Effects of Refrigerant-Lubricant Combinations on the Energy Efficiency of a Convertible Split-System Residential Air Conditioner

Travis BENANTI, Roberto URREGO, Edward HESSELL, Scott WUJEK, Chad BOWERS, Stefan ELBEL
Complementary Work

Lubricants Optimized for use with R-32 and Related Low GWP Refrigerant Blends
Paper 2413: HESSELL

Solution Properties Of Polyol Ester Lubricants Designed For Use With R-32 And Related Low GWP Refrigerant Blends
Paper 1491: URREGO

Refrigerant and Lubricant Mass Distribution in a Convertible Split System Residential Air Conditioner
Paper 2502: WUJEK

Effect of Lubricant-Refrigerant Mixture Properties on Compressor Efficiencies
Paper 1507: WUJEK
Background

Regulations drive the HVAC-R industry to develop and commercialize new and alternative refrigerants. Each refrigerant interacts differently with lubricants and this opens up opportunities to develop new products for new refrigerants.

- Montreal Protocol
- Kyoto Protocol
- European F-Gas Regulations
Lubricant-Refrigerant Pairs

1. Miscibility
   • Forms one liquid phase at all ratios of oil:refrig
   • Observed as a function of temperature
   • Primary importance in heat exchangers

2. Solubility
   • Tendency for the refrigerant to dissolve into the lubricant
   • Lowers the working viscosity of the fluid
   • Temperature and pressure changes can cause foaming

3. Working Fluid Viscosity
   • Always lower than the neat oil due to refrigerant
   • Changes as a function of T, P, dissolved refrigerant
In today’s systems, it is desirable to have a lubricant with controlled miscibility, since this behavior affords working fluids (oil + refrig) that provide good lubrication without negatively impacting the system as a whole.
Miscibility and Solubility

![Graph showing miscibility and solubility limits](image)

- **One Phase**
- **Two Liquid Phases**
- **Two Phases**

**Solubility**
- Refrigerant Vapor
- Lubricant-Rich Liquid
- Dissolved Refrigerant Lowers Viscosity of the Lubricant

**Miscibility Limits (°C)**

- % Oil in Refrigerant: 0, 20, 40, 60

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Working Fluid Viscosity

Outlet (T,P) 3.5 cSt
Inlet (T,P) 6.9 cSt

COMPRESSOR

Viscosity (cSt)

Temperature (°C)

Pressure (bar)
Liquid Phase Compositions
Possible Lubricant Effects

Build-up in components
Adversely affects energy balances
Saturation temps implied from pressure measurements
Two-phase pressure drops
Altered heat transfer coefficients
Reduces log-mean temperature difference
Lowered capacity

Improved wetting at low vapor quality
Nucleation of boiling
Foaming
Coating of microchannels
# Lubricant-Refrigerant Pairs Tested

<table>
<thead>
<tr>
<th>ID#</th>
<th>Type</th>
<th>ISO</th>
<th>R-410A</th>
<th>R-32</th>
<th>L-41b</th>
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<tbody>
<tr>
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<td><img src="image" alt="Tested" /></td>
<td><img src="image" alt="Good Miscibility" /></td>
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</tbody>
</table>

**Notes:**
- ![Tested](image) indicates the pair was tested in full system.
- ![Good Miscibility](image) indicates good miscibility.
- ![Poor Miscibility](image) indicates poor miscibility.

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Experimental Setup
Test Conditions

<table>
<thead>
<tr>
<th>AHRI Condition</th>
<th>Mode</th>
<th>Indoor Air T (°C)</th>
<th>Outdoor Air T (°C)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Dry Bulb</td>
<td>Wet Bulb</td>
</tr>
<tr>
<td>A</td>
<td>A/C</td>
<td>26.7</td>
<td>19.4</td>
</tr>
<tr>
<td>B</td>
<td>A/C</td>
<td>26.7</td>
<td>19.4</td>
</tr>
<tr>
<td>C</td>
<td>A/C</td>
<td>26.7</td>
<td>-</td>
</tr>
</tbody>
</table>

**Evaporator Energy Balance**

\[ \dot{Q}_{evap} = \dot{m}_{air} c_{p,air} (T_{in} - T_{out}) = \dot{m}_{refrig} (h_{out} - h_{in}) \]

**Coefficient of Performance (COP)**

\[ \text{COP} = \frac{\dot{Q}_{evap}}{W_{in}} = \frac{\text{Cooling Effect}}{\text{Power Input}} \]
Benchmark is Lubricant 1 (ISO 32) + R-410A, but this standard lubricant is not miscible with R-32.

Lubricant CTQs:
1. Good miscibility profile; no miscibility gap
2. Match working fluid viscosity in new refrigerants to that of the benchmark combination
3. Show no performance degradation when switching to higher viscosity grade oils
Miscibility Profiles

R-410A

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<td>6</td>
<td>80</td>
<td>🟡</td>
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</tbody>
</table>
## Miscibility Profiles

![Graph showing miscibility profiles for L-41b refrigerant.](image)

<table>
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<tr>
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Working Fluid Viscosity

AHRI Condition A

- ISO 32 (R-410A)
- Lubricant 1: 32 cSt
- Lubricant 2: 32 cSt
- Lubricant 3: 46 cSt
- Lubricant 4: 68 cSt
- Lubricant 5: 80 cSt

Working Fluid Viscosity (cSt)
Compressor Power

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-41b</td>
<td>R-32</td>
<td>R-410A</td>
</tr>
</tbody>
</table>

Refrigerant
- ● L-41b
- ■ R-32
- ▲ R-410A

Outdoor Unit Power (kW)

2.0 - 3.2 kW
Lubricant Effects on COP

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Refrigerant</strong>&lt;br&gt; • L-41b&lt;br&gt; • R-32&lt;br&gt; • R-410A</td>
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<thead>
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<th>COP</th>
<th>L-41b</th>
<th>R-32</th>
<th>R-410A</th>
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</tbody>
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Lubricant Effects on Compressor

Discharge Temperature (°C) vs. COP

Outdoor Unit Power (kW) vs. COP

Legend:
- L-41b A
- L-41b B
- L-41b C
- R-32 A
- R-32 B
- R-32 C
- R-410A A
- R-410A B
- R-410A C

AHRI
R-32 vs. R-410A Viscosities

Suction (T,P)

Discharge T, Suction P

Discharge (T,P)

ISO Grade

R-410A (cSt)

2 = 7.16
1 = 6.23

1 = 5.93

2 = 3.31
1 = 2.76
Conclusions

- Higher ISO grade lubricants are required for R-32 & L-41b
- R-32: Immiscible lubricant 1 gave lowest COP in all cases while optimized lubricant 5 afforded the highest COP
- L-41b: Similar working viscosity trends to R-32
Acknowledgements

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