State-of-the-art technologies for transcritical R744 refrigeration systems – A theoretical assessment of energy advantages for European food retail industry

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Presentation Content

• Introduction
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• Investigated solutions
• Investigated climate contexts
• Results
• Conclusions
**Introduction**

**Supermarkets**

- One of the most vital service facilities
  - ever-growing trend towards these applications in both developed and developing countries (especially when it comes to large stores)
  - accountable for 3÷4% of national energy consumption in industrialized countries
  - about 35÷50% of the electricity is required to run the refrigerating equipment
- Majority of supermarket refrigeration systems in Europe use R404A

“Copious indirect and direct contributions to global warming”
Introduction

EU F-Gas Regulation 517/2014

Centralised commercial refrigeration (≥40kW), except in the primary refrigerant circuit of cascade systems where f-gases with a GWP<1,500 may be used.

Source: Shecco (2016)
Introduction

Impact of EU F-gas Regulation 517/2014

• Availability and cost of HFCs
  ▪ 15% increase in price for R404A and R507 as of January 2016
• Availability and equipment cost of transcritical R744 refrigerating technologies
  ▪ installation price is currently at the level of conventional HFC technologies or 5-10% higher
• Technological innovation in transcritical R744 refrigerating technologies
  ▪ Parallel compression
  ▪ Overfed evaporators
  ▪ Multi-ejector concept
  ▪ “All-in-one” concept

“Consequently, transcritical R744 refrigeration systems has become the mainstream HFC-free technology for the European food retail sector”
Objectives

• Theoretically estimating the energy benefits related to:
  
  ✓ the usage of the most state-of-the-art pure R744 supermarket refrigeration systems for European food retail industry

• Boosting the confidence in the most state-of-the-art pure R744 supermarket refrigeration systems all over Europe
**Investigated solutions**

**R744 booster system**

- “Old” benchmark (*I generation*) for R744 supermarket systems
- Widely used solutions in Northern Europe
- Efficient implementation of heat recovery

*Source: EMERSON Climate Technologies (2010)*
**Investigated solutions**

*Parallel compression*

- “Current” benchmark (*II generation*) for R744 supermarket systems
- First step towards the usage of R744 in warm regions
Investigated solutions

**Overfed evaporators**

- Increase in medium temperature (MT) by 6 K
- Overfeeding of MT evaporators all year round
Investigated solutions

Multi-ejector based systems

- Increase in MT by 6 K
- Overfeeding of MT evaporators all year round
- Intermediate pressure is 4÷12 bar higher than medium pressure
- III generation of R744 supermarket systems
Investigated solutions

Multi-ejector based systems [2]

- Increase in MT by 6 K
- Increase in LT by 8 K
- Overfeeding of evaporators all year round
- Intermediate pressure is 4÷12 bar higher than medium pressure
Investigated climate contexts

<table>
<thead>
<tr>
<th>Zone</th>
<th>Oslo</th>
<th>London</th>
<th>Frankfurt</th>
<th>Milan</th>
<th>Athens</th>
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<tbody>
<tr>
<td>Subcritical</td>
<td>89.3%</td>
<td>88.3%</td>
<td>80.7%</td>
<td>69.6%</td>
<td>50.7%</td>
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<tr>
<td>Transition</td>
<td>10.7%</td>
<td>11.5%</td>
<td>18.2%</td>
<td>27.6%</td>
<td>38.0%</td>
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<tr>
<td>Transcritical</td>
<td>0.0%</td>
<td>0.2%</td>
<td>1.2%</td>
<td>2.8%</td>
<td>11.3%</td>
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</table>
Results
Coefficient of Performance

- R404A direct expansion
- R744 booster
- R744 parallel compression
- R744 parallel compression+MT overfed
- R744 multi-ejector (MT overfed)
- R744 multi-ejector (LT and MT overfed)
**Results**

**Relative energy consumption (R404A unit as baseline)**

![Graph showing relative energy consumption in various cities.](attachment:graph.png)
Results

Advancement in energy efficiency - Cold European climate context (i.e. Oslo)

-18÷-24%

-17÷-23%

Multi-ejector concept (supporting parallel compression)

-1%

Conventional booster

Parallel compression
Results

Advancement in energy efficiency - Mild European climate context (i.e. London, Frankfurt, Milan)

-18 ÷ -26%
-17 ÷ -23%
-1 ÷ -4%

Conventional booster
Parallel compression
Multi-ejector concept (supporting parallel compression)
Results

Advancement in energy efficiency - Warm European climate context (i.e. Athens)

-22÷-27%

-17÷-22%

-6%

Conventional booster

Parallel compression

Multi-ejector concept (supporting parallel compression)
Conclusions

• Parallel compression is a suitable technology only for “all-in-one” transcritical R744 refrigeration systems operating in cold regions

• Overfeeding of the evaporators is a much more energetically beneficial expedient than parallel compression
  ▪ this solution permits pure R744 systems to be energetically competitive with R404A units at outdoor temperatures up to 33 °C
  ▪ this technology leads to energy savings between 17.9% and 22.7% over R404A units in cold and mild European climate contexts
  ▪ this expedient allows consuming 12.4% less electricity than R404A units in Athens

• “CO₂ equator” disappears in Europe with the aid of multi-ejector concept
  ▪ this technology leads to energy savings between 26.2% and 37.1% over R404A units in cold and mild European climate contexts
  ▪ this expedient allows consuming between 19.9% and 24.6% less electricity than R404A units in Athens
Thank you!

Any questions?
Appendices
## Running modes

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Numerical value</th>
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<tbody>
<tr>
<td>$t_{MT}$</td>
<td>-10 °C (dry-expansion evaporator)</td>
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<tr>
<td></td>
<td>-4 °C (overfed evaporator)</td>
</tr>
<tr>
<td>$t_{LT}$</td>
<td>-35 °C (dry-expansion evaporator)</td>
</tr>
<tr>
<td></td>
<td>-27 °C (overfed evaporator)</td>
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<tr>
<td>$\dot{Q}_{MT,\text{design}}$</td>
<td>120 kW</td>
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<tr>
<td>$\dot{Q}_{LT,\text{design}}$</td>
<td>25 kW</td>
</tr>
</tbody>
</table>

- Evaluation of deviation from the design operating conditions by Zhang’s correlation (2006)
- Implementation of a suitable transition zone from subcritical to transcritical operating conditions
**Overfed evaporators**

- Being the air inlet temperature imposed, the superheating implies that the evaporating temperature has to be pushed down.
- With no superheating the entire heat transfer area is optimally used being completely at the evaporating temperature.
Final remarks

• Nowadays food retail industry can go HFC (and HFO)-free all over Europe, since the usage of R744 as the only refrigerant in this sector is no longer open to dispute
  ▪ the reason for this lies in the fact that a great energy efficiency can be accomplished in any European climate context by adapting the system layout to the peculiarities of R744

• The current main brake on the full penetration of such HFC-free technologies into European market is put by some remaining non-technological barriers (e.g. shortage of trained installers and service technicians, little confidence in transcritical R744 supermarket refrigeration systems, social and political factors)