Trends in Refrigeration System Architecture and CO$_2$

Andre Patenaude
Emerson Climate Technologies
What’s Hot in Supermarket Refrigeration?

**Energy**
- MT Cases With Doors
- LED Lighting
- Low Condensing
- ECM Fan Motors for Condenser and Case Fans

**Environment**
- EPA Proposal to Delist R404A
- R-22 Retrofits
- Natural Refrigerants
- LCCP Analysis

**Equipment**
- Mechanical to Electronic Control
- Connected Devices/Mobile
- Technician Shortage
- ASHRAE Commissioning Guide

**Economics**
- Information Age (Traceable, Feedback)
- Millennials (e-Commerce, Local, Organic)
- “Smaller” Format Stores
- Foodservice Integration

**Other**
- “Smaller” Format Stores
$35k/Year Energy Savings per Store by Implementing Low Condensing

**Boston Temperature Profile**

- **Opportunity for Savings**
  - 5°F: 0 Hours/Yr
  - 25°F: 100 Hours/Yr
  - 45°F: 500 Hours/Yr
  - 65°F: 1000 Hours/Yr
  - 85°F: 500 Hours/Yr

**Compressor Performance**

- **Capacity**
  - 50°F: $0K
  - 70°F: $50K
  - 90°F: $100K
  - 110°F: $150K

- **Power**
  - 50°F: $0K
  - 70°F: $25K
  - 90°F: $50K
  - 110°F: $75K

**≈20% Increase in Compressor Efficiency for a 10°F Drop in Condensing Temperature**

**% Time Below 60°F**

- 5°F: 90%
- 25°F: 80%
- 45°F: 70%
- 65°F: 50%
- 85°F: 20%

**Typical Boston Supermarket**

- 50 Min Cond: 35% Savings
- 70 Min Cond: 14% Savings
- 90 Min Cond: $35K Savings

**Total Annual Cost (@ $0.9/kWh)**

- 50 Min Cond: $35K
- 70 Min Cond: $50K
- 90 Min Cond: $75K

E360
CoreSense Provides Step Change in System Reliability and Troubleshooting

Compressor Protection & Control

- Discharge Temperature Protection
- Liquid Injection Control via Electronic Stepper Valve
- Digital Modulation Control
- 15 LED Alarm Codes
- Remote Communications (Modbus)
- Phase Monitoring, Short Cycling, Welded Contactor & Proofing Through Current Sensing

Remote Communications & Reset

- Remote Communications Management
- Facility Manager
- Emerson Site Manager
- Alarm Status
- Discharge Temp
- Run Time/Cycle Count
- Model & Serial #
- Amps
- 7-Day Alarm History
Convenience, Fresh, Specialty and e-Commerce Shake up Grocery Landscape

Wal-Mart Hopes To Boost Sales By Opening Convenience Stores

Target to Open 'Smallest Location Ever'
Test store will feature "everyday essentials," including grab-and-go sandwiches

Walmart U.S. accelerates small store growth
Expansion program doubles initial forecast

Dollar General and Family Dollar the New Small Format Grocery Stores?

US organic food market to grow 14% from 2013-18

Aldi to Boost Its Number of U.S. Stores by 50%

Lidl postpones plan to open U.S. stores to 2018

Ethnic Supermarket Industry Expands

AmazonFresh groceries arrive in Brooklyn
Energy Usage Will Become Primary Source for CO₂ Emissions

Boston, MA LCCP Analysis

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Energy Consumption (lbs CO₂/yr)</th>
<th>Life Cycle Climate Performance (LCCP)</th>
<th>Direct Global Warming</th>
<th>Indirect Global Warming</th>
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</thead>
<tbody>
<tr>
<td>CO₂ Booster</td>
<td>-15.3% / -62.9%</td>
<td></td>
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</tr>
<tr>
<td>Secondary – 300 GWP</td>
<td>-17.2% / -63.7%</td>
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<td></td>
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<tr>
<td>Cascase – 300 GWP MT</td>
<td>-12.5% / -61.6%</td>
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</tr>
<tr>
<td>1500 GWP DX</td>
<td>-14.8% / -44.1%</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1500 GWP DX</td>
<td>-3.4% / -39.1%</td>
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LT = Low Temperature
MT = Medium Temperature
DX = Direct Expansion
LCCP = Life Cycle Climate Performance
Understanding Assumptions Critical for “Apples to Apples” Comparisons

- **Minimum Condensing Temperature**:
  - Energy Savings vs. Condensing Temperature (F)
  - 90°F Baseline

- **Compressor Superheat**:
  - Energy Savings vs. Compressor Superheat (F)
  - 50°F Baseline

- **Subcooling**:
  - Energy Savings vs. Subcooling (F)
  - OF Baseline

- **Temperature Differential (TD)**:
  - Energy Savings vs. TD (F)
  - 17LT, 22MT Baseline
Refrigerant Change Being Driven by Regulations and Voluntary Actions

**Regulations**

- **Montreal Protocol**
  - Targets Ozone Depletion (R-22) Signed in 1987

- **North American Proposal**
  - Targets CO₂ Emissions (High Global Warming)

**Organizations**

- **United Nations Framework Convention on Climate Change**
- **CCAC**
  - CLIMATE AND CLEAN AIR COALITION TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS
- **ipcc**
  - INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
- **California Environmental Protection Agency**
- **Air Resources Board**
- **Danish Ministry of the Environment**
  - Environmental Protection Agency
  - HFC Ban & Tax
- **Australian Government**
  - Department of Sustainability, Environment, Water, Population and Communities
  - Carbon Tax
- **European Commission**
  - F-Gas Regulation
- **The Consumer Goods Forum**
- **Green Chill**
- **U.S. Environmental Protection Agency**
  - ADVANCED REFRIGERATION PARTNERSHIP
- **ammonia 21**
  - everything natural
- **shecco**
  - natural refrigerants
- **AMTOSphere 21**

Natural Refrigerants Gaining Traction in North American Supermarkets

Leading Edge Field Trials

- **H-E-B**  
  Austin, TX  
  R290  
  Micro-Distributed

- **Sprouts**  
  Dunwoody, GA  
  Transcritical CO₂ Booster

- **Albertsons**  
  Carpinteria, CA  
  Ammonia/CO₂ Hybrid

- **Walgreens**  
  Evanston, IL  
  Net Zero Store, Geothermal, CO₂

CO₂ Installed Base

Source: Shecco Guide 2012: Natural Refrigerants for Europe

Source: ATMOsphere America 2014 – Hillphoenix Market Progress
General Uses for CO$_2$

- Fire Extinguishers
- Beverages
- Plants
- Solvents
- Modified Atmospheric Packaging
- Refrigeration
Where Does CO₂ (R744) Come From?

- **By-product of:**
  - Fermentation of Ethanol
  - Combustion of Fossil Fuels
  - Liquefaction of Air

- **Naturally Occurring in Wells**

- **The Atmosphere Comprises Approximately 0.04% CO₂ (370 ppm)**

- **Manufacturing Process:**
  - Filtration, Drying and Purification
    - Results in Different Grades of CO₂ for Different Applications:
      - Industrial Grade, 99.5%
      - Bone Dry, 99.8%
      - Anaerobic, 99.9%
      - **Coleman Grade, 99.99%** (Used in Refrigeration)
      - Research Grade, 99.999%
      - Ultra Pure, 99.9999%
Benefits of Using CO$_2$ as a Refrigerant

- CO$_2$ is a natural refrigerant with very low global warming potential
  - ODP = 0; GWP = 1
- Non-toxic, non-flammable
- CO$_2$ is an inexpensive refrigerant compared with HCFCs and HFCs
- CO$_2$ has better heat transfer properties compared to conventional HCFCs and HFCs
- More than 50% reduction in HFC refrigerant charge possible (high volumetric cooling capacity)
- CO$_2$ lines are typically one to two sizes smaller than traditional DX piping systems
- Excellent material compatibility
- System energy performance equivalent or better than traditional HFC systems in cool climates
Basic Considerations When Using CO₂ as a Refrigerant

- The critical point is the condition at which the liquid and gas densities are the same. Above this point, distinct liquid and gas phases do not exist.
- The triple point is the condition at which solid, liquid and gas coexist.
- The triple point of carbon dioxide is high (60.6 psi) and the critical point is low (87.8 °F) compared to other refrigerants.
# Basic Properties of R744, R404A and R134a Refrigerants

<table>
<thead>
<tr>
<th></th>
<th>R744</th>
<th>R404A</th>
<th>R134a</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature at atmospheric pressure</strong></td>
<td>-109.3 °F (-78.5 °C) (Temp. of dry ice)</td>
<td>-50.8 °F (-46 °C) (Saturation temp.)</td>
<td>-14.8 °F (-26 °C) (Saturation temp.)</td>
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<tr>
<td><strong>Critical temperature</strong></td>
<td>87.8 °F (31 °C)</td>
<td>161.6 °F (72 °C)</td>
<td>213.8 °F (101 °C)</td>
</tr>
<tr>
<td><strong>Critical pressure</strong></td>
<td>1,055 psig (72.8 barg)</td>
<td>503 psig (34.7 barg)</td>
<td>590 psig (40.7 barg)</td>
</tr>
<tr>
<td><strong>Triple point pressure</strong></td>
<td>60.6 psig (4.2 barg)</td>
<td>0.44 psig (0.03 bar abs)</td>
<td>0.0734 psig (0.005 bar abs)</td>
</tr>
<tr>
<td><strong>Pressure at a saturated temperature of 20 °C (68 °F)</strong></td>
<td>815 psig (56.2 barg)</td>
<td>144 psig (9.9 barg)</td>
<td>68 psig (4.7 barg)</td>
</tr>
<tr>
<td><strong>Global warming potential</strong></td>
<td>1</td>
<td>3922</td>
<td>1430</td>
</tr>
</tbody>
</table>
Pressure — Enthalpy Diagrams for CO₂
Selecting the Best System: Secondary vs. Cascade vs. Booster

**SECONDARY**

**CASCADE**

**TRANSCRITICAL BOOSTER**
The high-stage system (HFC, HC or ammonia) cools the liquid CO$_2$ in the secondary circuit like a simple chiller system.
- CO$_2$ is cooled to 26 °F (275 psig) for the MT load and -13 °F (181 psig) for the LT load.

- The CO$_2$ is pumped around the load.
- **It is volatile, so unlike a conventional secondary fluid such as glycol it does not remain as a liquid. Instead, it partially evaporates.**
- It therefore has a significantly greater cooling capacity than other secondary fluids.
- This reduces the pump power and the temperature difference at the heat exchanger.
Selecting the Best System: Secondary vs. Cascade vs. Booster
Typical Retail Cascade (Hybrid) System

- **High-stage (HFC) System:**
  - Provides cooling for the medium-temperature load
  - Removes the heat from the condensing CO\(_2\) in the low stage at the cascade heat exchanger

- **Low-stage (CO\(_2\)) System:**
  - CO\(_2\) condensing temperature is maintained below the critical point
  - CO\(_2\) pressures are similar to R-410A
  - Utilizes CO\(_2\) as a direct expansion refrigerant
  - Uses efficient and quiet CO\(_2\) subcritical compressors
  - CO\(_2\)-specific evaporators
  - Electronic expansion valves with EEVs for steady, automatic control of superheat leaving the evaporators
  - All liquid lines must be insulated
Typical Cascade System Operating Pressures

Low Side (Suction)
- Typ. Operating Suction 200–275 psig

High Side (Discharge and Receiver)
- Typ. Operating Discharge 400–500 psig

- Normal Operating Suction: 200–275 psig
- High Suction: >275 psig
- Low Suction: <200 psig

- Low- Side Pressure Relief (Recip.): 350 psig
- Low-Side Pressure Relief (Scroll): 475 psig

- Normal Operating Discharge: 400–500 psig
- High Discharge: >500 psig
- Low Discharge: <400 psig

- Pressure Regulating Relief Valve: 560 psig
- Main Pressure Relief Valve: 625 psig

Courtesy of “The Green Chill Partnership and Hill Refrigeration”
Selecting the Best System: Secondary vs. Cascade vs. Booster
CO₂ Booster Refrigeration System in Transcritical Operation

- CO₂ is circulated in LT and MT sections
- Gas cooler in supercritical mode
- Condenser in subcritical mode
- Three separate sources of suction gas for MT compressors
- LT requires two stages to keep compression ratios low and discharge temperatures from exceeding the oil’s temperature limit
**CO₂ Booster Refrigeration System**

**Transcritical Compressors**

- Higher gas density of CO₂ results in smaller compressor displacement with equivalent R404A motor size
- PRV Relief Valves: 66/135 bar (957/1,958 psig) for low/high side
- Max. Operating Pressure = 120 bar (1,740 psig)
- Inverter Release: 25–70 hz
- CoreSense Protection
- Helps maintain sub-cooling in condenser when in subcritical mode
- Create pressure drop into the flash tank
- Optimizes COP during transcritical operation
Five Ways of Improving Efficiencies in Warm Ambient Regions

- Spray Nozzles
- Adiabatic Gas Coolers
- Parallel Compression
- Sub-Cooling
- Ejectors
**CO\textsubscript{2} Booster Refrigeration System**

**Case Controls and EEV Cases**

- Case controls and EEV (PWM or stepper)
- Due to high heat transfer coefficient of \textit{CO\textsubscript{2}} vs. HFC, if the same HFC rated evaporators are used, greater capacities and lower TD would result with improved efficiency
- Smaller tubing coils can be used to reduce material cost and footprint
CO₂ Booster Refrigeration System
Subcritical Compressors

- LT subcritical compressors are same as those used in cascade systems
- Discharges into suction of transcritical

- High side: 43 bar / 630 psig
- Low side: 28 bar / 406 psig
- Low side “PRV” supplied with – 34.4 barg (500 psig)
- Oil: RL68HB POE
**Emerson Offering**

- Centralized Controller
- Distributed Controller
- Transcritical Compressors
- Subcritical Compressors, Semi and Scroll
- Oil Level Controls
- Compressor VFD
- Condenser Motor VFD
- High-Pressure Controller
- Bypass Valve Controller
- High-Pressure Valves
- Case Controllers
- Electronic Expansion Valves
- System Protectors
- Pressure Transducers
- Leak Detection
Conclusions

Transcritical systems are usually used in areas where the ambient temperature is generally low (i.e., predominantly below 68 °F to 77 °F), such as northern Europe, Canada and the northern U.S. New system designs and technology are improving efficiency in warmer climates.

Cascade and secondary systems (subcritical CO₂) are usually used in high ambient areas such as southern Europe, the mid- to southern U.S., and much of Central and South America, Asia, Africa and Australia.

The use of transcritical systems in high ambients generally results in low efficiency; hence, cascade or secondary systems are preferred in those areas.
1. Introduction

2. CO₂ Basics and Considerations as a Refrigerant

3. Introduction to R744 Systems

4. R744 System Design

5. R744 Systems — Installation, Commissioning and Service
## System Architectures — Multiple Choices Being Evaluated

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<tr>
<th>Architecture</th>
<th>Energy</th>
<th>Environment</th>
<th>Equipment</th>
<th>Economics</th>
<th>Future</th>
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<tr>
<td>Centralized DX</td>
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<td>![Economics Icon]</td>
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<td>Sub-critical CO$_2$ (HFC/CO$_2$ Cascade)</td>
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<td>Transcritical CO$_2$ (CO$_2$ Booster)</td>
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<td>![Economics Icon]</td>
<td>Hydrocarbons HFOs</td>
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Thank You!

Questions?

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