DECK REFRIGERATION SYSTEM USING PROPANE AS REFRIGERANT IN A BOTTLE COOLER

ASHRAE Winter Meeting, Orlando, Florida, February 5-9, 2005
The **Complete Refrigeration System** shortly described here is the result of a Collaborative Project. The product was field tested during the last summer Olympics Games, Athens, 2004.

In the domain of small commercial appliances, manufacturers of Bottle Coolers Cabinets face troubles with **on-site maintenance** and challenges with **environmental impact**.

Development of an innovative cooling system has been based on the 3 mains **objectives**:
- system easier to handle;
- energy efficiency improvement;
- environmentally friendly.
System easier to handle:

Traditionally, a refrigeration system in a cabinet is split into two sub-assemblies:

- evaporating unit
- condensing unit

Difficult service at the point of sale.
DECK SYSTEM SOLUTION

System easier to handle:
- refrigeration module;
- plug-in type unit;
- replacing the deck instead of the cabinet;
- standardization opportunity.
DECK SYSTEM

Means to Improve Energy Efficiency:

- choice of refrigerant;
- optimization of electrical motors efficiency;
- air flow optimization.
# DECK SYSTEM

## Refrigerant Selection: HC vs HFC

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>R134a</th>
<th>R152a</th>
<th>R290 (Propane)</th>
<th>R600a (Isobutane)</th>
<th>RC270* (Cyclopropane)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latent Heat of Vap. @ 40 °F</td>
<td>84.1</td>
<td>129.75</td>
<td>156.744</td>
<td>149.7</td>
<td>178.66</td>
</tr>
<tr>
<td>(Btu/lbm)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Vap. Specific Volume @ 40 °F</td>
<td>0.9523</td>
<td>1.657</td>
<td>1.3483</td>
<td>3.265</td>
<td>2.001</td>
</tr>
<tr>
<td>(ft³/lbm)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Vap. Specific heat @ 40 °F</td>
<td>0.217</td>
<td>0.251</td>
<td>0.4507</td>
<td>0.395</td>
<td>0.3402</td>
</tr>
<tr>
<td>(Btu/lbm °F)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Vap. Viscosity @ 40 °F</td>
<td>0.027</td>
<td>0.0231</td>
<td>0.019</td>
<td>0.0175</td>
<td>0.0197</td>
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<tr>
<td>(lbm/ft hr)</td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Vap. Thermal Conductivity @ 40 °F</td>
<td>0.0072</td>
<td>0.0068</td>
<td>0.01</td>
<td>0.0083</td>
<td>0.00795</td>
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<tr>
<td>(Btu/hr ft °F)</td>
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</tr>
<tr>
<td>Latent Heat of Cond. @ 100 °F</td>
<td>71.2</td>
<td>115.48</td>
<td>132.924</td>
<td>133.1</td>
<td>159.63</td>
</tr>
<tr>
<td>(Btu/lbm)</td>
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<td></td>
</tr>
<tr>
<td>Liq. Density @ 100 °F</td>
<td>71.942</td>
<td>54.03</td>
<td>29.578</td>
<td>33.38</td>
<td>37.45</td>
</tr>
<tr>
<td>(lbm/ft³)</td>
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<tr>
<td>Liq. Specific heat @ 100 °F</td>
<td>0.359</td>
<td>0.434</td>
<td>0.6727</td>
<td>0.627</td>
<td>0.5823</td>
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<tr>
<td>(Btu/lbm °F)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Liq. Viscosity @ 100 °F</td>
<td>0.4114</td>
<td>0.376</td>
<td>0.222</td>
<td>0.35</td>
<td>0.3193</td>
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<tr>
<td>(lbm/ft hr)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liq. Thermal Conductivity @ 100 °F</td>
<td>0.0437</td>
<td>0.0565</td>
<td>0.0526</td>
<td>0.059</td>
<td>0.0755</td>
</tr>
</tbody>
</table>

* Data from National Institute of Standards and Technology (NIST REFPROP)

*Thermodynamic and transport properties of HC and HFC*
Refrigerant Selection:

Volumetric refrigerant capacity for the same cycle with 40°C cond. temp. (From Granryd E. Hydrocarbons as refrigerant-an overview. Int. J. Refrig. 2001; 24; 15-24)
Refrigerant Selection:
HC vs HFC (R134a) main advantages:

- thermodynamic and transport properties
  - higher latent heat of phase change;
  - lower viscosity;
  - higher thermal conductivity.

- cost savings:
  - smaller charge size (up to 50%) at lower cost;
  - compliant with lower cost mineral oil.

- availability
**DECK SYSTEM**

**Eco-friendly solution:**

<table>
<thead>
<tr>
<th>Table 1 Physical, Safety and Environmental Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refrigerant</td>
</tr>
<tr>
<td>-------------------------------------------------</td>
</tr>
<tr>
<td>Chemical Formula</td>
</tr>
<tr>
<td>Molecular Mass (g/mol)</td>
</tr>
<tr>
<td>Critical Temperature (°F)</td>
</tr>
<tr>
<td>Critical Pressure (psia)</td>
</tr>
<tr>
<td>Normal Boiling Point (°F)</td>
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<tr>
<td>Lubricant</td>
</tr>
<tr>
<td>Stability</td>
</tr>
<tr>
<td>OSHA Permissible Exposure Limit (ppm)</td>
</tr>
<tr>
<td>Lower Flammability (% Volume in Air)</td>
</tr>
<tr>
<td>Heat of Combustion (Btu/lbm)</td>
</tr>
<tr>
<td>Safety Group</td>
</tr>
<tr>
<td>Auto Ignition Temperature (°F)</td>
</tr>
<tr>
<td>Atmospheric Life (yr.)</td>
</tr>
<tr>
<td>Ozone Depletion Potential</td>
</tr>
<tr>
<td>Global Warming Potential (100 yr. **)</td>
</tr>
</tbody>
</table>

*POE = Polyolether, PAG = Polyalkylene Glycol, * POE/PAG good candidates for R152a
Safety Group = (A or B) lower and high toxicity respectively, (1, 2, or 3) not flammable, low and high flammability
** GWP for integrated time horizon, and based on 3500 kg CO₂ / kg of R11

Data from National Institute of Standards and Technology (NIST REFPROP)
DECK SYSTEM

Selected Refrigerant: R290 (propane)

R290 Pressure-Enthalpy Diagram
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Electrical motors design optimization:

Fan motor:
- electronically commutated synchronous permanent magnet;
- higher efficiency than shaded pole;
- lower component count than brushless.
DECK SYSTEM DESIGN

CAD from the 1st layout to the definitive one...
DECK SYSTEM

Air flow optimization:

Air velocity field

Air temperature field
LABORATORY TESTS
DECK SYSTEM TESTING

Experimental results:

Energy consumption of Bottle Cooler vs. Number of cans to cool

**BASELINE ENERGY CONSUMPTION for 32.2°C (90°F), 65% RH**
Increased motor cooling effect by using R290:

Compressor motor vs. evaporating temperatures for same condensing temperature by using **R22** or **R290**
LABORATORY TESTS

Performance: Pull down test
LABORATORY TESTS

Energy efficiency measurements:

Cabinet size: 630 cans (US size)

Baseline energy consumption
E = 9228 Wh/day

On/off cycle test
E = 6040 Wh/day
Ratio on/off = 0.49

Power Consumption Reduction: 35%
SYSTEM SAFETY

Safety measures:

Design:
- spark free design
- fully sealed system
- refrigerant charge limited (<150g)
- factory-built system

Standards:
- EC rules: Risk Analysis (FMEA), Public Area, LVD, PED, MD, EMC directive
- conformity with IEC60335-2-89
- conformity with IEC79-15
CONCLUSION

- A new Complete Refrigeration System using HC as refrigerant has been designed and integrated in a Bottle Cooler cabinet;

- Compactness and ease of handling as a plug-in peripheral unit are the main advantages of this HC system;

- A power consumption reduction of 35% at the same service rate was achieved by using this HC system;

- HC can be used safely as refrigerant in specially designed factory-built systems in compliance with International Standards requirements.