Global Trend in Industrial Refrigeration

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Agenda

01. Refrigeration Systems developments
02. Trends in NH3 charge
03. Typical Industrial Refrigeration system types
04. Trends in Industrial Refrigeration Systems
05. Overview Transcritical cycle
06. System Performance Comparison
07. Systems Layout
08. Defrost and Efficiency
08. Oil return/recovery
09. Conclusion
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 CO2 has been on the rise in Europe and North America.

System Optimization has been key to development but also charge reduction in NH3 systems.

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

In some applications, Transcritical CO2 may be considered a good option.
Refrigeration System Developments

Blending in of technologies and systems

Definition of Industrial Refrigeration?
NH3?, CO2?, Steel?, Welding?, Capacity?, Pump circulation?

Typical NH3 systems (steel/stainless, welded connections)
- Charge reduction
- Sub segment
- Multi stage pumped
- Single pumped

Commercial CO2 transcritical systems
- Liquid ejector
- Gas ejector
- Parallel compression
- Booster
- Single

CFC, HFC, HFO systems

HC

Capacity range
- Up to 150 kW
- 150 – 500 kW
- 500-1000 kW
- 1000-10000 kW
- > 10000 kW
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.

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

C. **Ammonia-DX system**
- Ammonia DX-system reduce the required liquid charge

D. **Ammonia-CO2**
- Ammonia-CO2 cascade system or Ammonia-CO2 brine system

E. **Low-charge Ammonia system**
- Install a number of rooftop mounted self-contained ammonia units

F. **CO2 TC**
- CO2 booster system

**Charge reduction is an attractive mitigation solution**

R717-charge

1 x 20,000 kg
(5 kg / kW)

R717-charge e.g.
4 x 5,000 kg
(5 kg / kW)

R717-charge e.g.
2 x 5,000 kg
(2.5 kg / kW)

R717-charge ~2,000 kg
(0.5 kg / kW)

R717-charge e.g.
8 x 200 kg
(0.4 kg / kW)

No R717-charge
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

- Subcritical
- Transcritical
- Two-Stage Combined

Diagram showing different cycles with CO$_2$.
Transcritical refrigeration process
Influence of compressor outlet pressure

\[ \text{COP} = \frac{\Delta h_{\text{EVAP}} \times m}{\Delta h_{\text{Comp-is}} \times m} \]

- 80 bar [1450 psi]: COP = 2.46
- 90 bar [1505 psi]: COP = 2.51
- 100 bar [1450 psi]: COP = 1.72

35 °C [95 °F]
Trend to NH3 charge reduction

Assessment of Emerging Systems Performance vs Traditional

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
Trend to NH3 charge reduction

Calculations performed on three different latitudes 365 day

<table>
<thead>
<tr>
<th></th>
<th>Dry bulb temperature</th>
<th>Wet bulb temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>Rome</td>
<td>-4.0°C</td>
<td>31.8°C</td>
</tr>
<tr>
<td>Frankfurt</td>
<td>-8.9°C</td>
<td>33.6°C</td>
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<tr>
<td>Oslo</td>
<td>-17.0°C</td>
<td>28.2°C</td>
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</table>
Compressor types used for calculations at different loads

<table>
<thead>
<tr>
<th>Load</th>
<th>R744 TC DX</th>
<th>R744 TC FL</th>
<th>R717 2ST</th>
<th>R744/R717</th>
<th>R507 2ST</th>
</tr>
</thead>
<tbody>
<tr>
<td>50/150</td>
<td>Recip/Recip</td>
<td>Recip/Recip</td>
<td>Recip/Recip</td>
<td>Recip/Recip</td>
<td>Recip/Recip</td>
</tr>
<tr>
<td>150/450</td>
<td>Recip/Recip</td>
<td>Recip/Recip</td>
<td>Recip/Recip</td>
<td>Recip/Recip</td>
<td>Recip/Screw</td>
</tr>
<tr>
<td>300/900</td>
<td>Recip/Recip</td>
<td>Recip/Recip</td>
<td>Screw/Screw</td>
<td>Recip/Screw</td>
<td>Screw/Screw</td>
</tr>
<tr>
<td>900/2700</td>
<td>Recip/Recip</td>
<td>Recip/Recip</td>
<td>Screw/Screw</td>
<td>Recip/Screw</td>
<td>Screw/Screw</td>
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</tbody>
</table>
Trend to NH3 charge reduction

Power Consumption comparison with NH3 as a baseline

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

<table>
<thead>
<tr>
<th></th>
<th>R744 TC DX</th>
<th>R744 TC FL</th>
<th>R717 2ST</th>
<th>R744/R717</th>
<th>R507 2ST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rome</td>
<td>129%</td>
<td>132%</td>
<td>100%</td>
<td>105%</td>
<td>106%</td>
</tr>
<tr>
<td>Frankfurt</td>
<td>113%</td>
<td>111%</td>
<td>100%</td>
<td>103%</td>
<td>104%</td>
</tr>
<tr>
<td>Oslo</td>
<td>108%</td>
<td>104%</td>
<td>100%</td>
<td>103%</td>
<td>103%</td>
</tr>
</tbody>
</table>

Dry cooler with no correction for parallel compression
Trend to NH3 charge reduction

Power Consumption comparison with NH3 as a baseline

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

<table>
<thead>
<tr>
<th></th>
<th>CO2 TC DX</th>
<th>CO2 TC Flooded</th>
<th>R717 2ST</th>
<th>Cascade</th>
<th>R507 2ST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rome</td>
<td>129%</td>
<td>121%</td>
<td>100%</td>
<td>105%</td>
<td>106%</td>
</tr>
<tr>
<td>Frankfurt</td>
<td>113%</td>
<td>105%</td>
<td>100%</td>
<td>103%</td>
<td>104%</td>
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<tr>
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<td>108%</td>
<td>100%</td>
<td>100%</td>
<td>103%</td>
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</tr>
</tbody>
</table>

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

Figure 1: Power consumption relative to two-stage R717. Optimized systems - dry cooler
Typical Industrial Refrigeration system types

The traditional NH3 pump circulation system

- Fully dedicated IR built
  - Pumped systems on MT and LT
  - Dedicated compressors per temperature level
  - Evaporative condenser
  - Industrial hotgas defrost
  - Oil return control
  - Complete system coordination
  - Steel/stainless steel pipes
  - Welded
  - Industrial built design
  - Reliable and proven technology

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

- -
  - NH3 charge
  - First costs
Fully dedicated IR built
- CO2 pump systems on medium temp. and low temp.
- Dedicated compressors 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

+ Up to 80% NH3 charge reduction
- High efficiency 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 lifetime

- Higher pressure
- Cascade cooler

NH3/CO2 cascade system

Achieved with standard components rated at 754 psig
**Fully dedicated IR built**
- Pumped systems on MT and LT
- Possibly DX on LY
- Parallel compression
- Air cooled gas coolers
- Industrial hotgas defrost
- Oil return control
- System coordination
- Gas ejector
- Steel/stainless steel pipes, welded,
- Industrial built
- Stand still pressure 65 bar

**CO2 sub critical**

- LT pumps
- LT separator
- LT evaporator

**CO2 (transcritical)**

- MT pumps
- MT separator
- MT evaporator
- Ejector

- Ie 1-5 MW

**Pump circulation and hotgas defrost**

**CO2 pump circulation**

- Multiple racks parallel connected

**Graphs:**
- The Industrial CO2 TC system
- Pump circulation and hotgas defrost

**Advantages:**
- 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 lifetime

**Disadvantages:**
- Less efficient compared to NH3

**Racks:**
- Need many racks
- Life time
- Serviceability
- Commercial compressors
- Complex HP control system
The industrial CO2 TC system

The key elements

1) Industrial valves (2 temp. Levels, LT)

Rack controllers, MT and LT
Static Height
• Calculations differ from those in NH3 systems

Communication. Integration with central compressor package controllers and evaporators is key to balance the system.
Hotgas defrost is by far the most efficient method compared to

Electric defrost: ~¼ of the efficiency

Glycol interlace: ½ of the efficiency
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
Sub critical pressures

Industrial pump circulating system   typical PS = 52 bar

Purpose
• Send accumulated system oil back to the racks

How ?
• Oil rectifying system

What to control?
• Oil rectifier injection control
• Oil collection receiver pressure
• Oil circuit back to racks
• Oil need signal from racks
• Safety

Transcritical pressures

Trancritical racks   typical PS = 120-140 bar

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

Oil rectifier

Liquid injection

Receiver pressure

Oil return
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.