Danfoss Cooling
Danfoss Multi Ejector

www.danfoss.com
Transcritical Booster system
most common CO\textsubscript{2} systems

Aprx 7000 systems up today with Danfoss components (2000 has been counted in 2015)
Transcritical Booster system

Energy comparison

Transcritical booster compared to R404A

Above 27°C is not efficient compared to R404A.
R404A is used as the benchmark for energy and CO2 booster system as benchmark for the swept volume of compressors.
Transcritical vs. Subcritical

Energy savings of transcritical CO2 compared to single stage R404A.
Evolution of Technology
How can we move / remove the CO2 equator?

New technologies targeting efficient CO2 systems in warm climate

- Heat reclaim
- Parallel compressions

- Ejectors:
  - Vapor ejector in DX system
  - Liquid ejector in Flooded system
  - Ejectors in flooded system
Parallel compression system

- Improvement of COP in warm climates
- Reduction of swept volume of the compressors
- Aprx 50 installations in 2014 and 200 in 2015
Parallel compression system

**Energy - Parallel compression compared to R404A**

Crossing point moved from 27 °C to 38 °C

**Swept volume - Parallel compression compared to Booster system**

Relative swept volume compared to booster

Ambient temperature

Relative energy consumption to R404A

Ambient temperature
What is an Ejector

- Expansion work recovery
  Ejector is used instead of throttling device and it can utilize part of expansion work. The primary flow of the ejector (flow form Gascooler) drives the secondary flow (from the evaporator) and “pump” it up in higher pressure levels than suction pressure levels.

Which are the benefits

- First Cost savings
  Lower cost compared to parallel compression trans critical CO2 racks due to lower swept volume of compressors. (i.e. smaller compressors or less number of compressors).

- Fast Pay Back – Energy saving
  Improved COP, enhanced operation of parallel compressors and lower swept volume to the MT compressors, result to lower energy consumption. Saving for End Users
• Motive nozzle is connected to gas cooler.
  • Motive flow: high velocity
• Suction port to the evaporator outlet
  • Low velocity, low pressure
• Motive flow is driving the suction flow, mixed in the mixing chamber.
• Diffuser is used to recover pressure
• The Exit of the ejector is connected to a receiver.
Let’s have a closer look
How does it work?
EJECTOR IN THE SYSTEM (with parallel compression)

Transcritical operation

System with a medium pressure receiver and a receiver compressor to compress.
EJECTOR IN THE SYSTEM (with parallel compression)

Subcritical operation

For ambient temperature is less than 21 °C, ejectors are not efficient to pump and the system is operating as a parallel compressor system or a booster system (if receiver compressors are off).
Ejector in a CO₂ system

Typical working pressures

- Pressure difference between receiver and suction pressure is aprx 7 to 10 bar
- Ejector is “pumping” a part of the evaporated mass flow to the receiver pressure.

Pressure HP inlet 75-110 bar

Pressure suction inlet 25-30 bar

Pressure outlet 32-37 bar
Ejector in a CO₂ system

Mass flow distribution
System operating with out parallel compressor and with out ejector (equivalent to booster system)

- Booster system, not energy efficient for high ambient temperatures ( >27 °C)
- Illustration of transcritical operation (~33 °C ambient temp.)
Ejector in a CO₂ system

Mass flow distribution
System operating with parallel compressor but without ejectors

- Parallel compressors, compresses gas from a higher start pressure and is therefore delivering a higher COP
- Efficient in higher ambient temperatures
- Illustration of transcritical operation (~33 °C ambient temp.)
Ejector in a CO$_2$ system

Mass flow distribution
System operating with parallel compressor and ejectors

- Illustration of transcritical operation (~33 °C ambient temp.)
- Ejector is lifting a part of the gas from a low pressure to the parallel compressor suction pressure and enhancing the effect of the parallel compressor.
- Increased COP
- The Use of ejectors is a saving on swept volume of the compressor
- Energy saving in high ambient temperature
- Ejector operate efficiently for temperature >21 °C)
- Ejector may enable operation of parallel compressor at lower temperatures
Ejector system

The energy saving a function of the ambient conditions and system design

Commercial refrigeration R744 systems equipped with ejectors can achieve COP higher than for conventional R744 systems (booster assisted by parallel compression) even by 20% at high ambient temperatures
Liquid ejector system
Enable systems with flooded evaporators

- Liquid ejector systems allow the MT evaporator to be flooded.
- Ejector is used as pump for excessive liquid
- System run with higher suction pressure. (increase saving)
- Evaporation temperature is in average raised by 5K.

- Trials has been running since 2013 (ENEX)

* HP diagram from A. Hafner (SINTEF) presentation @ NorskKjøleteknisk Møte 2014
Liquid and vapor ejector system

- There are few (3-4) stores operating in Europe (Enex)
- Limited experience on the design and configuration of the systems
- Limited experience with case controllers
- Technology currently not availed to other OEMs
# Energy Efficiency

The energy saving a function of the ambient conditions and system design

**Comparison made @ 40 °C**

<table>
<thead>
<tr>
<th>System</th>
<th>Energy saving VS. R404a</th>
<th>Compressor saving VS. Booster</th>
</tr>
</thead>
<tbody>
<tr>
<td>Booster</td>
<td>-25%</td>
<td>0%</td>
</tr>
<tr>
<td>Parallel compression</td>
<td>3%</td>
<td>19%</td>
</tr>
<tr>
<td>Gas ejector</td>
<td>7%</td>
<td>28%</td>
</tr>
<tr>
<td>Liquid &amp; gas ejector</td>
<td>16%</td>
<td>35%</td>
</tr>
</tbody>
</table>

**Comparison made @ 32 °C**

<table>
<thead>
<tr>
<th>System</th>
<th>Energy saving VS. R404a</th>
<th>Compressor saving VS. Booster</th>
</tr>
</thead>
<tbody>
<tr>
<td>Booster</td>
<td>-11%</td>
<td>0%</td>
</tr>
<tr>
<td>Parallel compression</td>
<td>7%</td>
<td>15%</td>
</tr>
<tr>
<td>Gas ejector</td>
<td>10%</td>
<td>18%</td>
</tr>
<tr>
<td>Liquid &amp; gas ejector</td>
<td>22%</td>
<td>27%</td>
</tr>
</tbody>
</table>
Parallel compression is not a possibility on small systems (<100kW)

Large energy saving potential in warm ambient with ejector technology – COP can increased by ~20% compared to the parallel compression systems

Liquid ejector solution is not ready for the large market yet. Better/optimal controller are required.
EJECTOR IN THE SYSTEM (Future simple system)

Bringing the first cost down

- Targets low first cost for small to middle size installation
- Danfoss is working towards that technology.

Pack price comparison (estimate)
Danfoss Multi Ejector