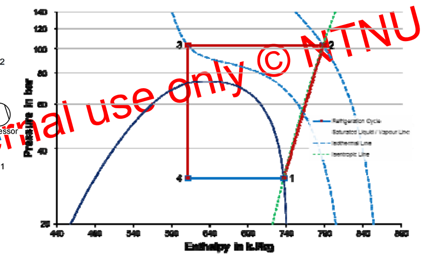
Sample calculations

- Development of Excel tool for easy calculation of different system configurations
- Parameters can be easily changed
- Cycle configuration originally from book *"Refrigeration Solved Examples"* by Ciconkov
- Cycles that were calculated:
  - Simple cycle
  - Parallel compression
  - Parallel compression with IHX
  - Ejector cycle
  - Ejector with parallel compression
  - Ejector, parallel compression, IHX

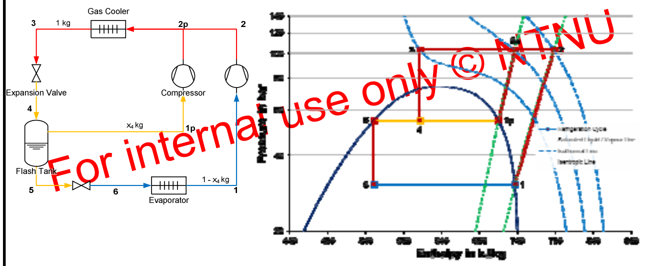


Simple cycle

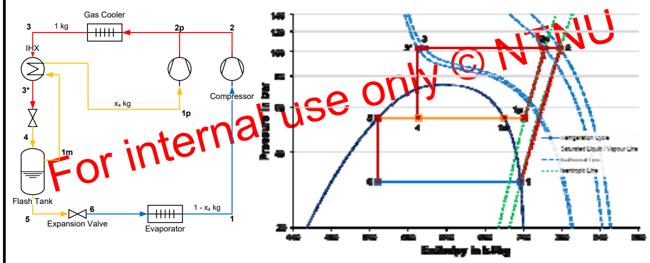




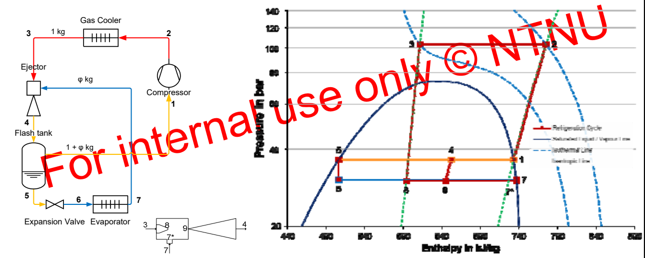
Parallel compression



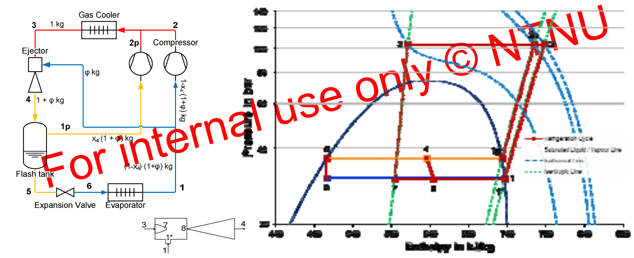
Parallel compression with IHX



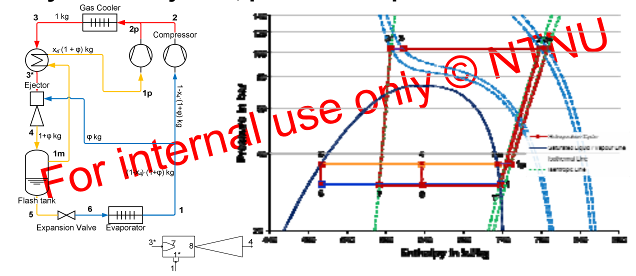
Cycle with ejector



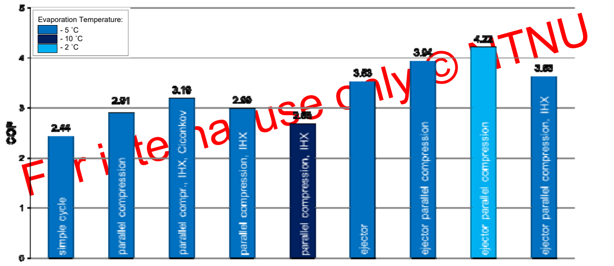
Cycle with ejector and parallel compression



Cycle with ejector, parallel compression and IHX



Comparison



6. Heat recovery from CO_2 systems

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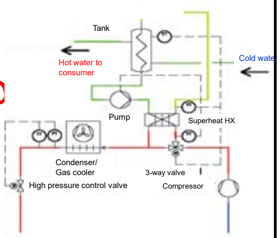
Content

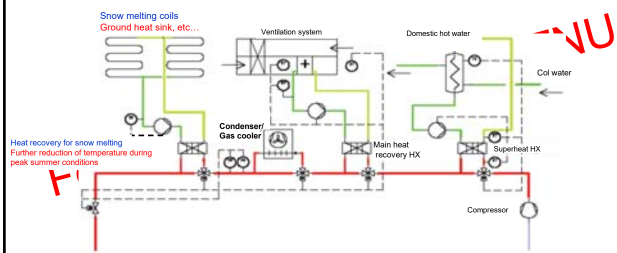
- Heat recovery and utilisation of condenser heat
- Heat recovery on several temperature levels
- Seasonal operational strategies

Heat recovery of condenser heat

- Highly relevant for subcritical operations
- 40 % of condenser heat in superheated area for a CO_2 process at t_0= -10 °C/ t_c=+25 °C
- Only 10-15 % for conventional working fluids
- Flexible in regards to amount of heat recovered
- Not crucial with low CO_2 return temperature at superheat HX due to serial connection

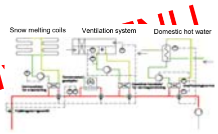


Heat recovery on several temperature levels



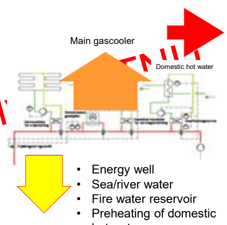
Heat recovery on several temperature levels (Europe)

- Summer
  - No demand for ventilation heat or snow melting
  - Only heat recovery to domestic hot water
- Spring/autumn
  - High pressure regulation in order to meet all demands
- Winter
  - Transcritical operations
  - Large heating demand and thus minimum heat rejection through gas cooler (ambient)



Heat rejection on several temperature levels (India)

- R744 for industrial applications



- Energy well
- Sea/river water
- Fire water reservoir
- Preheating of domestic hot water
- Etc.

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NTNU

7. Applications of CO_2 systems

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Content

- Areas of application
- CO_2 heat pumps
- Cascade system for fishing vessels
- CO_2 systems for supermarkets

Areas of application

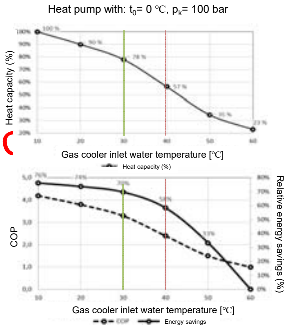
- Heat pumps for space heating/cooling/domestic hot water
- Supermarkets
- Refrigeration/ freezers in fishing vessels
- Chiller units (warm climates, data center cooling)
- Mobile AC (containers, trucks, cars)
- Industrial application (process cooling, heat recovery)

Refrigerated sea water (RSW) unit

CO_2 heat pumps

- Exceptional heat pump if operated correctly with a maximum return temperature of 30 ℃
- Large drop in efficiency when the inlet water temperature surpasses 40 ℃
- Possible to reject heat at different temperature levels
  - Domestic hot water, space heating, etc.

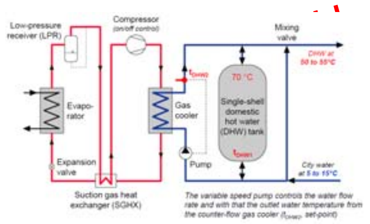
Heat pump with: t_0= 0 ℃, p_k= 100 bar



CO_2 heat pumps for domestic hot water (DHW) heating

Aspects to consider:

- Dimensioning: average heating capacity + 20%
- Δt_A of 3-5 K
- On/off regulation of heat pump
- Stores able to cover demand over 24 h
- Back-up solutions: heat elements in tanks, district heating interface, etc.

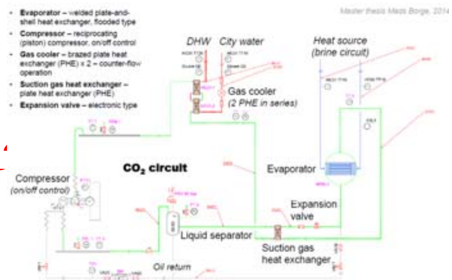


Example – Installation at Tveita Borettslag, Oslo

- Tveita borettslag (housing cooperative)
  - 3 block of flats with 819 flats in total (from 1969)
- Major renovation
  - Building envelope and technical installations
  - Energy use from 280 → 140 kWh/(m²year)
- CO_2 system for domestic hot water (2011)
  - One CO_2 heat pump water heater for each block of flats: ***3 x 100 kW – single-stage units***
  - Heat source –exhaust air from central vent. system (22 °C)
    - *Indirect system design with secondary brine circuit*
- Measured COP –approx. 4.0 excl. pump energy
  - ***73 °C DHW** –constant temperature (set-point)*

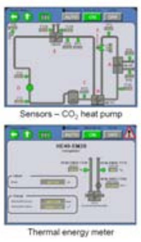
Example – Installation at Tveita Borettslag, Oslo

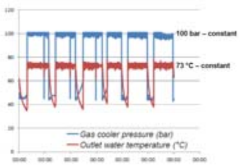
Heat pump design



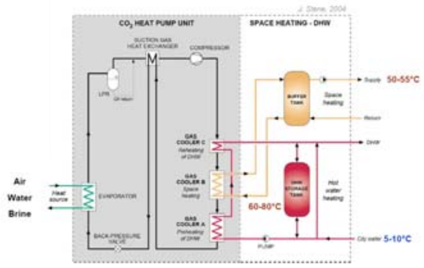
Example – Installation at Tveita Borettslag, Oslo

Control system





CO_2 heat pumps for DHW and space heating

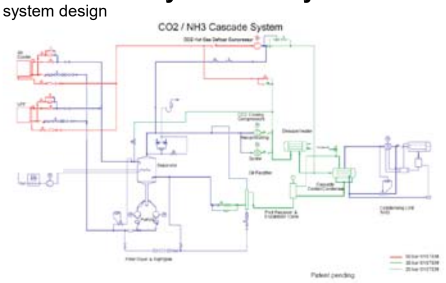


Cascade system for fishing vessels

- MS Kvannøy (trawler)
  - 84 meters long and built in 2002
  - Production: 12-160 tons fillets / 24 h
- CO_2 and ammonia refrigeration system
  - 11 plate freezers
  - **1350 kW** freezing capacity at **-48 °C**
  - 9 refrigerated sea water tanks
  - 40% reduction in product freezing time compared to R-22 system at – 40 °C)

Example – MS Kvannøy cascade system

Refrigeration system design



Premium quality fish from R744 equipped vessels

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

Helge Hansen & Yves Ladam

M/T ROALDNES

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

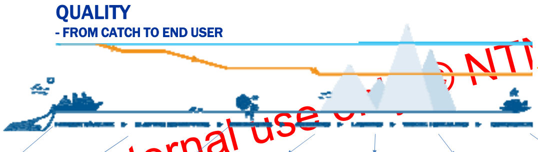
Premium quality fish from R744 equipped vessels

CONVERSION FROM HCFC 22 TO CO_2 (R744)

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	

Faster Freezing = Higher Food Quality



No delays on board after catch	No delay prior freezing	25% faster freezing	Faster de-icing	Excellent part load performance	«Refreshed»	Socio-Economically profitable.
No reduction in fish quality	No reduction in fish quality	Lower freezer temp. = smaller crystals = better/ premium quality	No boiling of fish surface Preventing discoloration	50% reduction in energy use	No reduction in quality Low wastage	Ethically correct Better quality than fresh fish. Higher price accepted

Premium quality fish from R744 equipped vessels

SUMMARY R744 (CO_2) IN MARIN APPLICATION

- deep-freezing time is reduced by 25%
- requires less space onboard
  - allows to apply smaller tubes / piping
  - approx. 20% less space for the unit
  - less freezers required for same freezing capacity
- CO_2 plate freezers achieve better food quality
- in general: service & maintenance becomes better and more easy

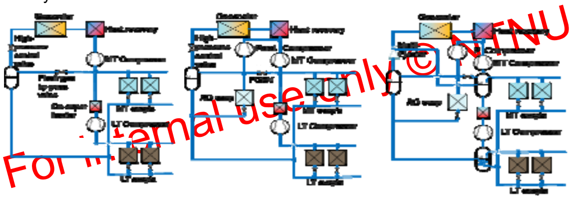
OTHER CO_2 UNITS FOR FISHING BOATS

Refrigerated Sea Water UNIT

One Vessel equipped with CO_2 – RSW unit was in operation around the Canarian Islands and is now outside Mauretania !

CO_2 systems for supermarkets

Booster systems



1st generation: Booster system

2nd generation: Booster system with parallel compression

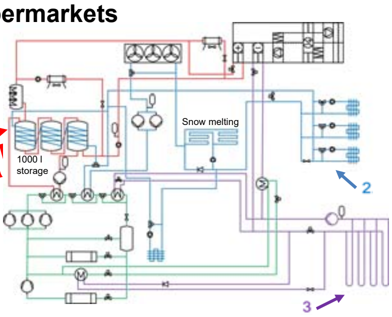
3rd generation: Ejector system

CO_2 systems for supermarkets

Integrated solutions

Supermarket, Trondheim, Norway

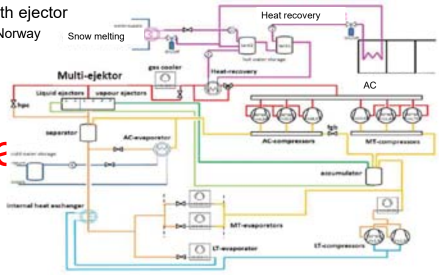
- Heat recovery at 3 temperature levels
  1. Hot water storage to heat ventilation air (60 °C)
  2. Floor heating (30 °C)
  3. Snow melting
     Energy wells



CO_2 systems for supermarkets

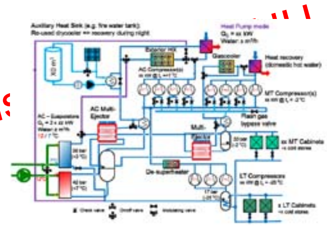
Integrated solutions with ejector

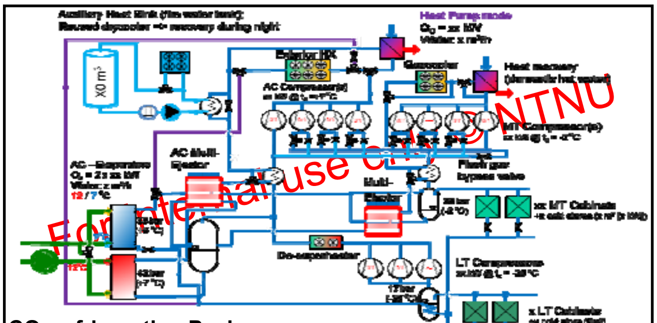
Supermarket, Trondheim, Norway



Supermarkets for the future

- "Standardized" systems for warmer climates
- Parallel compression
- Multi ejectors (MT and AC)
- Heat recovery
  - AC
  - Domestic hot water
- Estimated 30 % lower energy consumption compared to standard booster systems!

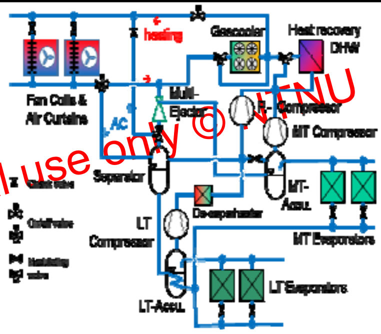




CO_2 refrigeration Pack

CO_2 ref. - Pack Integration of direct heating and cooling

- Alternative MultiPACK * solution



* www.ntnu.edu/multipack

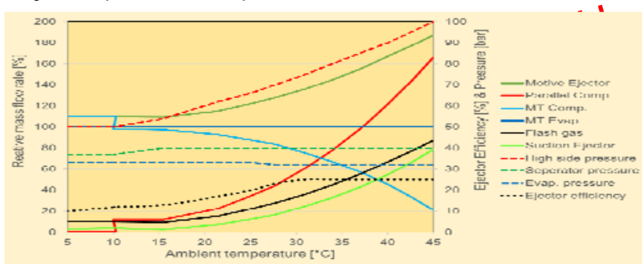
CO_2 ref. - Pack Integration of direct heating and cooling

- Alternative MultiPACK * solution

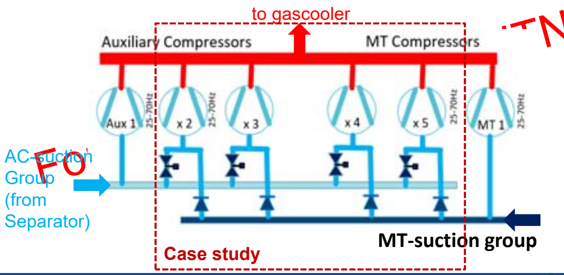
Direct heating and cooling fan coil unit inside a Supermarket (Girotto 2016).

* www.ntnu.edu/multipack

Behaviour of ejector supported parallel compression system (Generation 3)



Example: 4 Pivoting Compressors



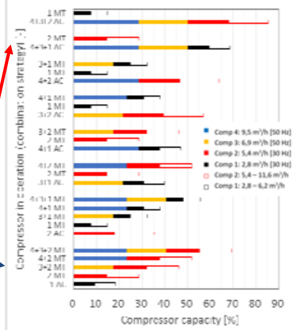
Example 4 Compressors:

MT and AC suction unit
(parallel compression)

Pivoting principle:

- Four compressors:
  -> min/max suction flow rate: 2,8 / 34,2
- High summer AC load
- Low load on parallel compressor (spring/fall)

Reduction in investment cost!



Latest developments

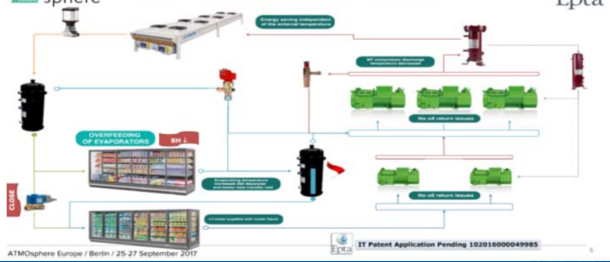
Epta

Flooded MT Evaporators

ATMO sphere

CO_2 Transcritical FTE System

Epta



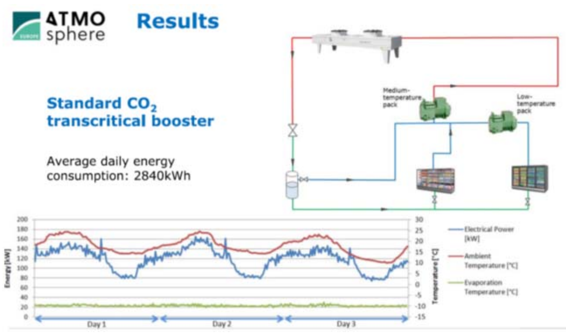
ATMO sphere

Results

Epta

Standard CO_2 transcritical booster

Average daily energy consumption: 2840kWh



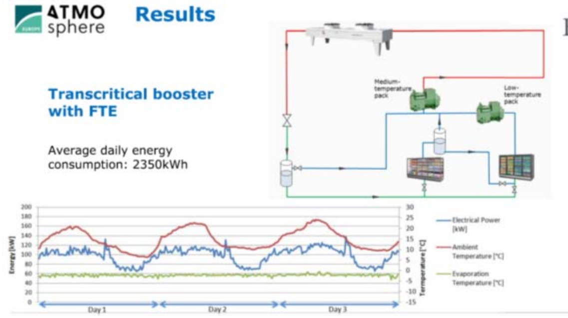
ATMO sphere

Results

Epta

Transcritical booster with FTE

Average daily energy consumption: 2350kWh



Carrier

FURTHER ENHANCEMENTS IN
THE APPLICATION OF MODULATING EJECTORS
SASCHA HELLMANN

ATMO sphere

NATURAL EVOLUTION

Carrier CO_2 technology status

More than 15 years of CO_2 projects

> 6500 CO_2 racks delivered[1]

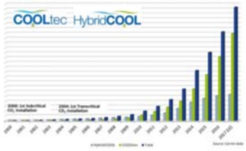
Sustained evolution, continuous improvement

Evolution of…

- **Technology**: HFC/CO_2 cascade → **full CO_2**
- **Applications**: Supermarkets → **all formats**
- **Climates**: Mild / cold → **all climates**

CO_2 refrigerant: Efficient, environmentally balanced, with A1 safety classification

Project Evolution: Carrier Commercial Refrigeration

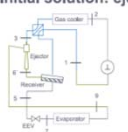


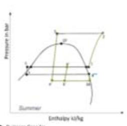
[1]Status as of end July 2017. Transcritical & subcritical, all brands

2

HIGH EFFICIENCY TECHNOLOGIES

Initial solution: ejector system with economizer cycle





First applications of high-efficiency technologies:

- **Baseline standard transcritical CO_2 system**
- **Economizer cycle (parallel compression)**
  Additional compressor to compress flash gas at a higher pressure level
- **Carrier modulating ejector**
  Pre-compression of 100% of the MT suction flow

Annual rack energy savings up to 20%[1], vs. initial transcritical CO_2

Especially beneficial for warm climates

[1]Rack only. Based on model store in warm climate. Compared to 1st generation transcritical system.

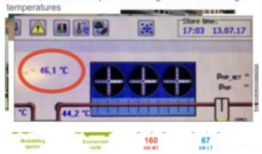
3

INITIAL HIGH EFFICIENCY TECHNOLOGIES

Case studies 1 & 2

Location:	Puertollano, Spain
Application:	Supermarket
Solution:	Modulating ejector Economizer cycle
Commissioned:	Q4, 2015

Efficient, trouble-free operation during recent extreme high temperatures



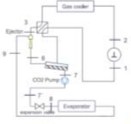
Location:	Venelles, France
Application:	Cash & Carry
Solution:	Modulating ejector Economizer cycle
Commissioned:	Q4, 2015

Full heat reclaim system w/ gas cooler bypass

4

LATEST HIGH-EFFICIENCY TECHNOLOGY

Flooded system with ejector and CO_2 pump



CO_2OLtecEvo baseline system:

- **Carrier modulating ejector**
  Reduced compressor work by pre-compressing the MT suction flow
  Optimal capacity-matching and part load performance across the entire range of operating conditions
  High entrainment / low pressure lift ejector; optimized to compress 100% of the MT suction vapor

- **CO_2 pump**
  Reduced energy consumption via full-year MT flooded operation
  Full-year flooded operation allows higher evaporating temperatures, delivering reduced energy consumption all year round
  No minimum high pressure is needed to operate the ejectors, so even the smallest pressure gains are utilized

COOLtecEvo provides a simple, high-efficiency flooded solution for all climates

5

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8. Practical advices: R744 / CO_2

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Content

- Materials and gaskets
- CO_2 and oil
- CO_2 and water

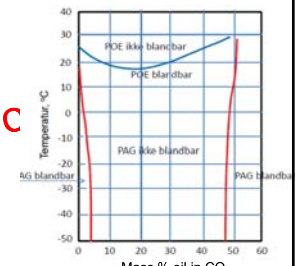
Materials and gaskets

- Possible low temperature (- 78 ℃)
  - Ductile materials (stainless steel, copper)
- CO_2 is generally not corrosive
- CO_2 at high pressures can migrate into gasket materials over time and case fractures
  - Natural rubber gaskets are discouraged
  - Standards neoprene/polychloroprene gaskets at pressures below 50 bar

CO_2 and oil

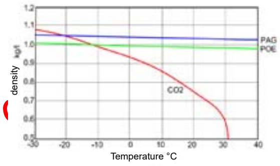
- CO_2 lubricants: POE, PAG, PVE and PAO
- POE:
  - Best miscibility with CO_2
  - Can form 2 phases at certain temperature (heavy oil media and heavy refrigerant)
- PAG:
  - Partially soluble in liquid CO_2
  - Necessary with oil-separator

Solubility of POE and PAG in CO_2 liquid



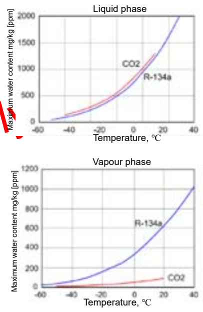
CO_2 and oil

- CO_2 density increased with increasing temperatures
- POE/PAG have relatively constant densities
- At -10/-20°C the density difference between the fluids change sign
  - **Oil accumulation in the bottom of MPRs**
  - **Oil accumulation in the top of LPRs**
- Problems related to this can be avoided by keeping the amount of oil **below** the solubility limit



CO_2 and water

- Water is one of the major challenges in CO_2 system
  - CO_2 can react with water and form a corrosive carbon acid
- Low solubility for CO_2 in vapour phase
  - Free liquid formation during evaporation of CO_2 with high water content
  - Water accumulates in the low pressure side of the system



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NTNU

9. Safety consideration when dealing with CO_2 systems

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Content

- Physical effects and safety measures
- Pressure and temperature precautions
- Dry ice safety and operational measure

Pressure and temperature precautions

- CO_2 is non-toxic (simple asphyxiant)
- CO_2 emissions will displace air
- Odourless
- (IDLH) 5 % (5000 ppm) – breathing difficulties, increased pulse, headache, etc.
- 2.2 times heavier than air at 20°C – collects in low-lying areas
- Leak detector required when leakage exceeds 70 gram per m^3

IDLH – Immediate Danger for Life and Health

Dry ice safety and operational measure

- CO_2 heat pumps have relatively high operating pressures
  - Materials operate closer to the rating pressure
  - Important with adequate procedures during pressure testing
- The CO_2 pressure can rise if the system is deactivated
  - Separate cooling system or controlled blowout
  - Safety measures against overfilling
  - Label all manual valves
  - Procedures for system deactivation and drainage
  - Proper pressure dimension filling station pressure

Pressure and temperature precautions

- Dry ice formation at pressures below 5.18 bar
- Safety measures:
  - Install manometer on system drainage equipment
  - Ensure that there is no liquid in the equipment before exposure to the ambient (1 bar)
  - Drain through pressure regulative valve that holds 6 bar
  - Drain to containers that hold a minimum of 6 bar
- Placement of safety valves:
  - Internal blowout of safety valve for overfilling
  - Safety valves for vapour is places far from liquid levels
  - Safety valve for sat vapour (above 40 bar/overcritical) placed at the end of the blowout tube

Summary

- CO_2 is an non-toxic and environmentally friendly working fluid
- CO_2 is superior in comparison to conventional working fluids for low temperature applications
- High energy efficiency if the **gas cooler/condenser temperature is below 30 °C**
- CO_2 systems for refrigeration, freezing and domestic hot water are well developed
- Great potential for heat recovery to several temperature levels when the CO_2 system is in the transcritical region

ADVANSOR by HILL PHOENIX

CO_2 based refrigeration systems for cooling and heating

March 2017

ADVANSOR

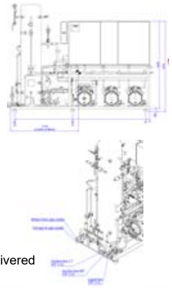
Installation and start-up

- Complete system from Advansor
  - Compressor rack, electrical panel, safety valves
  - Indoor/ outdoor
  - Condenser/ gas cooler – close coupled or remote
  - Evaporators for cabinets and storage
- Installation
  - Connection of gas cooler with K65 copper pipes (brazed) or steel?
  - Connection evaporators with (standard) copper pipes
  - Pipe dimensions/ pressure drop
  - Pipe layout: oil return
  - Pipe supports and insulation
- Start up
  - Pressure Testing and evacuation
  - Mounting of filter dryers and filling of oil
  - Filling of CO_2 gas and CO2 liquid
  - Start up of MT and then LT
  - Ensure correct operation: controls, CO2 and oil charge

ADVANSOR

Installation and service

- Basic design
  - 800 mm width
  - Low foot-print
  - Easy to service – all components
- Vibration feet's
  - Rubber or springs
- Connections
  - 3 x Mechanical + 1 x electrical
- Handling
  - Center of mass
  - Lifting points
- Full 3D drawings
  - Dimensions
  - Connections
  - Spare parts
  - We always know what we have delivered



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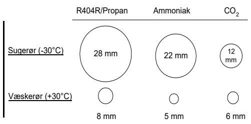
Pipes to be attached to the pack

- Pipes connecting the gas cooler (steel)
  - Carbon steel -> paint
  - Stainless -> paint not necessary
  - K65 copper -> no treatment
  - Use same dimension as connecting pipe on pack
  - Insulation not necessary (unless condensation or protection hot surface)
- Pipes for evaporators – liquid/ suction (copper)
  - Use copper
  - Remember to insulate (also liquid lines)
  - Silver/foscor brazing
  - Make schematics for lay-out
- Connection for PRV's
  - Hydraulic hoses to manifold (mounted by Advansor)
  - Use 1 5/8" copper pipes to connect to ambient (or DN 40 steel)

ADVANSOR

Smaller pipes (liquid and suction)

Tryktabsberegning	
Sugeledning og væskeledning	L = 20 m
Kuldeydelse	Q = 10 kW
Tryktab i sugeledning	dP ~ 0.5 K
Tryktab i væskeledning	dP ~ 1 K
Rørene regnes hydraulisk glatte med turbule	
Kondenseringstemperatur	Tc = -5°C
Fordampertemperatur	Te = -30°C



		CO2	NH3	R22
Sugeledning:				
Tryktab i 20 m ledning	[bar]	0,221	0,029	0,034
Hastighed af damp	[m/s]	7,121	17,330	9,165
Diameter for sugeledning	[mm]	12,550	22,010	28,740
Relativt til NH3	[-]	57%	100%	131%
Friktionsfaktor	[-]	0,015	0,021	0,016
Væskeledning:				
Tryktab i 20 m ledning	[bar]	0,789	0,137	0,141
Hastighed af væske	[m/s]	1,489	0,592	0,626
Diameter for væskeledning	[mm]	5,282	4,839	8,168
Relativt til NH3	[-]	109%	100%	169%
Friktionsfaktor	[-]	0,020	0,031	0,024

Husk enkelttab!

ADVANSOR

Pipes: material, pressure, insulation, support

- Copper standard (liquid line + suction side MT/ LT)
  - 80 bar => max. 1/2"
  - 60 bar => max. 7/8"
  - 52 bar => max. 1 1/8"
  - 40 bar => max. 1 5/8")
- Copper K65 (connecting rack and GC)
  - Up to 2 1/8" for 120 bar
- Pipe support
  - Use metal supports (polymer inliner)
  - Avoid stress/ vibrations
- Insulation (Armaflex)
  - LT suction: 19 mm
  - HP return, MT suction, liquid: 13 mm

Table 5 — Recommended maximum spacing for supports for copper pipe

Outside diameter (mm)	Spacing (m)
15 to 22 soft	2
22 to < 54 half hard	3
54 to 67 half hard	4
NOTE Information on soft and half hard is given in EN 12735-1 and EN 12735-2.	

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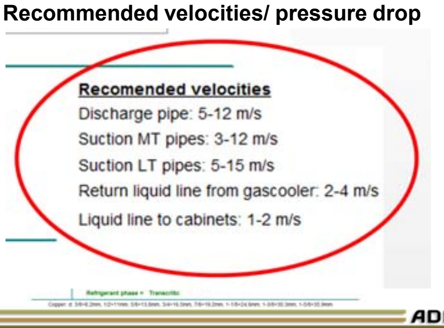
Recommended velocities/ pressure drop



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Pipes dimensions

Pipes connecting the gascooler

GC capacity [kW]	Massflow [kg/s]	Discharge line ["] / [m/s]	Return line [“] [m/s]	Pressure drop GC 10 m + 4 bends [bar]
55 (max)	0,260	1/2” / 12,9	1/2” / 3,1	1,24 bar / 0,35 bar
55 (max)	0,260	5/8” / 6,9	1/2” / 3,1	0,41 bar/ 0,35 bar
3,1 (min)	0,014 (6%)	1/2” / 0,7	1/2” / 0,2	0,007 bar/ 0,02 bar
3,1 (min)	0,014 (6%)	5/8” / 0,5	1/2” / 0,2	0,002 bar/ 0,02 bar
Max GC capacity is at MT/ LT = 32,4/3,3 kW, 34C, 92 bar				

Capacity [kW]	Massflow [kg/s]	Liquid line dim ["] / [m/s]	Suction line (MT/LT) ["] / [m/s]	Pressure drop suction 10 m + 4 bends [bar]
1	0,004	3/8” / 0,1	3/8” / 0,8/ 1,5	- / -
2	0,008	3/8” / 0,2	3/8” / 1,6/ 3,0	0,02 bar/ 0,04 bar
3	0,012			
4	0,016	3/8” / 0,3	3/8” / 3,2/ 6,3	0,07 bar/0,13 bar
8	0,032	3/8” / 0,5	3/8” / 6,4/ 12,5	0,24 bar/0,4 bar
16	0,064	3/8” / 1,0	1/2” / 7,6/-	0,23 bar/-
32	0,128	1/2” / 1,2	1/2” / 15,2/-	0,76 bar/-
Calculated with 38 bar receiver pressure, MT/LT = -8/-30°C evap, 8 K superheat (2 K not usefull)				

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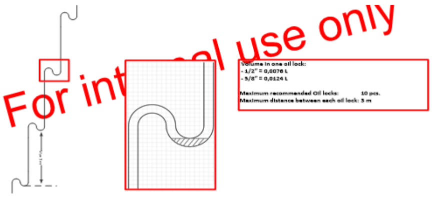
Selection of orifices in AKV valves

Capacity [kW]	Orifice size (MT / LT)	Orifice max capacity (MT/LT) [kW]
0-1	10-1/ 10-1	1,7/ 2,5 kW
1,5	10-2/ 10-1	2,7/ 2,5 kW
2	10-2/ 10-2	2,7/ 4,0 kW
3	10-3/ 10-2	4,3/ 4,0 kW
4	10-4/ 10-3	6,8/ 6,5 kW
6	10-4/ 10-4	6,8/ 10 kW
10	10-5/ 10-5	10,5/ 15 kW
15	10-6/ 10-6	16/ 25 kW
20	10-7/ 10-7	25/ 40 kW

Design for 80% open at full load and no subcooling
Design for low velocities in liquid line in front of expansion valve (0,5 - 1 m/s)

Pipes for the gas cooler (K65!)

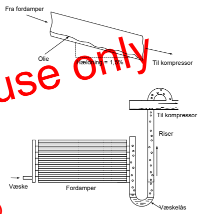
- The gas cooler can stand lower or higher (30 m)
  - Higher -> remember oil locks every 10 m (max 1-2 l oil traped)
  - Lower -> more liquid sub-cooling is nessesarry (set parameter in controller)



Pipe dimension	90° bend center radius [mm]	lenght of half circuit [mm]	di pipe [mm]	area pipe [mm2]	volume half circuit [mm3]	volume half circuit [L]	volume 10xoil lock's [L]
1/2	19,00	59,69	12,70	126,68	7.561,38	0,0076	0,075614
5/8	20,00	62,83	15,87	197,81	12.428,64	0,0124	0,124286

Installation of pipes (store, liq/suction)

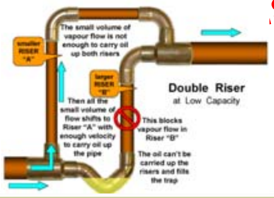
- Slope on suction lines (1%)
- Vertical suction lines:
  - Oil locks at every 3 m
- Riser at vertical suction lines
  - Riser one dimension down?
  - Double riser normally not used?

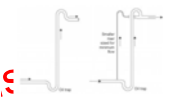


- Insulation of liquid lines (13 mm)
- Insulation of suction lines (13/19 mm)

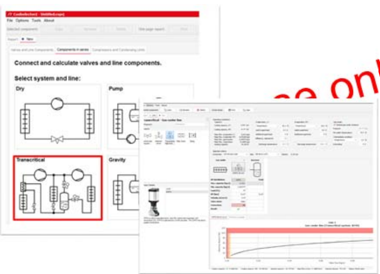
Installation of pipes – double vs single riser

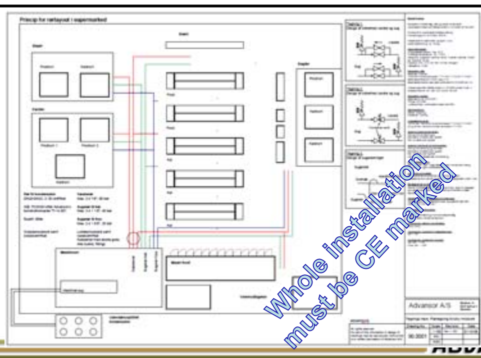
- Riser/ liquid trap for every 3-5 m
- Double riser normally not used
- What works with HFC also work with CO2





Calculation tool – COOLselector 2





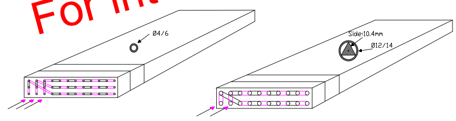
Whole installation must be CE marked

Part 7
Evaporators
Condensers/ gas coolers

Evaporators

- Pipes in evaporators (cabinets): max. 3/8”
- Pipes in evaporator (rooms): max. 1/2”
- Parallel Circuits: 1-3

- Controls: AKVH EXV
- Defrost: Electrical



Evaporators for cabinets (multideck)

Arneg Multideck	Internal volume evaporator [l]	Pipe diameter IN [mm]	Pipe diameter OUT [mm]
250	6,4	Max. 8	12
375	10	Max. 8	14

- Line of multideck is composed by cabinets as below (average 32,5m)
  - a. 250 cm – 1849 W – 2 circuits – 1,1 m/s (pressure drop = 0,1 bar)
  - b. 375 cm - 2744 W – 3 circuits
- Total volumen for 32,5 m = 83 l (30% void) = 25 l liquid
- Designe pressure PS=60/ 65 bar

Defrost

- Electrical
  - Solenoid closes
  - After 3 min. fans are stopped
  - Heaters energized
  - Length of defrost controlled by temp. + max. timer
  - Heaters turned off
  - After 3 min. solenoid opens (dripping delay)
  - After 2 min. fans are stating (fan delay = drip fixing)
- Natural (no heaters)
  - Fans are on
- Hotgas
  - Samme procedure as with Electrical
  - Beware of defrost scheduling to ensure sufficient heat

Condensers/ gas coolers

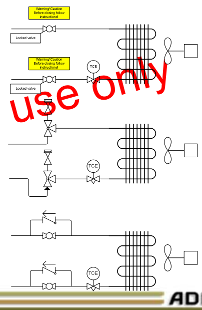
Condensator/ gas cooler installation (CO_2):
- Pipes: 1/4” or 3/8”
- Small volume as possible
- dT = 2-3K
- Service breakers
- EC fans
- Sound pressure = 30-40 dB(A) in 10 meters

Valve arrangements - evaporators

Solution 1: (preferred)
Allowed when:
- Valves not “automated”
- Locked valves
- Instructed personal
- Producedure (sticker)

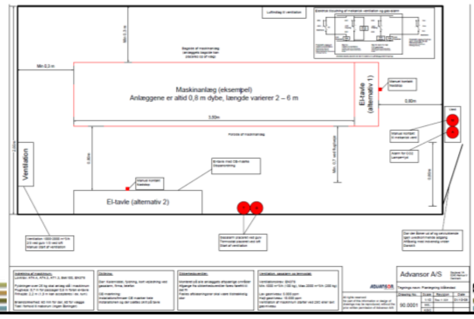
Solution 2:
- Use of relief valves
- Do not place relief valve inside store
- Risk of failure

Solution 3:
- Use of check valves
- Risk of leaks
- Risk of improper func. (not tight)



Part 7
Machine room

Design of machine room



Machine room

Part 7
Commissioning
”Quick start guide”

Commissioning

- Refer to User manual and Quick start guide!!

Part 8
Service and maintenance

User manuals

- 0_1_UK Index 20 user manual pdf
- 1_0_Who is who_UK pdf
- 3_1_UK Handling and Safety compSUPER ver 1_1_opd pdf
- 5_1_UK Quick start ver 1_4 pdf
- 5_2_UK Service manual Advansor ver 1_2 pdf
- 5_3_UK User manual compSUPER XSVP ver 1_2 pdf
- 5_4_UK User manual compSUPER S ver 1_2 pdf
- 5_6 User manual VGV EN_final LR_MHN 1 pdf
- 5_7 Guide - sequence of operations_UK - Maj 2014 - ver3 pdf
- UK_5_5 User manual SIGMA ver 1_1 pdf

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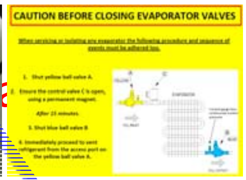
Safety valves

Locked valve in front of safety valves:

No safety valve on evaporators:



No safety valves by evaporators

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Danish pratice

Sticker on external valves:

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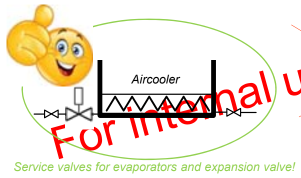
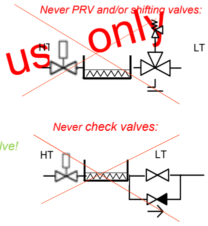
Safety valves – Danish practice

To do and NOT TO DO





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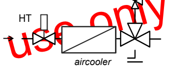
CO_2-leak at Migros (Switzerland)

Don't do this:



%CO2	Symptoms
2 to 3	Shortness of breath, deep breathing
5	Breathing becomes heavy, sweating, pulse quickens
7.5	Headaches, dizziness, restlessness, breathlessness, increased heart rate and blood pressure, visual distortion
10	Impaired hearing, nausea, vomiting, loss of consciousness
30	Coma, convulsions, death

0,5% CO2 (=5000ppm) is normal gas detector setpoint

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CO_2-leak at TESCO (UK)

Don't do this:

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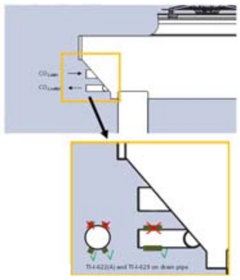
Service and maintenance

- User manual
- Service description (like HFC)
  - Oil
  - Filter dryer
  - CO_2
  - Semihermetic compressors
  - Heat exchangers
- General service step by step
  - Pump-down to receiver
  - Discharge of refrigerant
  - Repairing
  - Evacuating, pressure build up and re-start
- Annual compulsory inspection (test of safety – national rules)
  - Safety pressostats every year
  - Safety valves every second year
  - Containers every fourth year

Gas leaving sensors on gascooler drain pipe:

TI-I-622(A) and TI-I-623 must be mounted on outlet from gascooler at 5 or 7 o´clock on a horizontal pipe, min 30 cm from the gascooler, as shown on sketch .

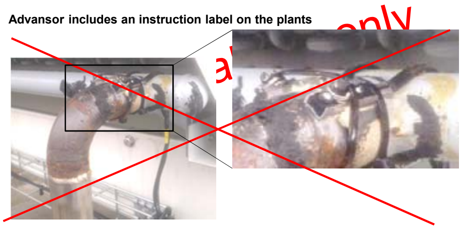
Materials to use:
- Metal clamps
- Thermal paste
- Waterproof insulation



Gas leaving sensors on gascooler drain pipe:

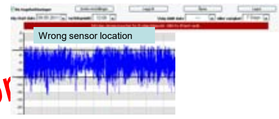
Correct mounting: insulated and at ”5+7 o'clock”.
Newer on top of pipe as shown below!!

Advansor includes an instruction label on the plants



Impact

- Wrong sensor location: MT fluctuates
- Wrong setting on LT cabinets: LT fluctuates



Wrong setting on LT cabinets

Water content? Acid formation?

- Water in CO2 < 10 ppm
- Water in oil < 30 ppm

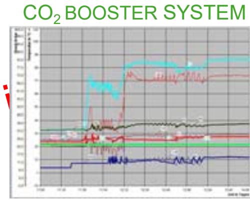
Keep water content low
Evacuate – tipple break with nitrogen

After operation
Water in oil max. 300 ppm?
TAN (Total Acid Number) = 1-2?

Advansor is currently investigating the acceptable limits and test methods!

CHEMICAL REACTIONS

COMMISSIONING:
CO_2 BOOSTER SYSTEM



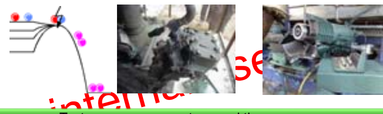
BITZER Kühlmaschinenbau GmbH

Status August 2017

CLEANLINESS

PRESSURE AND LEAK TEST

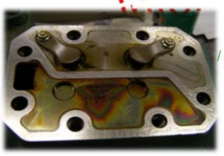
- With dry nitrogen, not with air or oxygen



- Compressors: Test pressure may not exceed the max. pressure indicated on the name plate (strength – and leak test in the factory)
- Pipe work: Strength test acc. EN 378-2 ➡ MOP x 1.43 and min. 1.1, respectively (≥ category II) // subsequent EN12799 (brazed connection), EN12517 (welded connection)
- Pipe work: Leak test acc. EN1779 MOP x 1.0
- Isolate different sections of the system, logged data: pressure and temperature

CHEMICAL REACTIONS

- Moisture and high temperatures can trigger chemical reactions

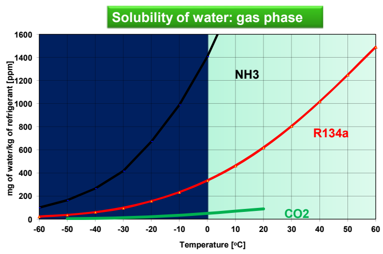


- CO_2 with POE-oil is an effective solvent
  - Pollutants of the whole system will accumulate inside the compressor
  - This may easily create chemical reactions

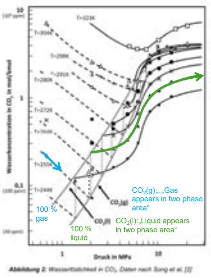
CHEMICAL REACTIONS: DISCHARGE TEMPERATURE & MOISTURE

CHEMICAL REACTIONS

SOLUBILITY OF WATER: EVALUATION IN THE PAST

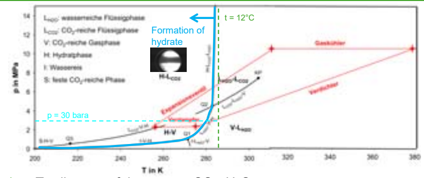


SOLUBILITY OF WATER



- CO_2 gas: Solubility of water is reduced for p = ↑, t = *const.*
- Significant difference: Solubility of H_2O in gas and liquid phase
- CO_2 liquid: Solubility of water is increased for p = ↑, t = *const.*
- CO_2 gas & liquid: Solubility of water is reduced with lower temperatures

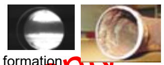
CHEMICAL REACTIONS



- p-T - diagram of the system CO_2–H_2O Reference: Ullrich, A., Hydratbildung bei der Hochdruckentspannung von feuchtem CO_2
- Phase characteristic of the system CO_2–H_2O in a trans-critical cycle Reference: Petereit, K.A., Eggers , R., Experimentelle Methoden zur Bestimmung des H_2O-Gehalts im CO_2-Kreislauf
- Formation of hydrate downstream the expansion device in all standard applications
- No adsorption of hydrate by molecular sieves!

EVACUATION

Moisture and CO_2



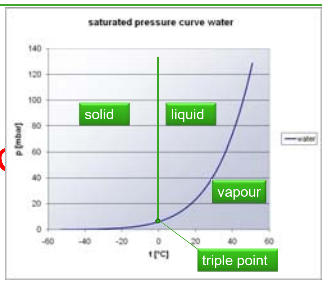
- CO_2 vapour: low solubility of water
  - Acidification, corrosion, ice and hydrate formation
  - Suitable filter dryer, generously dimensioned in liquid line
  - CO_2 with low water content (< 5 ppm, e.g. purity class 4.5)
  - Break vacuum with dry nitrogen several times

How to remove moisture?

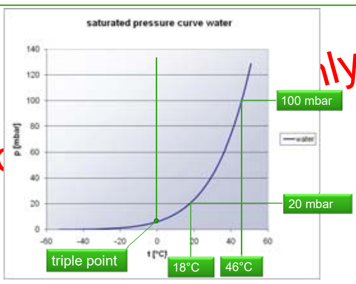
- Zeolithe (micro porous & crystalline) filter dryer cores
- Water is very polar
- CO_2 is non-polar

- Both molecules with approx. the same size
- Water molecules get adsorbed by the molecular sieve
- High polarity of water displaces CO_2 from the molecular sieve

EVACUATION



EVACUATION



EVACUATION

- Liquid water can still be present at a system pressure of 23 mbar and an ambient temperature of < 20°C
- **Water can hardly be removed only by evacuation**
  - Evaporation of water by evacuation takes a long time
  - Break vacuum two to three times with dry nitrogen
- Solid state conditions should be avoided because of ice formation
  - No temperatures below 0°C
- **Recommended standing vacuum: 500 microns ≈ 0.7 mbar**

EVACUATION

For small to medium size systems:

Check the quality of the vacuum after 3 – 4 hours:

- $\Delta p > 23$ mbar → Leakage
- $\Delta p \leq 23$ mbar → Hermetic with certain content of water
- $\Delta p \leq 0.5$ mbar → O.K.

Reference: Hainbach C. (Hrsg.), Krug N. (Hrsg.) (2008): Pohlmann – Taschenbuch der Kältetechnik. 19. Aufl. Heidelberg, München, Landsberg, Berlin: C.F.Müller, Verlagsgruppe Hüthig Jehle Rehm

EVACUATION

Example:

/ The specific vapour volume of water at 20°C is v = 57.9 m^3/kg

/ Assumption: Performance data of vacuum pump:

$\dot{V}_{Pump}$ = 200 l/min = 0.2 m^3/min = 12 m^3/h

/ Water content inside the system: m = 0.5 kg

/ $V_{gas\_H2O} = v \cdot m$ = 57.9 m^3/kg • 0.5 kg = 28.95 m^3

/ $t = V_{gas\_H2O} / \dot{V}_{Pump}$ = 28.95 m^3/ 12 m^3/h = 2.41 h

It takes 2.5 hours to dry the plant by evacuation with the pump!

We recommend to evacuate the plant to about 20-30 mbar and break the vacuum several times with dry nitrogen!

EVACUATION

What do you measure?

Reference: Fischer Kälteklima, catalogue 2009

/ Analog vacuum meter:
- Accuracy class 1.
- Measurement range 0-150 mbar
- Absolute accuracy 1.5 mbar

/ Digital vacuum meter:
- Accuracy 10 % for atm. $\leq p \leq$ 1.33 mbar
- Accuracy 7 % for 0.133 mbar $\leq p \leq$ 1.33 mbar
- Accuracy 3 % for 0.0013 mbar $\leq p \leq$ 0.133 mbar

Reference: www.mastercool.com

LEAKAGE

Use of the CO_2 leakage detector:

/ Turn the detector on
- Heating up the infrared cell (1 min.) – LEDs in running mode
- Detector ready for use + short sound / LEDs in running mode turned off

/ Leak detector probe as close as possible to the suspected leak (≤ 5 mm)

/ Moving probe slowly (2,5 – 5 cm/s) past every possible leak point

Reference: operating manual – D-TEK Select Refrigerant Leak Detector, Inficon / www.infocon.com

LEAKAGE

/ Detector only responds to changes in concentration

/ Leak detection => LEDs illuminate / sound is emitted

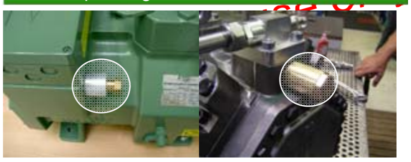
/ Leak is detected => pull away probe and bring it back to pinpoint the leak

/ Too high refrigerant concentration:
- Press sensitivity button to switch to low sensitivity setting

Reference: operating manual – D-TEK Select Refrigerant Leak Detector, Inficon / www.infocon.com

PRESSURE RELIEF VALVES

Have you ever experienced a pressure relief valve responding?



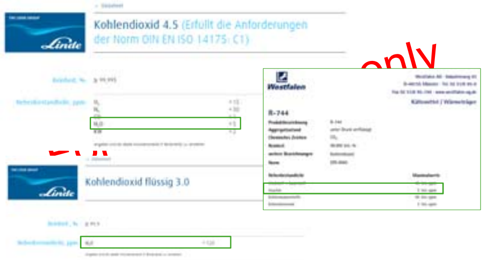
Let us see!

REQUIREMENTS ON CO_2 AS REFRIGERANT

Because of special requirements of CO_2 plants regarding moisture:

- We recommend to use special refrigerant CO_2 or CO_2 of purity class 4.5 (max. 5 ppm of moisture)
- According to EN 51503-1 for fresh oil and EN 51503-2: Maximum moisture content fresh oil = 100 ppm (BITZER 30 ppm), warning level used oil = 150 ppm
- If you use CO_2 of the purity class 3.0:
  - Only charge via filter dryer
  - Change the filter dryer several times
  - Make sure that no moisture penetrates the system during maintenance work

REQUIREMENTS ON CO_2 AS REFRIGERANT



Reference: Linde, Westfalen AG

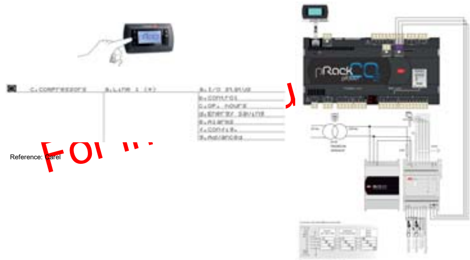
MOST IMPORTANT: VERIFICATION

Verification of the proper function of all protection and monitoring devices

Check list:

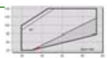
- Calibration of sensors and transmitters
- Signal and logic check
- Check for cross wirings
- Awareness of layout data, such as max. permissible pressures @ standstill and in operation, temperature differences in HX, etc.
- Pipelines and instrumentation diagram on site

RACK CONTROLLER FOR THREE SUCTION LINES, FGB-VALVE, HP-EEX, ..



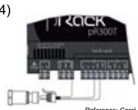
Reference: Carel

PARAMETERS RELATED TO HP-EEX AND GAS COOLER



Please control the following parameters*

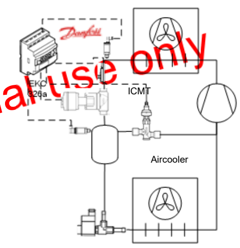
- HP-EEX and gas cooler
  - Max. opening degree HP-EEX, p100% (Eib05): 109 barg
  - Max. pressure HP-EEX provided as offset in case of heat reclaim, "safety" (Eib28): 90 barg
  - Min. pressure inside the gas cooler (Eib28): 45 barg
  - Signal / calibration pressure transmitter (Bab04)
  - HP-EEX safety position (Eib10): 50 %
  - Max. opening degree HP-EEX (Eib32): 100 %
  - Min. opening degree HP-EEX (Eib02): 0 %



Reference: Carel

* No general recipe for all kinds of system configurations

HIGH PRESSURE EEX – CONFIGURATION



Reference: Danfoss

HIGH PRESSURE EEX – CONFIGURATION

Please control the following parameters of the high pressure expansion valve*

- High pressure expansion valve
  - Main switch (i01): 1 (automatic control)
  - Configuration, type of installed valve (i26): 1
  - Analog input signal (i03): 3 (0…10 V)
  - Failsafe operation (i07): 1 (closed position)
  - Self calibration (i05): 1 (active)

* No general recipe for all kinds of system configurations

PARAMETERS RELATED TO FGB-VALVE AND THE RECEIVER

Please control the following parameters*

- Receiver
  - Receiver pressure regulation (Eib18): YES !!!
  - Receiver pressure, reference value (Eib22): 35..40 barg (has to be equal to Cca04)
  - Signal / calibration pressure transmitter (Bab66)
  - Receiver pressure alarm value (Eib25): 48 barg
  - FGB valve safety position (Eib23): 50 %
  - Max. opening degree FGB valve (Eib21): 100 %
  - Min. opening degree FGB valve (Eib19): 0 %

* No general recipe for all kind of system configurations

PARAMETERS RELATED TO OPERATION OF PARALLEL COMPRESSION

Please control the following parameters*

- Parallel compression stage
  - Start parallel compression (Cca02)
    - Min. opening degree / time FGB-valve: 30 % / 60 s
    - Min. gas cooler outlet temp.: 24°C
  - Set point parallel compression (Cca04): 35..40 barg (has to be equal to Eib22)
  - Offset FGB-valve (Cca04): 3 bar
  - Stop parallel compression (Cca16): 22°C

* No general recipe for all kind of system configurations

CONTROLLER ISSUES

Please control the following parameters of the case controllers

- Case Controllers MT stage:
  - Reference value room temperature (St): 2°C
  - Start-up valve opening (CP1): f(Qo $_{evap}$/Qo $_{nom}$), e. g. 10..20 %
  - Reference value superheat (P3): 8 K
  - Low superheat threshold (P7): 4 K
  - MOP (PM1): 35 bars (= to 0°C)
  - Type of pressure transmitter (/P3): 4 => 0..5 V
  - Calibration pressure transmitter (/c6)
  - Type of valve, PWM or stepper: 2 (Carel stepper)

CONTROLLER ISSUES

Please control the following parameters of the case controllers

- Case Controllers LT stage:
  - Reference value room temperature: -22°C
  - Max. superheat (n09): e.g. 10 K
  - Min. superheat (n10): 6 K
  - MOP (n11): 20 bars (= to -20°C)

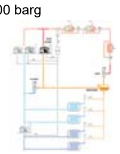
Set menu
1. Push the upper button until a parameter r01 is shown
2. Push the upper or the lower button and find that parameter you want to change
3. Push the middle button until the parameter value is shown
4. Push the upper or the lower button and select the new value
5. Push the middle button again to freeze the value.

Reference: Danfoss

PARAMETERS RELATED TO THE COMPRESSION STAGES

- MT-stage (line 1):
  - Reference value (Cab03): 27 barg
  - Neutral zone (Cab08): 1 bar
  - Load up and down time (start of additional comp) (Caf12): 15 s / 25 s *
  - Min. on and off time (Caf05): 5 s / 5 s *
  - HP load reduction of compression stage (Gba02): 100 barg

  * Short time delays just for the initial commissioning!



- LT-stage (line 2):
  - Reference value (Cbb03): 12 barg
  - Etc.
- Parallel compression stage (Parallel)

COMMISSIONING

Please bear in mind that the commissioning of CO_2 booster systems requires a careful approach!

- Considerable potential for lack of lubrication and overload caused by:
  - High pressure levels
  - High refrigerant solubility in oil
  - Strong pressure variations
  - Wrong parameter settings of controllers / valves
- Operating behaviour and conditions have to be observed carefully
- Last but not at least:
  - Supervision of the system during entire initial process of commissioning

CO_2 – SYSTEM START UP MT & LT BOOSTER SYSTEM WITH PARALLEL COMPRESSION

Note!

- Commissioning of the MT stage of a booster system is essential before the LT stage is commissioned
- In regard to the commissioning, the parallel compression stage is just an extension of the MT stage. Dependent on the ambient conditions, size and number of evaporators, the stage must be ready for operation before adding load to the system
- Once the MT stage is in operation, it must have attained stable operating conditions
- Please consider the influence of the FGB during the solely operation of the MT stage! Consider the system configuration and adapt the procedure accordingly if required (e.g. booster systems without IHX for the flash gas)

CHARGING REFRIGERANT – MT & LT BOOSTER SYSTEM

- Energise the crankcase heater(s) in LT and MT stage
  - Oil sump temperature(s) should correspond to 35 .. 40°C, at least 20 K above the ambient
- Check oil level of the compressor(s)
- **Do not switch on the compressor(s)!**
- Connect CO_2 gas cylinder at LP and HP side of the system: Pressure reducer and appropriate charging lines are required
- Purge the charging lines with CO_2 vapour

START UNDER VACCUUM

CHARGING REFRIGERANT - MT & LT BOOSTER SYSTEM

- Open the charging connection and break vacuum with CO_2 vapour up to approximately 10 bar
  - In case the gas cylinder is severely cooled down it should be warmed in a water bath (max. temperature 40°C)
- Shut the suction and discharge shut-off valve of the compressor(s) in LT and MT stage
- Make sure that LT evaporators cannot further be pressurized (close shut-off valves, EEV's, solenoid valves)

CHARGING REFRIGERANT - MT & LT BOOSTER SYSTEM

Continue charging of the MT stage of the system:

- Charge gaseous CO_2 into the receiver or inlet of the gas cooler
- Do not further charge the suction side of the MT system when approx. 20 bar are attained
- Make sure that MT evaporators cannot further be pressurized (close shut-off valves, EEV's, solenoid valves)
- Start manual operation of the fans of the gas cooler (liquefying CO_2 if ambient allows)
- Further charging of liquid into the receiver, therefore close liquid outlet (cylinders with dip pipe, stand still cooling unit)
- Minimum liquid level inside the receiver required before the start of the first evaporator
- Stop charging the receiver with appr. 30 bar*, ensure the pressure is below the reference value for the operation of the FGB valve

* Dependend on the MOP of the receiver

COMMISSIONING OF MT CO_2 COMPRESSORS

/ Start fans of first evaporator(s)

- Evaporator capacity may match the compressor capacity

/ Open the discharge shut-off valve of one (the) CO_2 compressor(s) in the MT stage and open the suction shut-off valve by turning the spindle just one turn*

/ Start the first evaporator(s) and start one (the) compressor in automatic operation, if necessary in manual mode

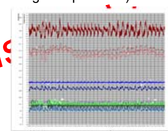
- Observe the operating pressures
- Keep throttling position of suction shut-off valve*
- Open it slowly with decreasing suction pressure*

/ Energise evaporator solenoid(s) as required according to compressor capacity

* A careful approach - dependent on system charge, evaporator sizes and capacities, etc. shut-off valves can be opened completely

COMMISSIONING OF CO_2 COMPRESSORS

/ Switch off the compressor immediately if application limits are exceeded or abnormal conditions occur (suction gas superheat?)



/ Avoid high start/stop cycles!

/ Start additional compressors in the MT and parallel compression stage and evaporators dependent on operating conditions

/ Adjust refrigerant charge as required

COMMISSIONING OF LT CO_2 COMPRESSORS

/ Start first evaporator(s) in LT stage (EEX and fans in operation)

- Evaporator capacity may match the compressor capacity

/ Open the discharge shut-off valve of one (the) CO_2 compressor(s) in the LT stage and open the suction shut-off valve by turning the spindle just one turn*

/ Start the first evaporator(s) and start one (the) compressor in automatic operation, if necessary in manual mode

- Keep throttling position of suction shut-off valve
- Open it slowly with decreasing suction pressure

/ Energise evaporator solenoid(s) as required according to compressor capacity

*** A careful approach - dependent on system charge, evaporator sizes and capacities, etc.**
shut-off valves can be opened completely

CO_2 – SYSTEM START UP - MT & LT BOOSTER SYSTEM WITH FGB

Danger!

If the valves of the gauges between the compressor or system and CO_2 gas cylinder are closed, ensure that no CO_2 remains inside the connecting hose!

CHECKING THE OPERATING DATA

After successfully commissioning and charging of the system, check operating data and prepare data protocol:

- Operating temperatures
  - Evaporating temperature and gas cooler outlet or condensing temperature
  - Discharge pressure
  - Suction gas temperature
  - Discharge temperature > 50°C
  - Oil temperature > 35°C
- Start / Stop cycles
  - MT: min. time for a start / stop cycle corresponds to 10 min
  - LT: min. operating time 2 min
  - max. starts per hour, MT: 6 & LT: 8
- Voltage & operating current in all three phases
- Change: suction strainer, filter dryer (200 h), oil separator (50 h)

FOR THE UNLIKELY EVENT OF A LOSS OF SYSTEM PRESSURE DUE TO AN INADVERTANT CO_2 – EMISSION DURING THE NEXT HOURS….

/ Leave room immediately (fork lift traffic!)

/ Inform and warn other participants

/ Wait for further instructions from the trainer in front of the training centre

/ If harmlessness of atmosphere has not been proven:

- Access area only with respirator

TROUBLE SHOOTING AND FREQUENT MISTAKES


BITZER Kühlmaschinenbau GmbH
Status August 2017

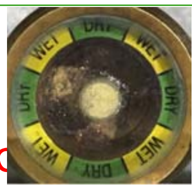
THE FOLLOWING SLIDES SHOW ROOT CAUSES FOR TROUBLES IN THE FIELD….

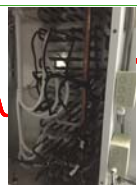
"DON'T DO THIS AT HOME!"

DIRT

Possible root cause	Remedy
Pipe cutting	Use pipe cutter
Welding and brazing	Use inert gas

MOISTURE



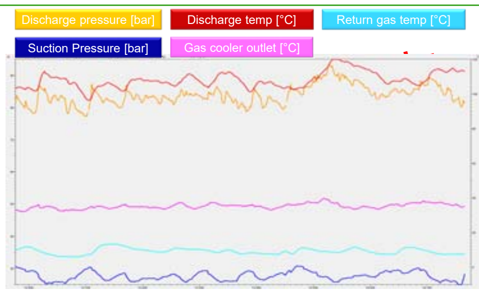


Possible root cause	Remedy
No effective evacuation	Check vacuum pump, connection of vacuum meter, open every section
Gas cooler in cold ambient	Use tent or heaters, purge with nitrogen
Leak test under vacuum	Perform leak test under pressure

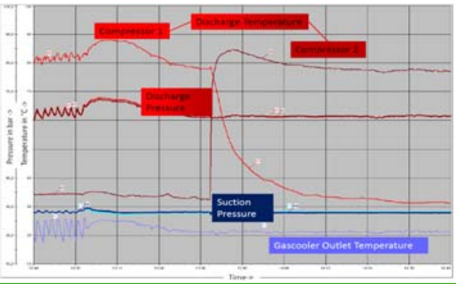
LIQUID SLUGGING

Possible root cause	Remedy
Liquid flood back	Fail safe EEX, check installation of pipe work, size of the receiver, refrigerant charge
Compressor flooded with oil	Too much oil inside the system, installation of pipe work, faulty oil management
Defrost operation in parallel	Reduce number of evaporators in parallel defrost operation

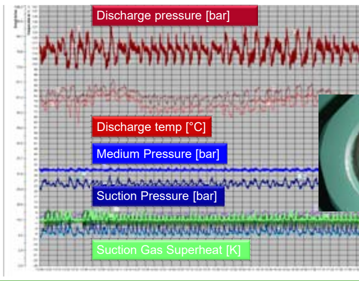
FLUCTUATING OPERATING CONDITIONS CAUSED ON EVAPORATOR SIDE…



FLUCTUATING OPERATING CONDITIONS CAUSED ON GASCOOLER SIDE…



…MAY CAUSE WET OPERATION AND DEGASSING EFFECTS



FLUCTUATING OPERATING CONDITIONS

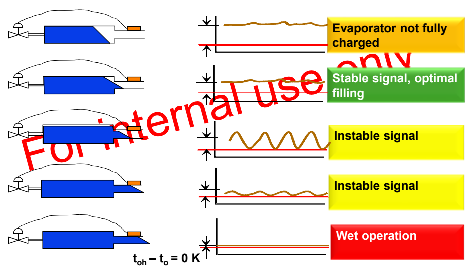
Possible root cause	Remedy
High evaporator capacity compared to rack capacity + high opening degree of EEX	Limit the start opening degree
Control of optimum discharge pressure	Keep gas cooler fans in operation to a minimum temperature, temperature probe not close to gas cooler outlet or in wrong position (5 or 7 o'clock)
Parameter setting for control of suction pressure	Evaluate neutral zone, time delays, actual vs. requested capacity and introduce changes only step by step

CAPACITY REGULATION

CAPACITY REGULATION

Possible root cause	Remedy
Parameter setting for control of suction pressure	Evaluate neutral zone, time delays, actual vs. requested capacity and introduce changes only step by step
Significant changes in capacity per step in capacity regulation	In the field: Try to change parameters to enable a more stable operation, e. g. higher minimum gas cooler pressure. During design stage: Increase the number of compressors, choose a different displacement for the lead compressor

CONTROL OF SUPERHEAT - WET OPERATION



CONTROL OF SUPERHEAT

Wrong control parameters may be the reason for:

- Fluctuating operating parameters, e.g. operating pressures
- Unstable superheat ➡ wet operation or liquid overfeed
- Low efficiency

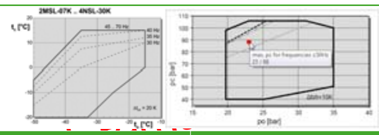
Adapt the parameters to the specific plant:

- Standard values from the control manufacturer may be helpful ➡ operating guidelines

OBSERVATION OF APPLICATION LIMITS

OBSERVATION OF APPLICATION LIMITS

OBSERVATION OF APPLICATION LIMITS



Possible root cause	Remedy
Operation close to the limits and overshoot of controls	Adapt PID control of involved valves and inverters, adapt parameter setting
Neglected influence of application limits in case of VSD	Change minimum discharge pressure or frequency
Influence of part load operation in a booster system on return gas temperatures	Evaluate the options for changing parameter setting, application of liquid injection or de-superheater

OVERSIZING IN CAPACITY

Operating time

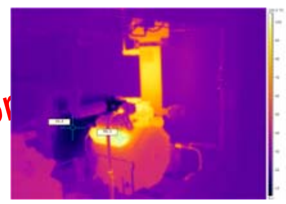
24 Std.	Total
100,0 %	13719 h
20,9 %	6731 h
2,0 %	1951 h
2,7 %	1952 h

On-Off-Cycles

24 Std.	Total
0,0	34
71,0	47786
5,0	5580
2,0	5185

OIL FOAMING WITH START-STOP-CYCLES

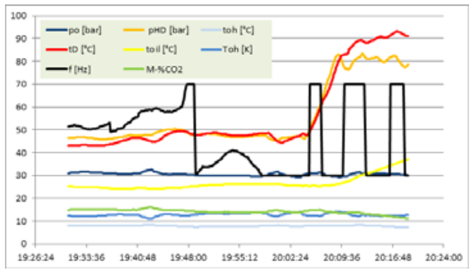
Start / Stop Cycle, 55 bar – 120 bar



Pressure equalization @ 60 bar

OIL MANAGEMENT

OPERATING TEMPERATURES



PULSATIONS AND VIBRATIONS – CRITICAL PIPE LENGTH

/ Calculation of the critical pipe length

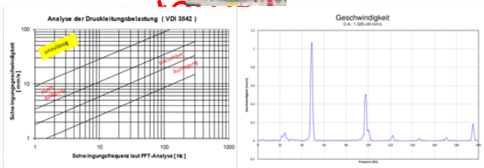
⇨ **Resonance!**

⇨ **Bursting of pipes** ⇨ Cu-pipes v_{smax} > 25 mm/s
St-pipes v_{smax} > 40 mm/s

$$\boxed{L_{crit.} = \frac{V_{sonic}}{2 \cdot z \cdot f_{compressor}}}$$

V_{sonic} = f (refrigerant, discharge temperature) in m/s
z = effective number of cylinders
$f_{compressor}$ = compressor speed in 1/s (= Hz)

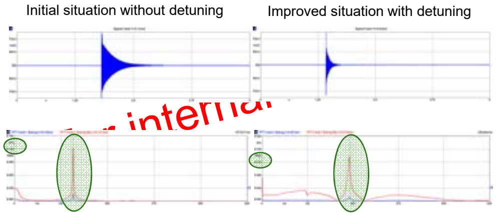
PULSATIONS AND VIBRATIONS – VIBRATION VELOCITIES



ACCELERATION OVER TIME AND FFT-ANALYSYIS OF THE VIBRATION VELOCITY

Initial situation without detuning

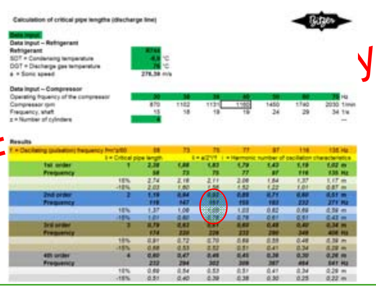
Improved situation with detuning



m/s²: Extended decay function
FFT: Peak with low natural frequency, high vibration velocity

m/s²: Short decay function
FFT: Peak with higher natural frequency, low vibration velocity

PULSATIONS AND VIBRATIONS – OSCILLATING FREQUENCIES



CHECK YOURSELF...

Exercise: Compile remarks for a reliable operation.

Thank you for your attention

Contact:

armin.hafner@ntnu.no