Global Trend in Industrial Refrigeration

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Agenda

Why The Changes?

Industrial Refrigeration systems had enjoyed a higher degree of stability in terms of refrigerant choices.

Ammonia has been the predominant choice thanks to efficiency and heat transfer properties. Subcritical CO_2 has been on the rise in Europe and North America

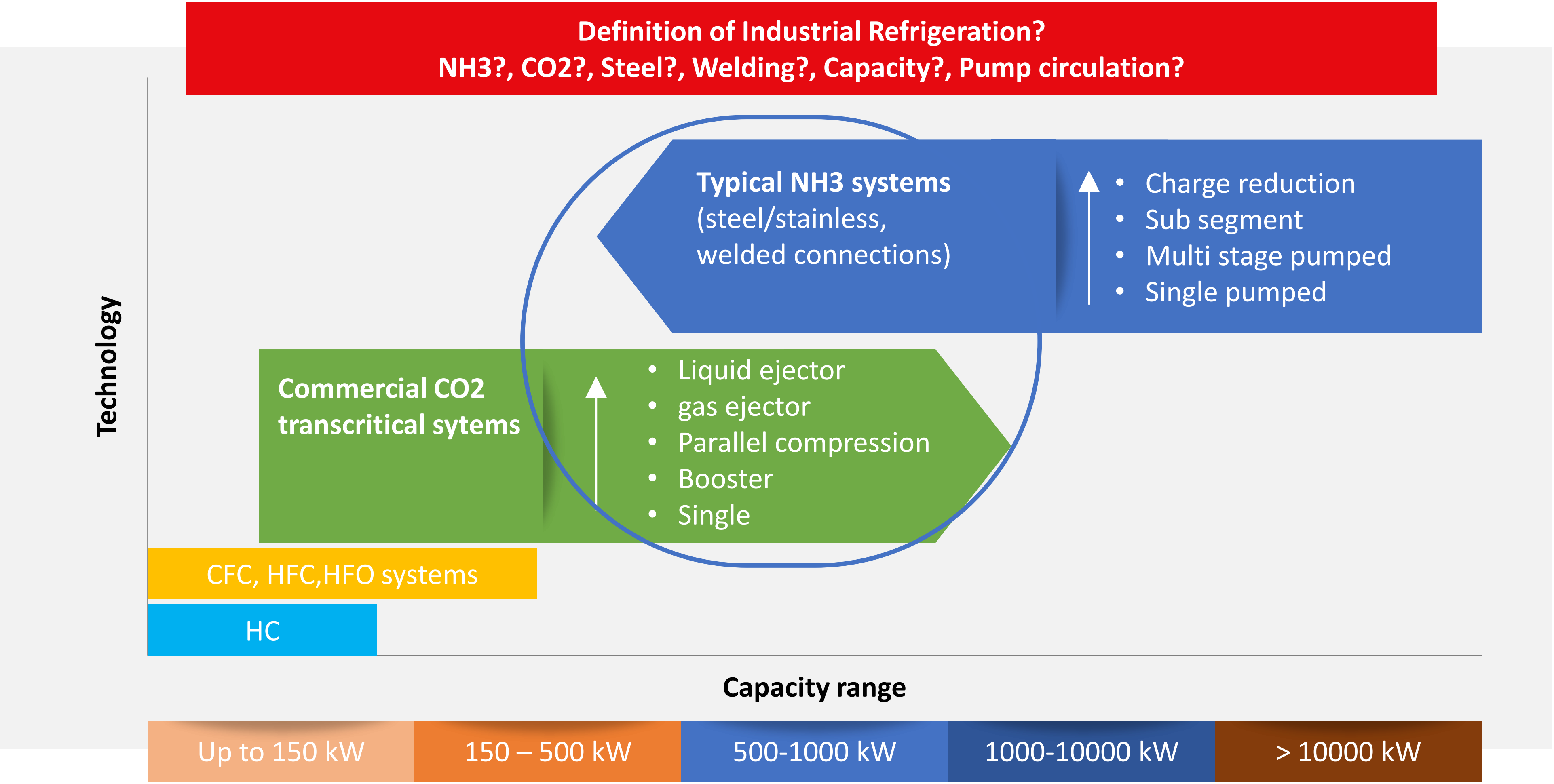
System Optimization has been key to development but also charge reduction in NH_3 systems

In some developing economies, Urbanization is playing a significant role in the design and choice of refrigeration systems.

In some applications, Transcritical CO_2 may be consider a good option.

01. Refrigeration System Developments -Industry reaction

Blending in of technologies and systems



02. Trend to NH3 charge reduction

How to reduce NH3 charge ?

4 MW ammonia system
Charge: 5 kg / kW
20.000 kg

A – Increase general safety level of system.

- Documented risk assessment.
- Offsite risk assessment.
- Safety quick closing section valves.
- Safety gas detection.
- Etc.

R717-charge
1 x 20.000 kg
(5 kg / kW)

B – Sub-segments

- Design system with a number of sub-segments, which can be separated from each other in the event of leakage.

R717-charge e.g.
4 x 5.000 kg
(5 kg / kW)

C – Ammonia-DX system

- Ammonia DX-system reduce the required liquid charge

R717-charge e.g.
2 x 5.000 kg
(2,5 kg / kW)

D – Ammonia-CO2

- Ammonia-CO2 cascade system or Ammonia-CO2 brine system

R717-charge
~2.000 kg
(0,5 kg / kW)

E – Low-charge Ammonia system

- Install a number of rooftop mounted self-contained ammonia units

R717-charge e.g.
8 x 200 kg
(0,4 kg / kW)

Charge reduction is an attractive mitigation solution (C, D, E)

F – CO2 TC

- CO2 booster system

Charge elimination

No R717-charge

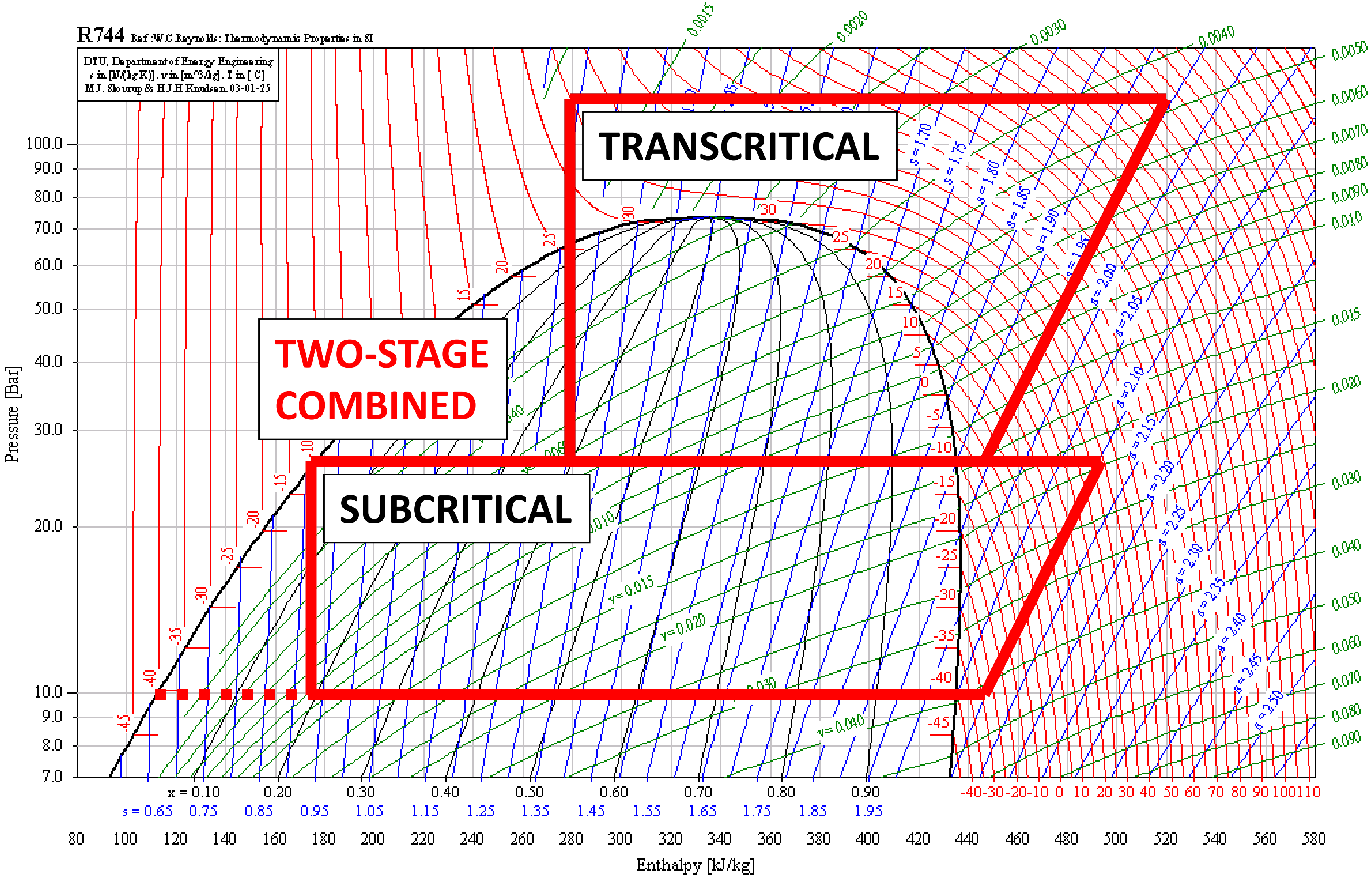
04. Industrial Systems

Variables to consider

System Design

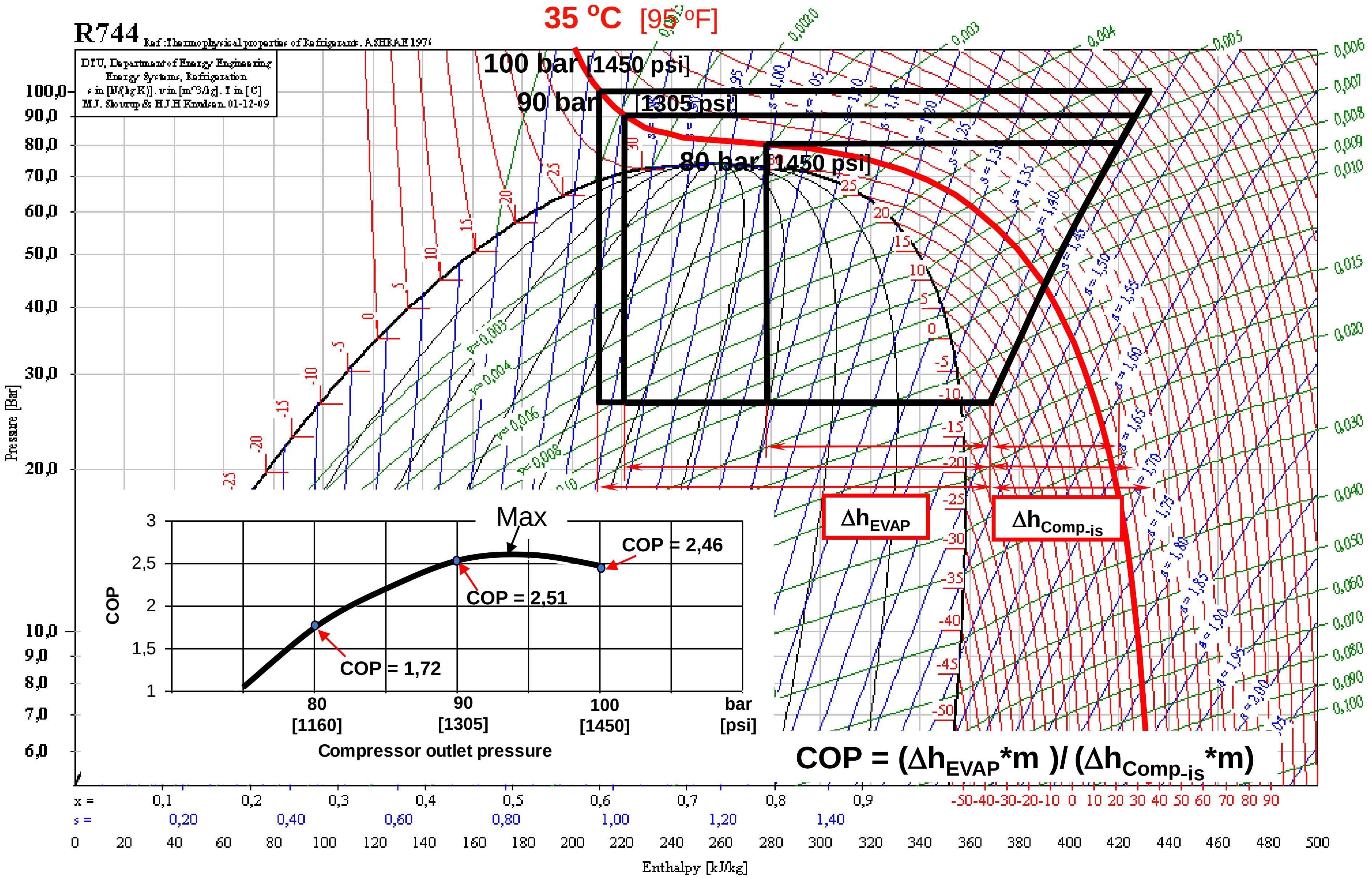
- Capacities: 1 to 5 MW / 300TR to 1500 TR
- Performance and Efficiency
- Maximum pressure ratings
- Components availability
- Efficiency of evaporators/system due to fouling. (e.g. Oil)
- Operators and contractors learning curve

Refrigeration cycles with CO_2 - General Overview



Transcritical refrigeration proces

Influence of compressor outlet pressure



02. Trend to NH3 charge reduction

Assessment of Emerging Systems Performance vs Traditonal

Fair Calculations have been made to provide an impartial assessment of industrial Ref Systems.
(White paper presented at IRC Montreal 2019, Thomas Lund-Danfoss)

- Two Stage R717, Pump circulation (2 Stage) Baseline
- R744/R717 cascade pump circulation
- Transcritical R744 DX Operation
- Transcritical R744 pump circulation
- Two stage R507, Pump circulation

02. Trend to NH_3 charge reduction

Calculations performed on three different latitudes 365 day

Table 1. Mean ambient temperatures for chosen locations

	Dry bulb temperature			Wet bulb temperature		
	Min	Max	average	Min	Max	Average
Rome	- 4.0°C	31.8°C	15.8°C	- 6.0°C	25.8°C	13.4°C
Frankfurt	- 8.9°C	33.6°C	10.1°C	- 9.3°C	22.4°C	7.7°C
Oslo	- 17.0°C	28.2°C	6.7°C	- 17.2°C	20.5°C	4.4°C

02. Trend to NH3 charge reduction

Compressor types used for calculations at different loads

Table 2. Selected compressor types

Load	R744 TC DX	R744 TC FL	R717 2ST	R744/R717	R507 2ST
50/150	Recip/Recip	Recip/Recip	Recip/Recip	Recip/Recip	Recip/Recip
150/450	Recip/Recip	Recip/Recip	Recip/Recip	Recip/Recip	Recip/Screw
300/900	Recip/Recip	Recip/Recip	Screw/Screw	Recip/Screw	Screw/Screw
900/2700	Recip/Recip	Recip/Recip	Screw/Screw	Recip/Screw	Screw/Screw

02. Trend to NH3 charge reduction

Power Consumption comparison with NH3 as a baseline

Table 11. Power consumption relative to two-stage R717. Optimized systems

-	R744 TC DX	R744 TC FL	R717 2ST	R744/R717	R507 2ST
Rome	129%	132%	100%	105%	106%
Frankfurt	113%	111%	100%	103%	104%
Oslo	108%	104%	100%	103%	103%

Dry cooler with no correction for parallel compression

02. Trend to NH3 charge reduction

Power Consumption comparison with NH3 as a baseline

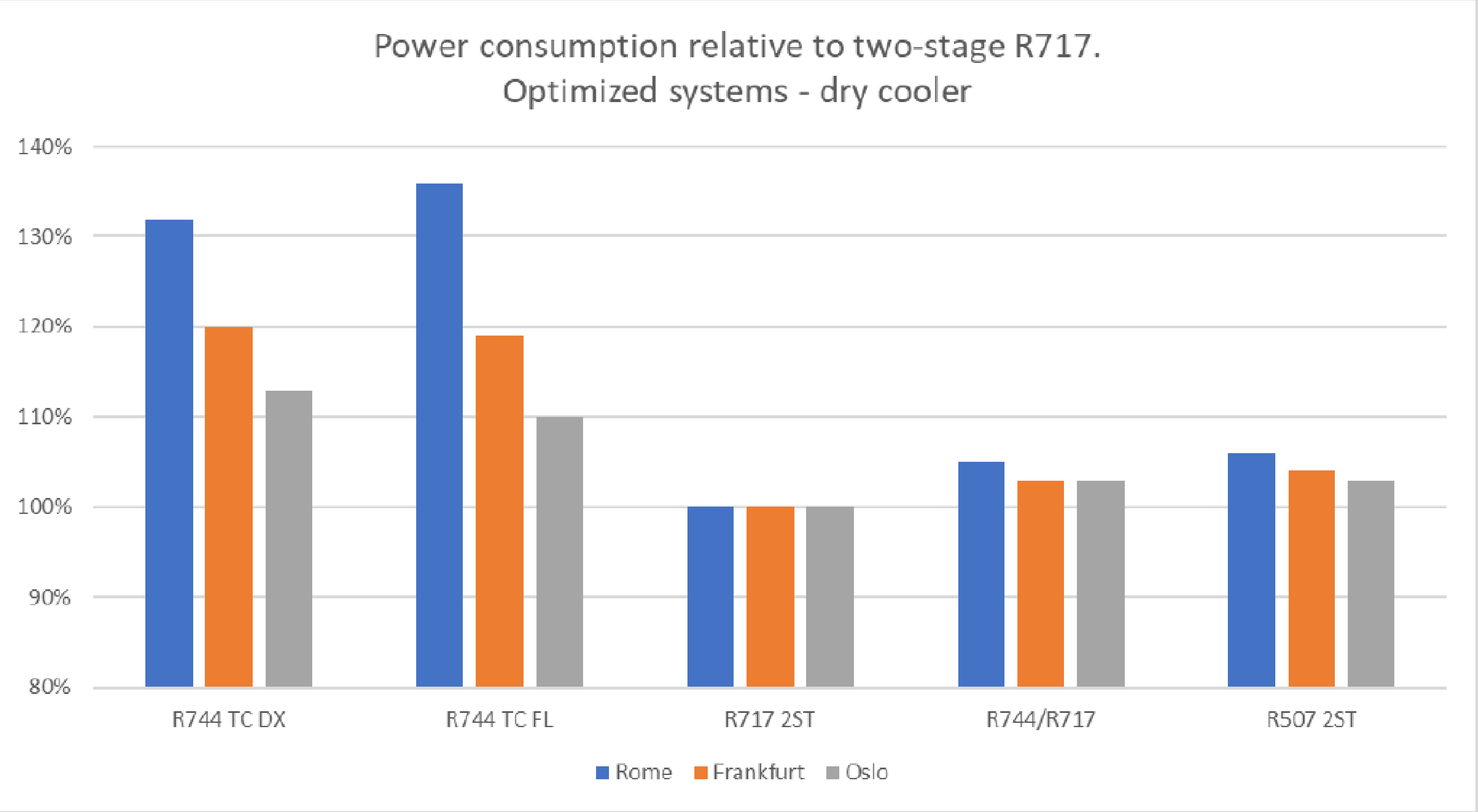


Figure 1: Power consumption relative to two-stage R717. Optimized systems - dry cooler

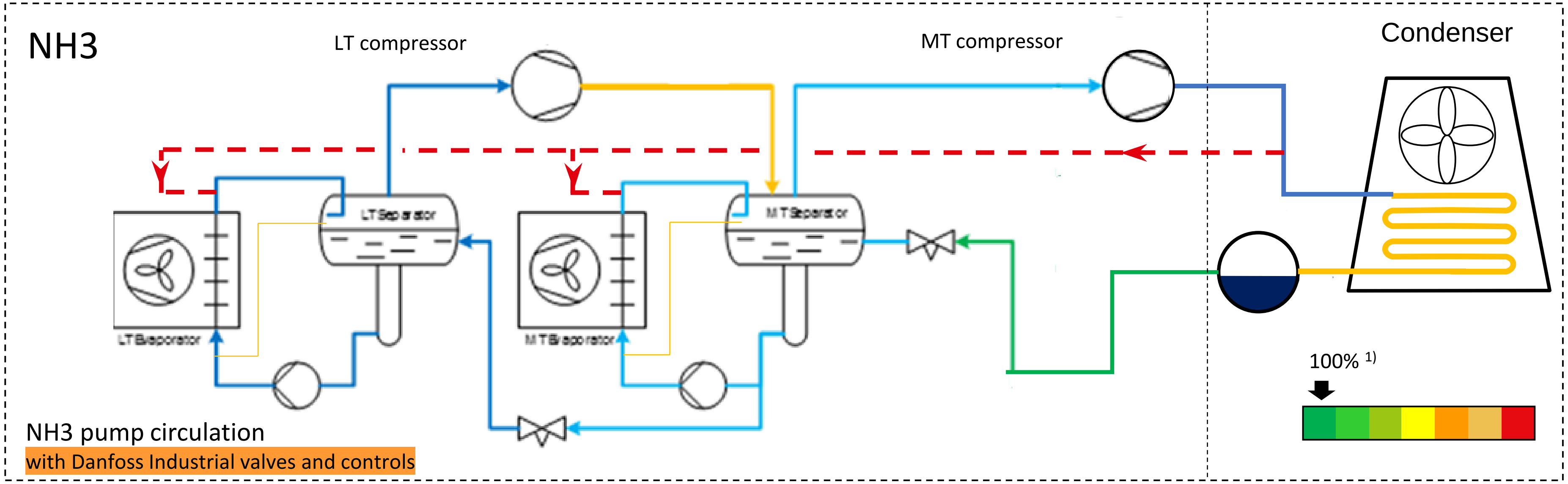
Bar graph TC flooded (recirculated) in warm climate does not include efficiency gain from parallel compression due to software constraints

	CO2 TC DX	CO2 TC Flooded	R717 2ST	Cascade	R507 2ST
Rome	129%	121%	100%	105%	106%
Frankfurt	113%	105%	100%	103%	104%
Oslo	108%	100%	100%	103%	103%

Table shows best possible results with adiabatic coolers and manual estimation with parallel compression for TC

03. Typical Industrial Refrigeration system types

The traditional NH3 pump circulation system



Fully dedicated IR built

- Pumped systems on MT and LT
- Dedicated compresssors per temperature level
- Evaporative condensor
- Industrial hotgas defrost
- Oil return control
- Complete system coordination
- Steel/stainles steel pipes
- Welded
- Industrial built design
- Reliabile and proven technology

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- Generally most efficient system
- Superior cooler efficiency
- Easy to control
- Efficient and safe hotgas defrost
- High safety integrity
- Leak tight
- Long litefime
- New emerging technologies for charge reduction

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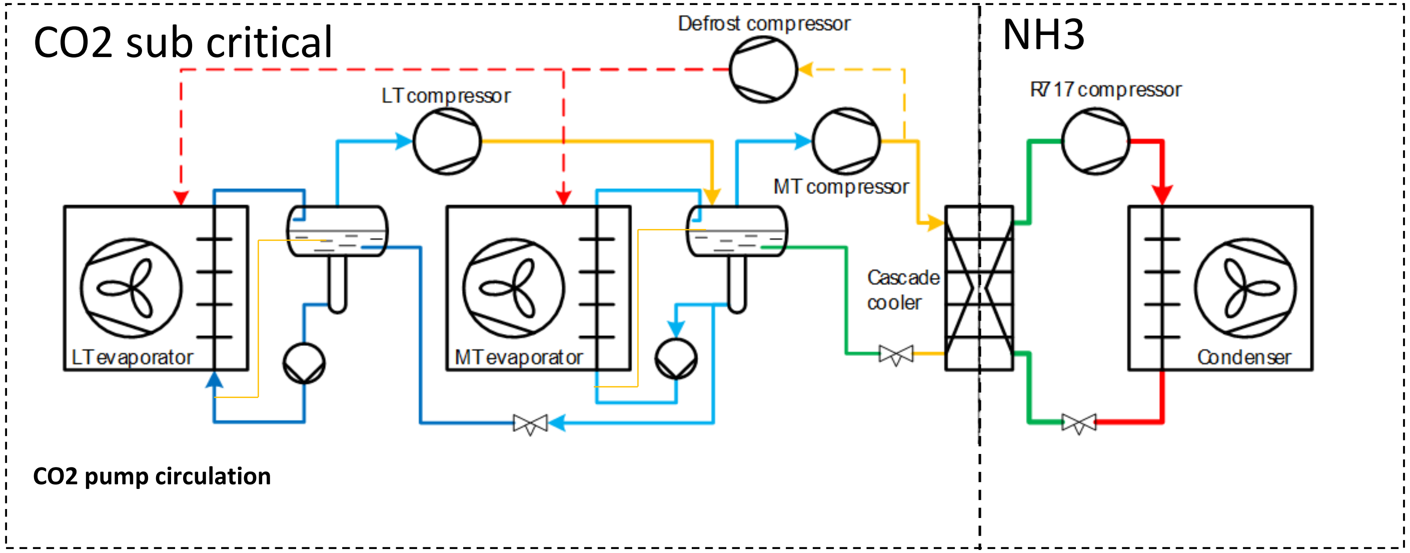
- NH3 charge
- First costs

03. Typical Industrial Refrigeration system types

NH3/CO2 cascade system



Achieved with standard components rated at 754 psig

Fully dedicated IR built

- CO2 pump systems on medium temp. and low temp.
- Dedicated compresssors per temperature level
- Evaporative condensor
- Industrial hotgas defrost
- Oil return control
- System coordination
- Steel/stainles steel pipes, welded
- Industrial built quality
- Reliable and proven technology

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- Up to 80% NH3 charge reduction
- High efficienty compared to brine systems
- Small CO2 compressor foot print
- CO2 liquid overfeed
- Superior cooler efficiency
- Easy to control
- Efficient and safe hotgas defrost
- High safety integrity
- Leak tight
- Long litefime

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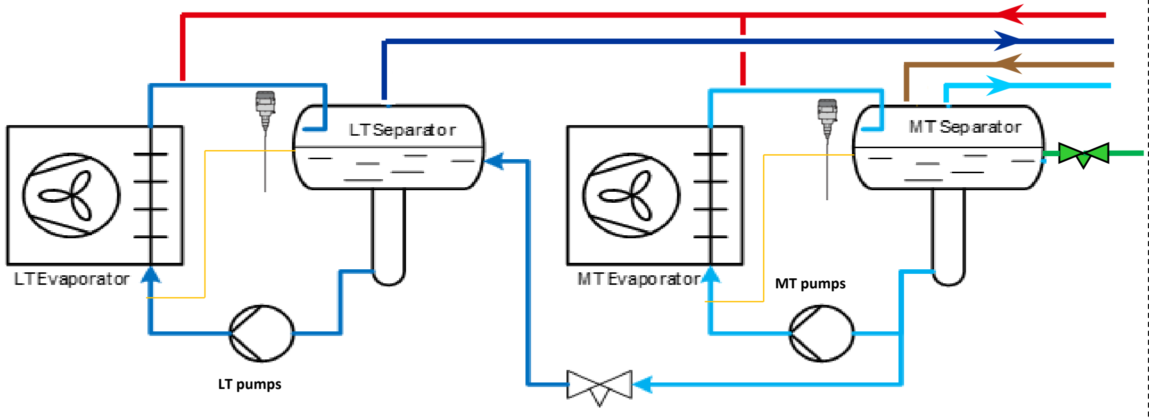
- Higher pressure
- Cascade cooler

04. The Industrial CO2 TC system

Ie 1-5 MW

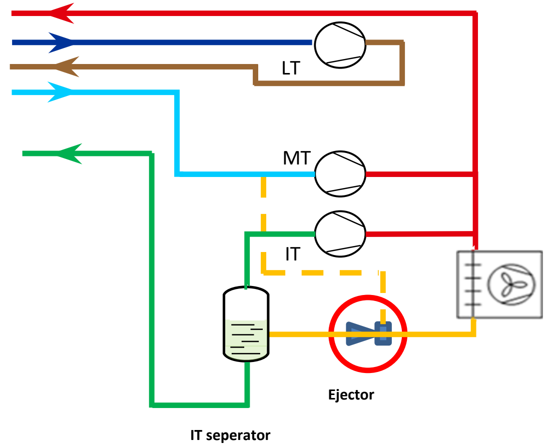
Pump circulation and hotgas defrost

CO2 sub critical



CO2 pump circulation

CO2 (transcritical)



Multiple racks parallel connected

Fully dedicated IR built

- Pumped systems on MT and LT
- Possibly DX on LY
- Parallel compresssion
- Air cooled gas coolers
- Industrial hotgas defrost
- Oil return control
- System coordination
- Gas ejector
- Steel/stainles steel pipes, welded,
- Industrial built
- Stand still pressure 65 bar

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- No NH3
- No superheat, so better efficiency compared to CO2 TC DX
- Better HTE
- Better cooler efficiency
- Easy to control
- Efficient and safe hotgas defrost
- High safety integrity
- Leak tight
- Long litefime

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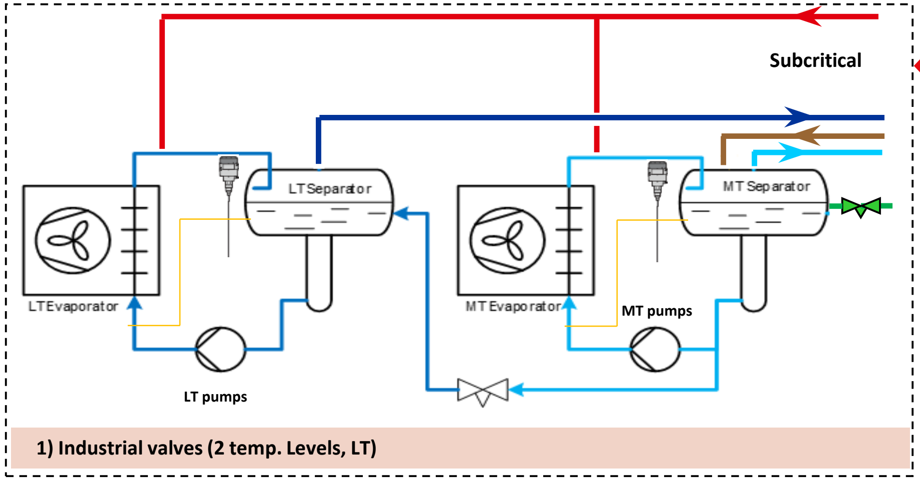
- Less efficient compared to NH3

Racks:

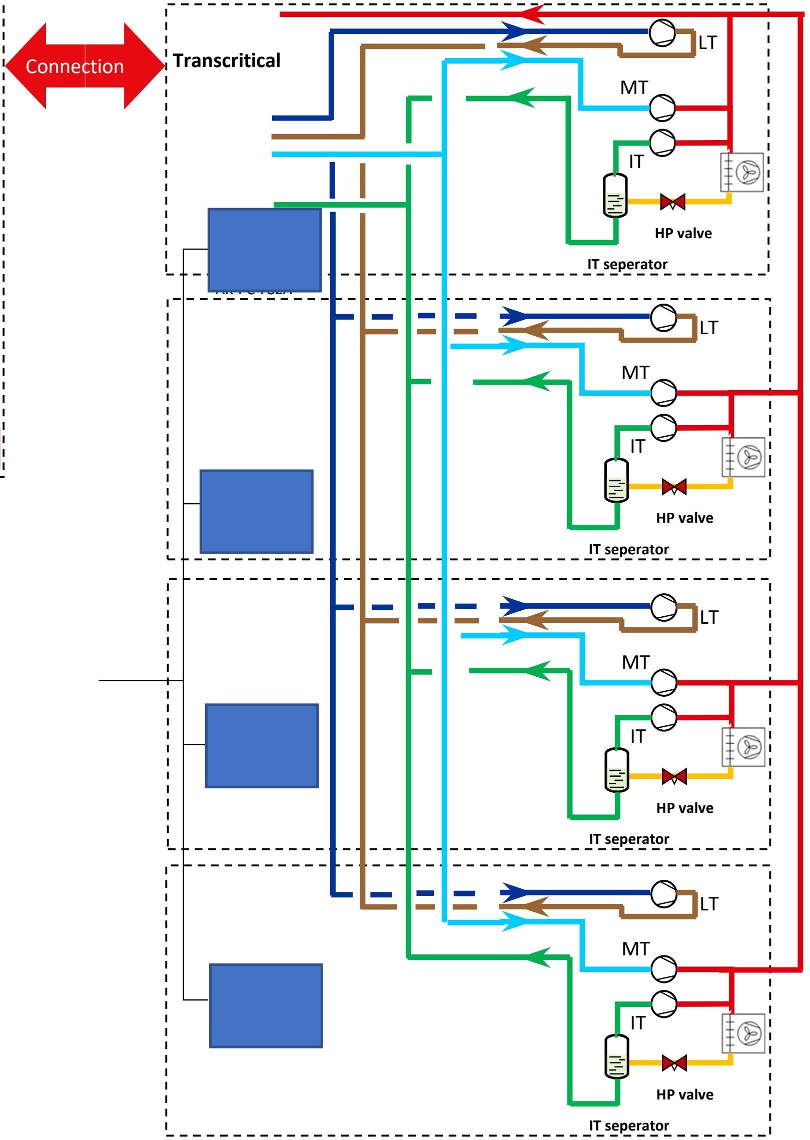
- Need many racks
- Life time
- Serviceability
- Commercial compressors
- Complex HP control system

04. The industrial CO2 TC system

The key elements



Rack controllers, MT and LT



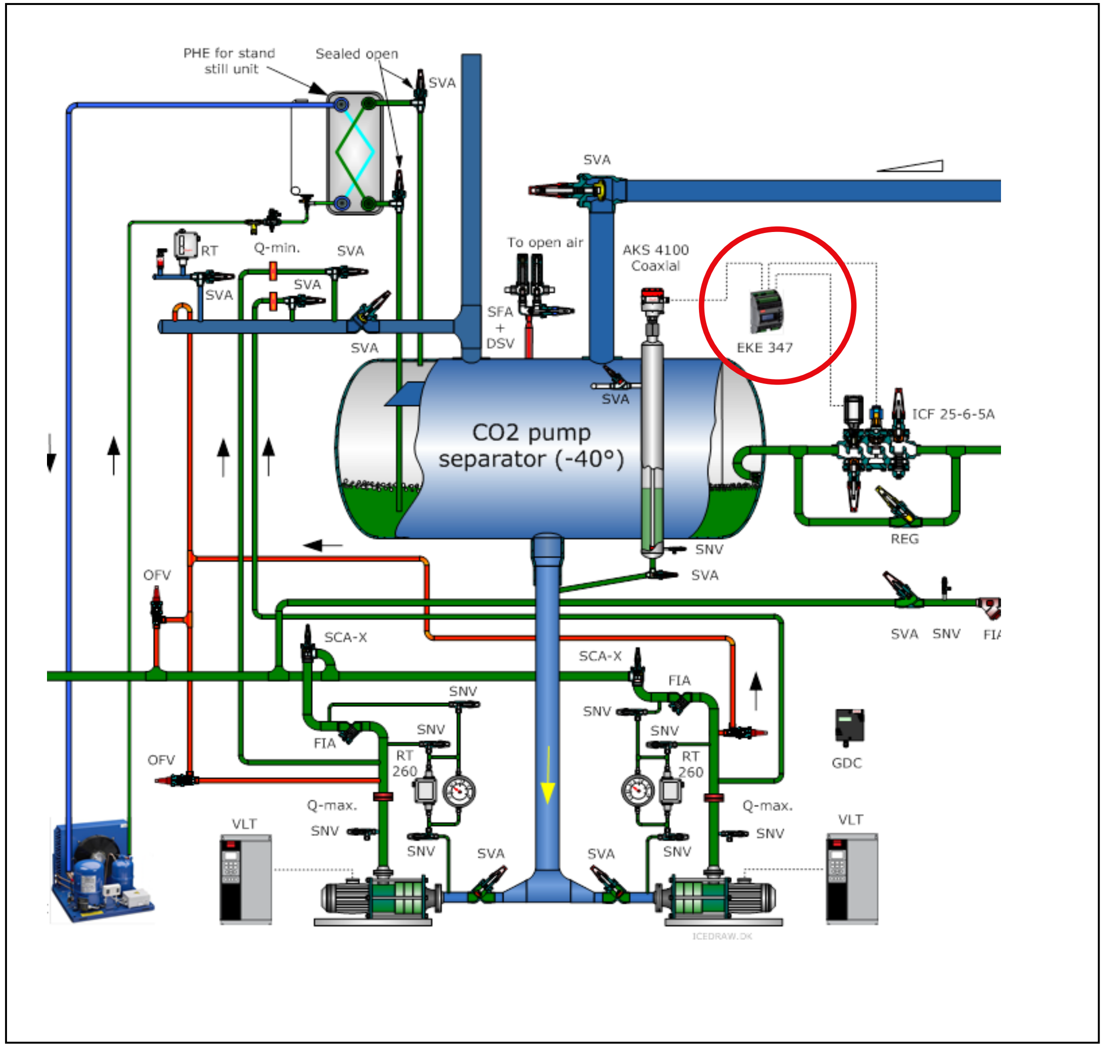
Industrial Pumped System

Level Control of recirculators – Similar to NH_3 systems

Static Height

- Calculations dffer from those in NH_3 systems

Communication. Integration with central compressor package controllers and evaporators is key to balance the system



06. Industrial Pumped System

Hotgas defrost is by far the most efficient method compared to

Electric defrost: ~ ¼ of the efficiency

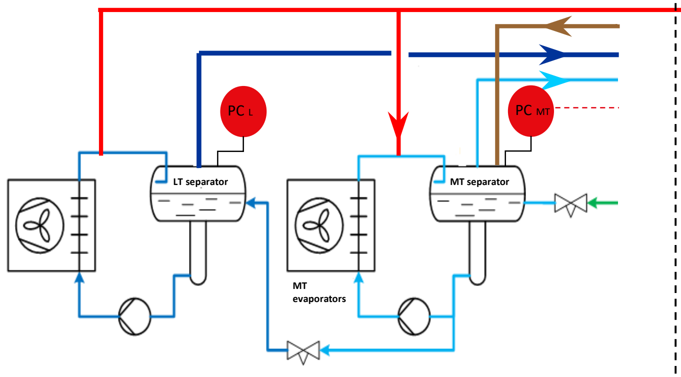
Glycol interlace: ½ of the efficiency

06. Danfoss Industrial Pumped System

2c) Hotgas supply for defrost

Sub critical pressures

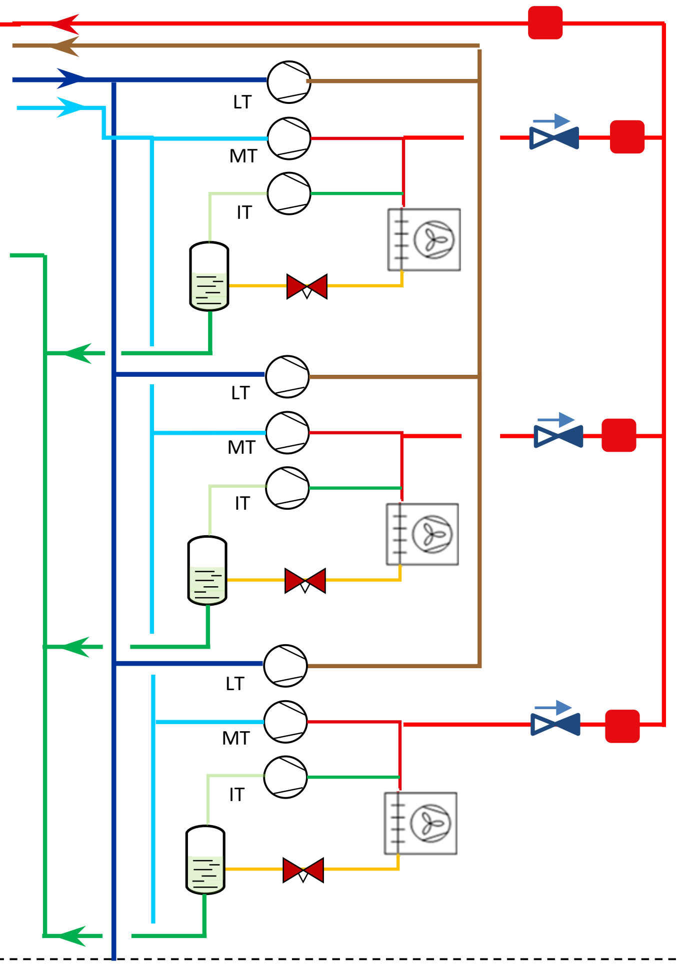
Industrial pump circulating system **typical PS = 52 bar**



Downstream pressure control

Transcritical pressures

Trancritical racks **typical PS = 120-140 bar**



The pressure in the sub critical system must be controlled

ALWAYS Focus on **controlled** and **safe** injection

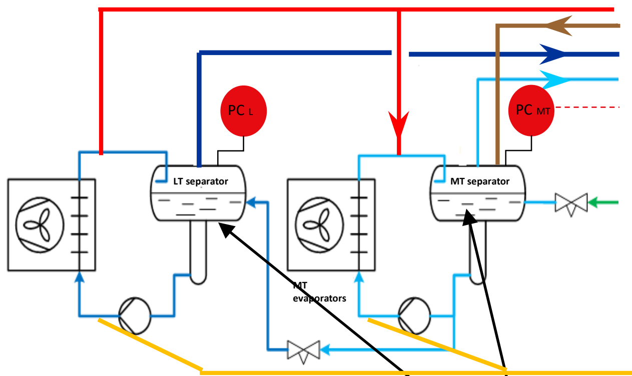
- Controlled defrost pressure between 7-12 degr.C
- Take care of long lines and pressure loss (1 bar ~ 1 K)
- Hotgas supply pressure to be controlled
- Back up safety needed (internal pressure relief)
- Final safety: external pressure blow off

06. Industrial Pumped System

2d) Oil rectify – and oil return control

Sub critical pressures

Industrial pump circulating system **typical PS = 52 bar**



System oil

Purpose

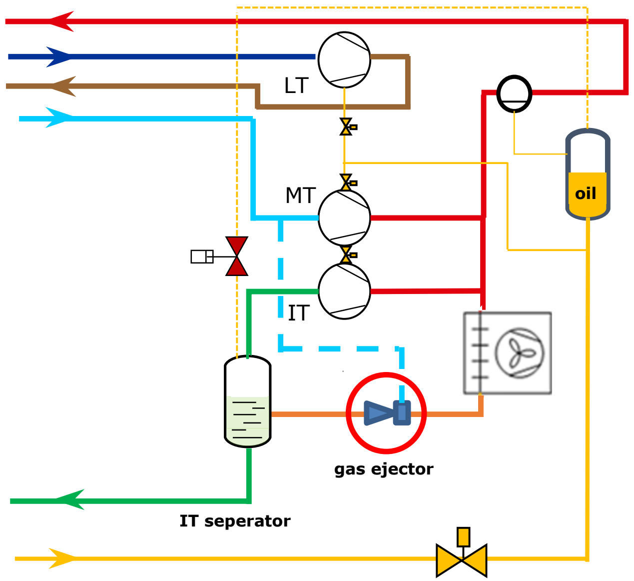
- Send accumulated system oil back to the racks

How ?

- Oil rectifying system

Transcritical pressures

Trancritical racks **typical PS = 120-140 bar**



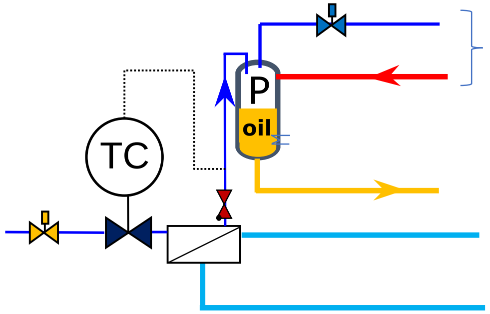
CO2 TC rack 1,2,3,4,5

What to control?

- Oil rectifier injection control
- Oil collection receiver pressure
- Oil circuit back to racks
- Oil need signal frtom racks
- Safety

Oil rectifier

Liquid injection



Receiver pressure

Oil return

09. Conclusions

1. NH3 (ammonia) is still the most efficient refrigerant for Industrial Systems going forward
2. NH3 charge reduction (at same or better efficiency) remains an obvious goal and offer a significant lower regulatory burden
3. NH3/CO2, NH3 low charge or CO2 TC systems are possible options.
4. Commercial and Industrial CO2 TC systems are different-both due to different performance, lifetime, reliability and safety expectations!
5. Transparent comparison of energy efficiency of different system types is extremely important!
6. CO2 transcritical pump systems close the gap for mid size plant capacities when NH3 is not considered in the first place
7. The connection of the Industrial pump systems to a transcritical cycle world however demands some industry efforts
8. OEMs are investing in solutions to make these systems easier accessible
9. Larger transcritical CO2 compressor capacities are critical for further development of CO2 TC applications in Industrial Refrigeration
10. The viability of CO2 TC Systems in Industrial Refrigeration applications should become more clear in the next few years.